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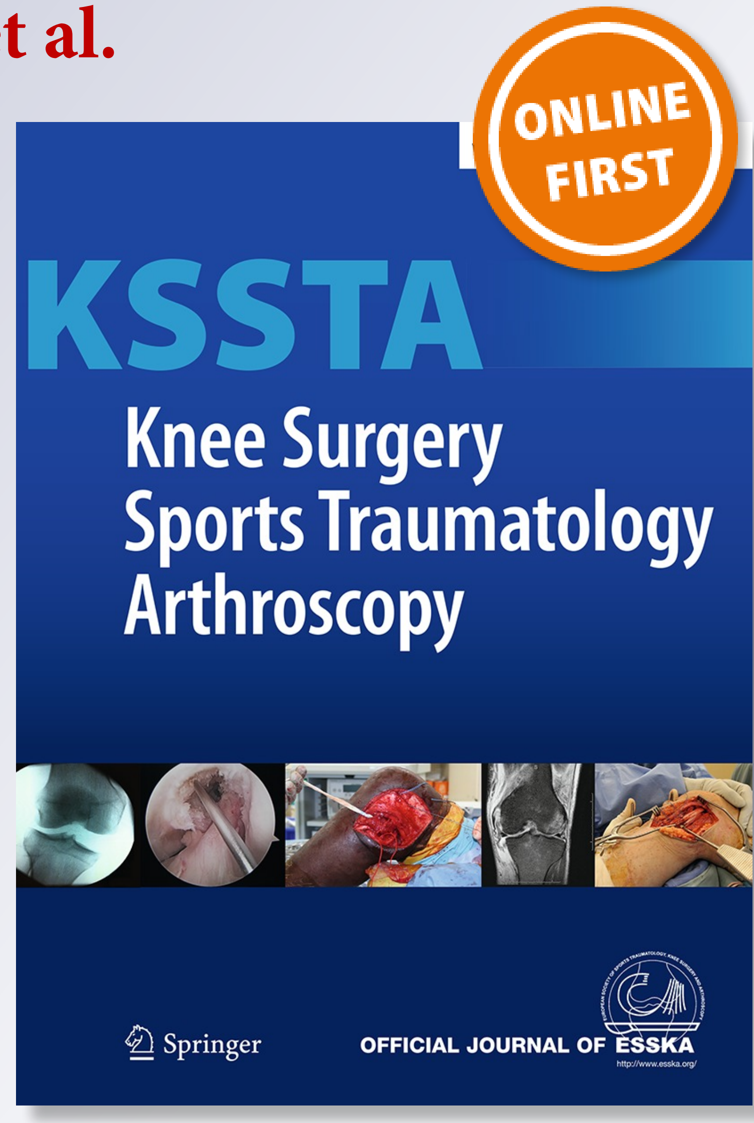

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Anterolateral ligament anatomy: a comparative anatomical study

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Abstract

Purpose Some anatomical studies have indicated that the anterolateral ligament (ALL) of the knee is distinct ligamentous structure in humans. The purpose of this study is to compare the lateral anatomy of the knee among human and various animal specimens.

Methods Fifty-eight fresh-frozen knee specimens, from 24 different animal species, were used for this anatomical study. The same researchers dissected all the specimens in this study, and dissections were performed in a careful and standardized manner.

Results An ALL was not found in any of the 58 knees dissected. Another interesting finding in this study is that some primate species (the prosimians: the red and black and white lemurs) have two LCLs.

Conclusion The clinical relevance of this study is the lack of isolation of the ALL as a unique structure in animal species. Therefore, precaution is recommended before assessing the need for surgery to reconstruct the ALL as a singular ligament.

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Keywords Knee · Anatomical study · Anterolateral ligament · Comparative anatomy

Introduction

Anatomy is a key to the understanding of the function, injury and treatment of human diarthroses. Recently, the anterolateral ligament of the knee (ALL) has gained the spotlight in anatomical [9] and imaging studies [16, 37] and has been designated by some as a "new ligament" [5, 29]. The presence of the ALL in the different anatomical studies ranges from 83 to 100 % [29], and it has been postulated that the ALL plays a significant role in knee rotatory stability, mainly in tibial internal rotation [5] (Fig. 1).

