The Anterolateral Ligament

An Anatomic Study on Sex-Based Differences

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Background: The anterolateral ligament (ALL) has been shown to have an important role in rotatory stability of the knee. While there is abundant research on sex-based differences related to anterior cruciate ligament (ACL) rupture, there is a paucity of literature related to such differences in the ALL.

Purpose: To define any sex-based differences in the ALL with regard to length, width, and thickness.

Study Design: Descriptive laboratory study.

Methods: The ALL was initially evaluated in 165 unpaired knees (92 males and 65 females after exclusion criteria applied). The length, width, and thickness of the ALL were measured using a digital caliper. Width and thickness were measured at the joint line just superior to the lateral meniscus. The Mann-Whitney test and Student *t* tests were used to compare measurements between males and females. The Pearson product-moment correlation was subsequently used to determine the correlation between height and weight and the statistically different morphometric variables.

Results: The mean (±SD) thickness of the ALL in males was 2.09 ± 0.56 mm, almost twice as thick as females (1.05 ± 0.49 mm; $P = 8.8 \times 10^{-20}$). There was also a statistically significant difference in ALL length ($P = 3.8 \times 10^{-7}$), but no significant difference was found for width. A moderate association was found between donor height and ALL thickness and length.

Conclusion: The anatomic measurements of the ALL demonstrate a difference between sexes, and the ALL is significantly thicker in males than females.

Clinical Relevance: As the role of the ALL in rotatory stability of the knee becomes better understood, the difference in the thickness of the ALL we have found between the sexes may be another factor why female athletes have an increased incidence of ACL rupture compared with males. This may also help explain why females have issues with knee laxity and rotatory instability.

Keywords: anterolateral ligament; anterolateral rotatory instability; gender differences; anterior cruciate ligament; anatomy

Injuries to the anterior cruciate ligament (ACL) are a common occurrence, with 100,000 to 250,000 annually in the Unites States alone.[17,39] Females are especially at risk for suffering this injury, as female athletes are 2 to 8 times more likely to suffer an ACL injury than their male counterparts.[4,46] This trend continues in athletes of the same sport, as female soccer and basketball players are 3 times more likely to suffer an ACL injury than their male counterparts.[35] Multiple risk factors have been identified in females attributing in part to this discrepancy. These include an increased quadriceps angle,[11] smaller notch width,[28] smaller ACL size,[17] increased laxity in tibial rotation,[6] and an increase in posterior tibial slope,[22] yet much debate remains regarding the primary factors for this disproportionate discrepancy.[1,11,16,17,22,28,48]

Historically, much interest has been placed on the anterolateral structures of the knee and their contribution to knee rotational stability and protective function of the ACL.[30,44] Recent investigations into the anterolateral ligament (ALL) of the knee have provided a renewed focus on these anterolateral structures and their contribution to knee stability[‖] and correlation with the pivot-shift test.[41,42]

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Its potential clinical importance is exemplified by patients with possible combined ACL and ALL rupture who do not progress satisfactorily after isolated ACL reconstruction.[23,24] A recent anatomic study performed also suggested that a difference between the ALL in males and females might exist.[37]

The purpose of our study was to define the anthropometric parameters such as length, width, and thickness differences between males and females in a large sample. We hypothesized that there might be a significant difference in the thickness of the ALL between sexes, which likely contributes to the sex-based differences that are seen in knee laxity and subsequent discrepancy by sex seen with ACL injuries.

METHODS

The ALL was initially evaluated in a total of 165 unpaired knees (97 males, 68 females) at 2 separate institutions (Kansas City University and São Paulo University). Specimens were obtained through the donation program at each university. Knees with previous total knee arthroplasty, above knee amputation, below knee amputation, evidence of ACL injury, previous ACL reconstruction, evidence of prior surgery affecting the lateral aspect of the knee, and history of knee infection were excluded from analysis. This left 92 male cadavers and 65 female cadavers available for dissection (median age at death, 60 years; range, 38-91 years).