The association of ALL injuries with anterior cruciate ligament (ACL) ruptures has been postulated as a possible cause for anterolateral rotatory instability resulting in a positive pivot-shift test [5, 9]. In a prior biomechanical study, damage to the ALL resulted in knee instability at high angles of flexion [28]. Other studies have theorized that the ALL is responsible for the Segond avulsion fracture, a well-known radiographic sign for an ACL tear [1, 4, 12]. However, there is inconsistent information regarding ALL anatomy, including discrepant findings and confusing definitions of the structure [26]. Some authors have advocated that the ALL is an extra-articular distinct ligamentous structure [3, 5], while others have identified it as a thickening of the knee joint capsule [35] or as merely a bundle of fibrous tissue [32].

Another point of discrepancy has been associated with one (tibial) or two (meniscal and tibial) sites of ALL distal insertion, at a point midway between the Gerdy's tubercle and the fibular head. [3, 5, 9, 29]. In the femur, the ALL attaches to the lateral femoral epicondyle (LFE) [29, 42]

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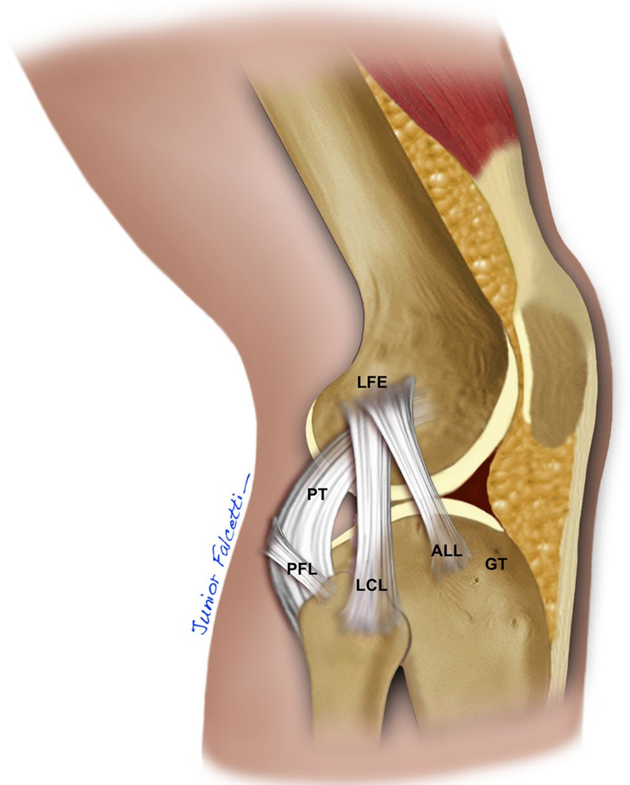

Fig. 1 Anatomy of the anterolateral ligament described in previous studies. *LFE* lateral femoral epicondyle, *ALL* anterolateral ligament, *GT* Gerdy's tubercle, *PT* popliteus tendon, *PFL* popliteal-fibular ligament

but some authors have described its fixation site as anterior and distal to the LFE [5, 15]. Others state that it is proximal and posterior to the LFE [9] or both [3] (see Table 1).

From the first anatomical human dissections until the classic studies from Hughston [17–20] and Seebacher et al. [31] in the 1970s, the ALL has never been described in detail. In recent times, knee dissection studies have not mentioned the isolated ALL [23–25]. The lateral structures have been described in three recognized layers [31], and in the deep layer, there is a thickening of the capsule in close connection with the lateral meniscus [27]. Some authors have reinforced the diverse terminology as a means of justifying the presence of an ALL in normal knees and have been given various names including: "lateral capsular ligament" [6, 8, 19, 22], "midthird lateral capsular ligament" [13, 19, 22, 27], "anterior oblique band of the lateral collateral ligament" [1, 21], "anterior arm of the short head of the biceps femoris" [39]. An ALL terminology had been previously suggested by Vieira et al. [41] and Vincent et al. [42] (Table 1).

Based on the anatomy of the anterolateral structures in animal models, including bipedal and quadrupedal species, some insights into the form and function of the lateral knee ligaments may assist clinicians in their interpretation of the ALL "enigma" in humans [26, 29]. Comparative studies with other knee ligaments in humans and different animal species can provide the surgeon with information on different shapes, sizes, morphologies and insertion sites of the ALL and other relevant ligaments [30, 38].

Table 1 Summary of the most recent cadaveric studies evaluating the presence of the anterolateral ligament

References	*N* cadaver knees	Presence ALL (%)	Origin	Insertion	ALL length (mm)	Attachment to meniscus
Vincent et al. [42]	10	100	Lat fem condyle just anterior PT	Posterior to Ge tubercle (5-mm distal joint line)	34.1 ± 3.4	Closely associated
Claes et al. [5]	41	97	Lat fem epicondyle	Posterior to Ge tubercle (21.6 ± 4.0)	38.5 ± 6.1	Strong connection
Helito et al. [15]	20	100	Lat fem epicondyle (ant + distal LCL)	Two: proximal lat meniscus; 38 % to FH	37.3 ± 4.0	
Caterine et al. [3]	19	100	Lat fem condyle; together with LCL	Posterior to Ge tubercle (halfway to LCL insertion)		Yes—100 %
Claes et al. [4]	29	100	Lat fem epicondyle	Posterior to Ge tubercle (22.0 ± 4.0)		
Dodds et al. [9]	40	83	Posterior to lat fem epicondyle	Posterior to Ge tubercle (18.0 ± 3.0)	59 ± 4	Branching attachments
Stijak et al. [35]	14	50	Lat fem epicondyle	Posterior to Ge tubercle (halfway to FH)	41 ± 3	Posterior to Ge tubercle

ALL anterolateral ligament, *Lat fem* lateral femoral, *PT* popliteus tendon, *LCL* lateral collateral ligament, *Ge* Gerdy's, *FH* fibular head