Specimens were dissected in a standard manner according to previous protocols.[10,12,13,19] The deep fibers (Kaplan fibers) were sharply resected to expose the lateral aspect of the knee.[25,44] The scalpel blade maintained contact with the fibers of the iliotibial band (ITB) well proximal to the lateral epicondyle so that the integrity of the proximal ALL was maintained, as its fibers closely adhere to the ITB in this region. With the knee stressed in varus, the lateral collateral ligament (LCL) was palpated. The overlying tissue was sharply incised just posterior to the LCL, parallel to its course, to delineate its posterior aspect. The knee was then flexed to 30°, and the tibia was internally rotated to tension the tissue just anterior to the LCL. The 30° point was chosen because the ALL was easily identified and further knee flexion was limited in some embalmed specimens. Fibers running from the lateral femoral epicondyle to the anterolateral tibia were clearly identified, and any tissue not stretched with this maneuver was removed. The posterior border was identified first, followed by the anterior border. This clearly isolated the remaining fibers identified as the ALL (Figure 1). To protect the origin of the ALL, care was taken proximally to further isolate the fibers of the ALL origin in proximity to the LCL with the knee in flexion and internal rotation.

After complete identification of the ALL, it was carefully separated from its insertion on the lateral meniscus using scalpel dissection.[19] Using a digital caliper (Mitutoyo IT-005D caliper), the thickness and width of the ALL were measured just superior to the superior surface of the lateral meniscus (Figure 2). The ALL length was measured from the center of its femoral attachment to the center of its tibial attachment. The width was measured transversely at the level of the joint line. Results were recorded as mean, standard deviation, median, maximum, and minimum.

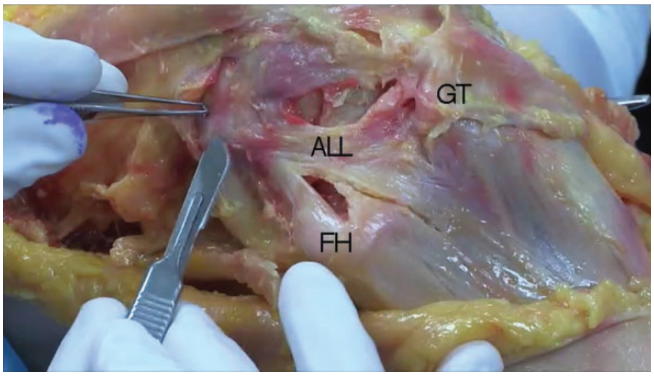

Figure 1. After meticulous dissection, the anterolateral ligament (ALL) can be seen attaching near the lateral epicondyle on the femur and in between the fibular head (FH) and Gerdy tubercle (GT) on the tibia in a right knee of a supine specimen.

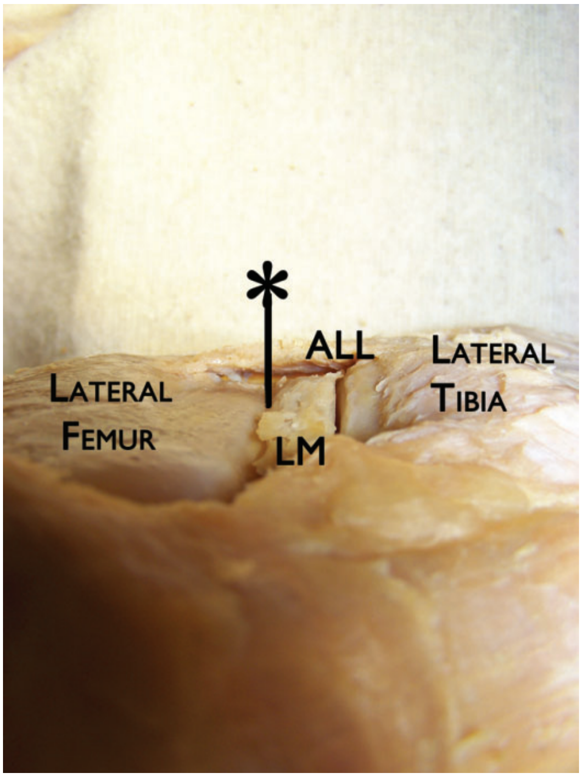

Figure 2. The thickness of the anterolateral ligament (ALL) was measured just superior to the lateral meniscus (LM) at the level of the joint line. The asterisk indicates the level in which the measurement was taken.