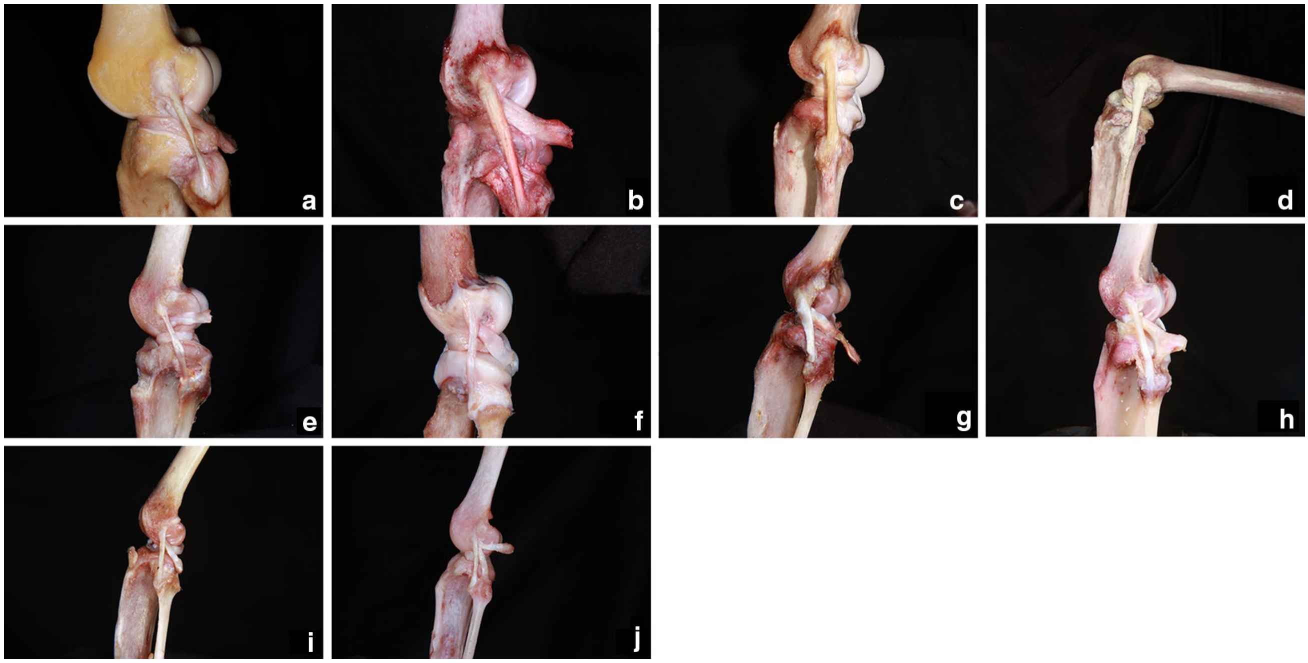

Fig. 2 Lateral dissection of primate knees. **a** Human, **b** bonobo, **c** gorilla, **d** orangutan, **e** diana monkey, **f** rhesus monkey, **g** saki monkey, **h** squirrel monkey, **i** cotton-top tamarin monkey, **j** lemur

To the best of our knowledge, there are no previous studies that have systematically compared the anatomy of the ALL in different animal species. The purpose of this study is to compare the lateral anatomy of the knee among human and various animal specimens.

Materials and methods

Fifty-eight fresh-frozen knee specimens, from 24 different animal species, were used for this anatomical study (all adult), as previously described [38]:

- Primate knees included (ten species): four humans, two bonobos, eight gorillas, ten rhesus monkeys, three diana monkeys, one saki monkey, two squirrel monkeys, two cotton-top tamarins, two red lemurs, three black and white lemurs;
- Mammal knee included (eleven species): two tigers, one lion, three Kodiak bears, one gazelle antelope, one sheep, one deer, one dog, two kangaroos, one groundhog, two tamanduas and two armadillos;
- Reptilian knees (one species): two tortoises;
- Bird knees (two species): one gentoo penguin and one hawk.

All the specimens in this study were dissected by the same researchers (SJMI, CAQM, PL). The knee specimens were kept frozen at −20 °C and defrosted at room temperature for 24 h prior to dissection. Dissections were performed in a careful and standardized manner, and the skin and subcutaneous tissues were removed from all specimens.

For the human cadaver knees, prior approval was obtained from the institutional review board of the University of Pittsburgh [Committee for Oversight of Research involving the Dead (CORID) number 224]. All other animal hind limbs (except for gorillas and bonobo) were donated by the Pittsburgh Zoo, after the animals had passed by natural causes. The gorilla and bonobo specimens were donated by the Cleveland Museum of Natural History.

Results

An ALL was not found in any of the 58 knees dissected Figs. 2 and 3. Another interesting finding in this study is that the prosimians (the two red lemurs and the three black and white lemurs) have two lateral collateral ligaments.

Discussion

The most important finding of the present study was the absence of ALL in any of the animal species examined. In addition, the ALL was not identified as an independent ligament in any of the human knees dissections performed by us. Definitive osseous landmarks allowed us to qualitatively identify the origin and insertion sites of the lateral structures in the human knee [11, 36]. The LFE was clearly identified in all animal knees analyzed. All other lateral apophysis, tubercle or bony prominences of the femur were distinguished in the macroscopic evaluation relative to the LFE. Our results suggest that the unique structure attached in the LFE is the LCL that was well defined in all species. All LCLs examined were inserted in the postero-distal slope of the apex of the LFE, in agreement with Takeda's findings in humans [36].

This study also revealed the presence of the popliteus tendon (PT) in all knees. The femoral insertion site of the popliteus tendon was anterior and distal to the LFE similar to other human studies [23]. Positional relationships between the LCL and PT varied among the animal species.

It is important to note that other cadaveric human studies showed disagreement when referring to the topography of the ALL's origin from the femur and its relation to the LFE (Table 1).

The presence and function of an ALL in humans remain controversial [3, 5, 9]. In spite of the fact that a few recent anatomical studies have recognized the ALL as a differentiated ligamentous structure [5, 9, 15, 42], other studies have shown divergent findings and have shown that the ALL is merely a dense capsular thickness [1, 3, 35]. Even among the authors that have described the ALL as a separate structure, there is conflicting information regarding its origin and insertions sites, as well as the ligament's course. In humans, the femoral origin of the ALL has been described in three different regions: the LFE [5, 35]; anterior and distal to the LFE [3, 15, 42]; posterior and proximal to the LFE [3, 9]. The tibial insertion site of the ALL has also been a point of controversy [3, 5, 9, 42]. The most commonly described tibial ALL attachment is located midway between the centre of Gerdy's tubercle posteriorly and the anterior margin of the fibular head [3, 5, 9]. Other studies specify (with quantitative measures) different tibial ALL points of insertion [15, 42]. A clear characterization of the ALL's origin and insertion sites has a primary role in defining its possible biomechanical function, mainly in pivot-shift phenomena and surgical reconstruction, if necessary. Recently, in a detailed anatomical study, the presence of small bundles inside the ligamentous structure with different patterns and shapes in the bony attachment was verified and this fact should also be taken into account during ligament reconstructive surgery [14]. Knee surgery is under scrutiny [2], and care should be taken for correct surgical indications. Additionally, a recent biomechanical study has shown that an anatomical ALL reconstruction was not able to reduce anterolateral rotational laxity [34].

The pathways taken by ligaments have also been a topic of interest [20, 27, 39]. Our study has found that prosimians (lemurs) have two LCLs (Fig. 2j). In most animal species, the LCL runs in an oblique direction from the LFE to the fibular head posteriorly in the sagittal plane similar to its course in human knees [27, 31, 39]. The interesting finding was the double LCL (in prosimians) with the same femoral origin in the LFE but with an additional tibial insertion. In humans, the ALL's course has been described in several ways. Dodds et al. [9] showed that the ALL crosses over the LCL superficially and in an oblique direction (from lateral to medial and from proximal to distal) to its tibial insertion. Others have delineated that the ALL runs anteroinferiorly to the LFE towards the proximal tibia across the knee joint [5, 15, 35, 42]. Its close connection and attachments to the lateral meniscus have been reported [3, 5, 9, 15, 35, 42]. However, it is important to note that our investigation was performed under 2D visualization that can mitigate a more meticulous evaluation (Fig. 3). When 3D technology is employed, the course and footprints of the ligament can be scrutinized in more details [40].

The presence of the anterior arm of the LCL that was identified in some animal species can be correlated with one study by De Maeseneer et al. [7] that identified a similar structure (that was not the ALL) in humans that could be involved in Segond's fracture. However, the first description of Segond's fracture occurred in the tibial region "definitely posterior and above the tibial tubercle" due the existence of "a pearly, resistant, fibrous band" [32]. Thereby, recent studies have assumed that Segond's fracture is an avulsion bone injury caused by the ALL's tibial detachment and, consequently, some authors therefore presumed that the ALL is a distinct fibrous structure [3, 4, 9, 29]. Other studies have shown that Segond's fracture is caused by the anterior oblique band of the LCL [1, 8, 9, 21] that could be a similar anatomical structure found in some animal species in this study. The real incidence, clinical relevance and type of optimal treatment related to Segond's fracture require more investigation.

There is also controversy in regard to the ALL being an intra- or extra-capsular structure [3, 9]. The lateral joint capsule can incorporate a thickened band of fibres deep to the ALL [1, 3, 22, 42] or can be extra-capsular [9, 29, 35, 42]. It has been reported that the differentiation between the capsule and the ALL is difficult in cadaveric and imaging studies [3, 9, 13, 29, 35]. Another recent study [10] also reported that a consistent capsuloligamentous structure in the lateral capsule of the knee during fresh-frozen human cadaver dissections and MRI could not be identified. The dissections performed by us were not able to verify the presence of a separate ligamentous structure from the lateral joint capsule. During all dissections, we observed a thin capsule in the anterolateral part of the tibia located in