Student *t* tests were used to compare the differences in ALL length, width, and thickness between sexes. Parametric variables (height and weight) were analyzed using an unpaired *t* test, while nonparametric variables (ALL thickness, length, and width) were analyzed using the

TABLE 1
Measurements of the ALL in Males and Females[a]

	Male	Female	P Value[b]
Height, cm, mean ± SD	170.8 ± 8.9	160.6 ± 7.3	<.001[c]
Weight, kg, mean ± SD	69.2 ± 12.7	66.1 ± 14.7	.17
ALL thickness, mm			
Mean ± SD	2.09 ± 0.6	1.05 ± 0.5	<.001[c]
Maximum	3.65	2.53	
Minimum	1.11	0.43	
ALL width, mm			
Mean ± SD	8.39 ± 2	8.6 ± 2.2	.8
Maximum	14.09	14.38	
Minimum	4.98	5.22	
ALL length, mm			
Mean ± SD	38.42 ± 2.9	35.7 ± 3.9	<.001[c]
Maximum	46.20	46.77	
Minimum	30.08	21.22	

[a]ALL, anterolateral ligament.
[b]Student t test.
[c]Statistically significant difference between males and females.

TABLE 2
Association Between Height and Weight Compared With Length and Thickness of the Anterolateral Ligament

	Thickness	Length
Height	0.34 ($P = 1.02 \times 10^{-5}$)	0.279 ($P = .0004$)
Weight	0.025 ($P = .77$)	0.013 ($P = .86$)

Mann-Whitney test. A P value <.05 was deemed statistically significant. The Pearson product-moment correlation was then subsequently used to determine the correlation for statistically different morphometric variables.

RESULTS

The ALL was identified in all specimens. The mean height of males was statistically superior to that of females, whereas no statistical differences were found for weight. The mean (±SD) thickness of the ALL in males (2.09 ± 0.6 mm) was statistically different than the ALL thickness in females (1.05 ± 0.5 mm). The ALL lengths were also different between males (38.42 ± 2.9 mm) and females (35.7 ± 3.9 mm). No statistical differences were found in ALL width between the 2 groups (Table 1).

The Pearson correlation coefficient revealed a statistically significant association between ALL thickness and height and between ALL length and height, with these variables demonstrating a moderate association (Pearson correlation coefficient, <0.4). No association was found between weight and ALL thickness or length (Table 2).

DISCUSSION

In our cadaveric dissections for this study, we were able to confirm the existence of the ALL in all 157 dissected knees, confirming its existence as a constant structure at the anterolateral portion of the knee. We did find a statistically significant difference in length and thickness of the ALL at the level of the lateral meniscus but not for width measurements. The ligament in males was on average 1.04 mm thicker than that in females, over twice as thick in male subjects when compared with females (Figure 3).

Recent anatomic and biomechanical studies of the ALL have brought more focus to this anterolateral structure, first described by Paul Segond[38] in 1879. The anatomy of the ALL, including its femoral origin, tibial insertion, orientation, and histological structure, has been well defined.[10,12,13,15,20,47] The femoral origin of the ALL is seen with some variability, from the center to proximal and posterior to the lateral epicondyle.[13] The ALL extends distally with contributing fibers to the lateral meniscus[19] and then inserting in a broad, fan-like fashion on the tibia in between the Gerdy tubercle and the fibular head.[10] Runer et al,[37] in an anatomic study, compared the ALL measurements between males and females. These authors suggested the ALL was shorter in females but did not find any differences regarding thickness and width. Different from this study, Runer et al[37] did not perform any correlation with height and weight, which could have biased their results, as females are shorter than males.

Biomechanically, the ALL serves as an important contributor to rotational stability of the knee in varying degrees of flexion, showing maximum strength similar to the medial patellofemoral ligament.[18,27,34,36,42] Sonnery-Cottet et al[42] further demonstrated its significance in the presence of ACL injury. In their study, an isolated lesion of the ACL did not produce a pivot shift, which was instead only seen with a concurrent lesion of either the ALL or the ITB. In a separate investigation, in vitro robotic assessment of the ALL provided further evidence of its role in rotatory stability when subjected to a simulated pivot-shift test.[36] Through this same modality it was shown that a combined ACL/ALL reconstruction provided better rotatory control than an ACL reconstruction alone.[32]

Our findings have potentially significant implications moving forward. It has been shown that approximately 70% of ACL injuries are from a noncontact injury.[31] The mechanism of these noncontact injuries has been researched by video analysis and clearly demonstrates that these injuries occur with pivoting and cutting movements, seen in sports like basketball, soccer, and handball.[33] This is due to the knee being put in a precarious position where there is a rotational force applied to the tibia and a valgus moment at the knee as it nears extension on a planted foot, thus causing a pivot shift injury.[33] These rotatory forces, coupled with deceleration or landing in these positions, put the ACL and lateral structures of the knee in a vulnerable position.[5]