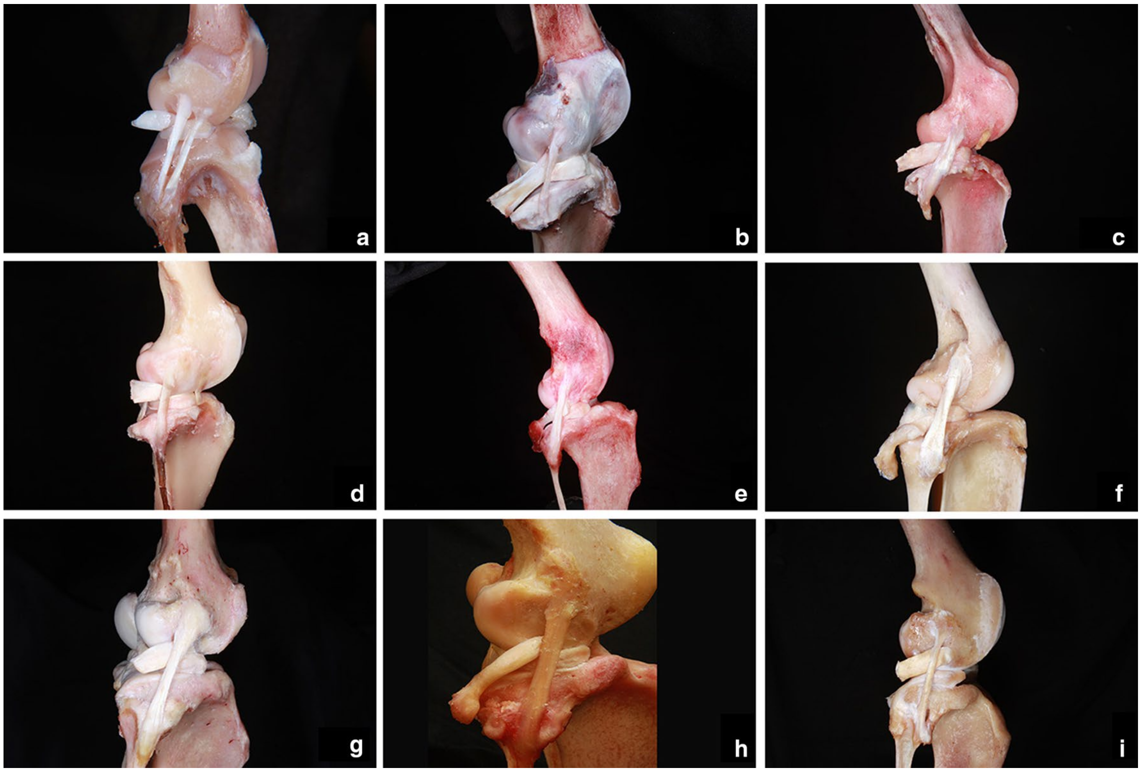

Fig. 3 Lateral dissection of several animal knees. **a** Ground hog, **b** deer, **c** gazelle, **d** sheep, **e** dog, **f** kangaroo, **g** bear, **h** lion, **i** tiger

the third layer, mainly in the human knees. The thickened part of the capsule was posterior and near the LCL in the majority of the animal species.

In addition to the dissection technique, extensive photography of each specimen was performed to document a comparative analysis. Fresh-frozen knee specimens were used, similar to others [1, 3, 9], while some authors have utilized fresh [38, 39], embalmed, [3, 5] or still formalin-fixed cadavers [35]. The outside-in (from superficial to deep layer) approach was employed in all knee specimens, similar to the majority of dissections [1, 3, 5, 9, 15, 22, 30, 31, 41, 42]. The inside-out dissection was not performed in our sample. The ALL resists motion to varus and internal rotation of the tibia between 30° and 60° of knee flexion and becomes taut in these flexion angles [9]. We could not palpate any isolated taut structure in this range of motion (30°–60°) that could be perceived as a ligament. Similar to others [3, 35], safety measures were applied to avoid iatrogenic damage to well-defined structure.

Some limitations of our study should be noted. First, quantitative analyses were not evaluated and variability among animal species can occur. Second, different flexion angles of the knee were not evaluated and anatomical structures can change according to range of motion. Third, our study lacked correlation with imaging exams that have proved to be a relevant tool in assessing anatomical structures in clinical settings. Fourth, no biomechanical assessment was performed. Lastly, only adult animals were evaluated and anatomy may be different in perinatal animals [33]. As a strong point of this study, it is important to note the large diversity of animal studies evaluated, including many primate species.

The clinical relevance of this study is the lack of isolation of the ALL as a unique structure in animal species. Therefore, precaution is recommended before assessing the need for surgery to reconstruct the ALL as a singular ligament.

Conclusion

The ALL was not identified as a unique structure in any of the animal species analyzed.

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