Females suffer noncontact ACL injuries at a significant disproportion than males. Studies have shown females are 2 to 8 times more likely to rupture their ACL than their male counterparts.[4,8,35,46] There have been many risk

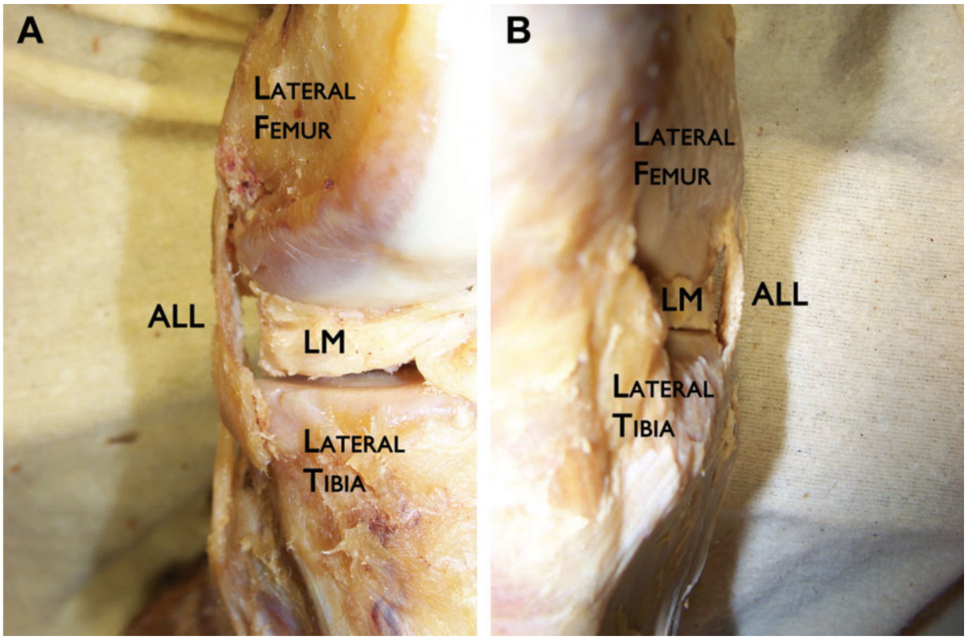

Figure 3. The mean thickness at the level of the joint line of the anterolateral ligament (ALL) in (A) females was 1.05 mm, while that in (B) males was 2.09 mm. LM, lateral meniscus.

factors previously identified that likely contribute to this discrepancy. The quadriceps angle has been measured in various positions and is significantly increased in females compared with males.[11] This changes the forces generated and places more of a lateral force across the knee. It has been suggested that this difference places the female knee at an increased risk of ACL rupture.[17] Dienst et al[14] linked smaller notch sizes to smaller cross-sectional area in the midsubstance of the ACL. When controlled for height, women were found to have thinner ACLs than men. However, in another study, Anderson et al[3] were unable to find this association. Hohmann et al[22] compared men and women who suffered ACL injuries and found that women had a significantly greater posterior tibial slope, which was postulated to place the female knee at an increased risk for a pivot shift injury, a finding that has also been supported by other studies.[43,45]

We believe that the findings of our study demonstrating that female ALLs are on average half the thickness of their male counterparts is a potential reason for the increased propensity for ACL injury in the female knee. Increased rotational laxity has been previously demonstrated in females and is believed to be why there is an increased propensity for females to suffer ACL injuries.[6] When a pivot-shift-type injury occurs, the forces are distributed through the external structures of the knee and then progress through the ACL. We hypothesize that the forces going through the female ALL are either greater than the strength of the ligament or circumvent the ligament altogether due to the increased laxity, thereby subjecting all these forces to the ACL itself. Given the findings of this study, we hypothesize that the anatomic differences in the female ALL place the female ACL at a significantly greater risk for rupture.

While there are many strengths to our anatomic study, including sample size, the inclusion of multiple centers, and a standardized dissection technique, cadaveric dissection does have some limitations, especially when performed in embalmed knees. While our findings demonstrate a potentially important anatomic difference between sexes in this structure, further research is needed to determine the biomechanical and clinical significance, if any, of our findings.

CONCLUSION

The anatomic measurements of the ALL demonstrate a difference between sexes, and the ALL is significantly thicker in males than females.

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