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A cadaveric study of the anterolateral ligament: re-introducing the lateral capsular ligament.

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A cadaveric study of the anterolateral ligament: re-introducing the lateral capsular ligament

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Abstract

Purpose The purpose of this study was to verify and characterize the anatomical properties of the anterolateral capsule, with the aim of establishing a more accurate anatomical description of the anterolateral ligament (ALL). Furthermore, microscopic analysis of the tissue was performed to determine whether the ALL can morphologically be classified as ligamentous tissue, as well as reveal any potential functional characteristics.

Methods Three different modalities were used to validate the existence of the ALL: magnetic resonance imagining (MRI), anatomical dissection, and histological analysis. Ten fresh-frozen cadaveric knee specimens underwent MRI, followed by anatomical dissection which allowed comparison of MRI to gross anatomy. Nine additional fresh-frozen cadaveric knees (19 total) were dissected for a further anatomical description. Four specimens underwent H&E staining to look at morphological characteristics, and one specimen was analysed using immunohistochemistry to locate peripheral nervous innervation.

Results The ALL was found in all ten knees undergoing MRI and all nineteen knees undergoing anatomical dissection, with MRI being able to predict its corresponding anatomical dissection. The ALL was found to have bone-to-bone attachment points from the lateral femoral epicondyle to the lateral tibia, in addition to a prominent meniscal attachment. Histological sectioning showed ALL morphology to be characteristic of ligamentous tissue, having dense, regularly organized collagenous bundles. Immunohistochemistry revealed a large network of peripheral nervous innervation, indicating a potential proprioceptive role.

Conclusion From this study, the ALL is an independent structure in the anterolateral compartment of the knee and may serve a proprioceptive role in knee mechanics.

Keywords Anterolateral ligament (ALL) · MRI · Histology · Immunohistochemistry · ACL · Lateral capsular ligament

Introduction

A thorough understanding of anatomy continues to form the foundation upon which surgeons should develop treatments for pathological musculoskeletal conditions. In the past 10 years, the technique of anterior cruciate ligament (ACL) reconstruction has evolved due to a greater understanding of ACL insertional anatomy [13]. As a result, the term anatomical ACL reconstruction has become commonplace to describe current surgical techniques [11]. However, clinical studies demonstrate that despite these new ACL reconstruction techniques, surgical treatment still fails to reproducibility control rotational instability compared with the uninjured knee. These findings have prompted researchers and clinicians to look for alternative

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causes of instability, which may lead to altered treatments that improve current ACL reconstruction practice.

In 2012, Vincent et al. [36] performed an anatomical study of the anterolateral capsule, identifying and describing a structure they called the ‘anterolateral ligament’ (ALL). In a similar study in 2013, Claes et al. [4] described the origin and insertion of the ALL in embalmed knee specimens. Most recently, Dodds et al. [9] dissected 40 fresh-frozen cadaveric knees, locating the ALL in 83 % of the specimens. All three of these studies suggest that the ALL plays an important role in controlling knee stability, suggesting that this ligament is responsible for the Segond avulsion fracture, a finding which is pathognomonic of ACL injury. As a result, a renewed interest in the anterolateral structures of the knee, and their subsequent relationship with ACL injury and resulting rotational instability, has evolved. However, the anatomical descriptions in all three studies vary and they have significant similarities to the ‘lateral capsular ligament’ previously described by Hughston et al. [17, 18] in 1976, all of which leads to considerable confusion. Hughston et al. demonstrated that sectioning this structure resulted in a high grade of anterolateral rotational instability, and thus many surgeons continued to treat ACL pathology with a lateral extra-articular tenodesis (LET). Unfortunately, isolated LET often resulted in poor functionality; therefore, the focus of ACL surgery switched to intra-articular reconstruction. More recently, it has been suggested that reconstruction of the ALL could result in improved results when combined with an anatomical ACL reconstruction, although there is not sufficient evidence to support this concept. A thorough understanding of the ALL’s anatomical structure is required first to set the foundation for future functional studies that will hopefully lead to improved clinical outcomes involving ACL reconstruction surgery.

The purpose of this study was to verify and characterize the anatomical properties of the anterolateral knee region, with the aim of establishing a more accurate anatomical description of the ALL and investigate its relationship with similarly reported structures such as the lateral capsular ligament. Furthermore, microscopic analysis of the tissue was performed to determine whether the ALL can morphologically be classified as ligamentous tissue, as well as reveal any potential functional characteristics.

Materials and methods

This is a controlled laboratory study in which the anterolateral capsule of fresh-frozen cadaveric knees underwent 3 T magnetic resonance imaging (MRI), anatomical dissection, and histological/immunohistochemical analysis.

Magnetic resonance imaging

Ten fresh-frozen cadaveric knees (eight males; two females; median age 70.5 (range 53–94)) underwent MRI analysis prior to anatomical dissection to determine whether MRI can positively identify the ALL. MRI scans were taken on a Siemens Magnetom Tim Trio 3.0 T MRI scanner (Siemens, Erlangen, Germany). Coronal three-dimensional (3D) T1-weighted volume interpolated GRE (VIBE) images were acquired with fat suppression in an extended position using an eight-channel knee coil. Images were taken with the following MR protocol:

1. Repetition time (TR) 11.10 ms; echo time (TE) 4.92 ms; flip angle 10°; matrix 336 × 384; field of view (FOV) 172 × 150 mm; slice thickness 0.4 mm; parallel imaging (iPAT) factor 2; repetitions 2; bandwidth 300 Hz/px; and acquisition time 14 min 35 s.

MR images were exported to OsiriX DICOM viewer for Mac, which was used to analyse sequences of interest. Scans were analysed in the coronal plane starting from a posterior view and travelling anteriorly. The fibular collateral ligament (FCL) and popliteus were positively identified and used as anatomical landmarks, following which visualization of the ALL was attempted.

Anatomical dissection

Nineteen fresh-frozen cadaveric knees [13 males; 7 females; median age 70 (range 51–94)] underwent anatomical dissection using a standard dissection protocol. It should be noted that there were three sets of paired knees to give a total number of 16 different specimens ($n = 16$). In total, 10 of the 19 knees were those previously scanned with MRI to determine how well MRI would match to corresponding anatomical dissection. Dissection began with removing the skin on the lateral side of the knee, creating a large rectangular window. The iliotibial band (ITB) was then cut at the level of the mid thigh and reflected inferiorly to its distal insertion. Care was taken not to disturb the ITB’s insertion point onto the tibia. Once the ITB was reflected, a varus and internal rotational force was applied between 30° and 60° flexion to highlight any structure coming under tension, as the ALL has been described to resist this motion [4]. Any tissue in the anterolateral region of the knee that did not come under tension could then be resected, leaving only a ligamentous band recently described as the ALL. Once the area of interest containing the ALL had been exposed, isolation of the FCL and the popliteus tendon was carried out. The FCL was isolated by palpating its tubular structure at its distal insertion onto the head of the fibula just above the biceps femoris tendon, exposing it posteriorly as not to disrupt any tissue in the anterolateral region. To make sure that no part of the FCL was confused for any other additional structure, the FCL was completely isolated from any surrounding structures by following its distal and proximal fibres to their attachment points with the use of a blunt probe. Deep to the FCL, the popliteus tendon was isolated by identifying the popliteofibular ligament and tracing it to the popliteus tendon. After the FCL and popliteus were identified, visualization and identification of the ALL were performed.

If the ALL was positively identified, evaluations of its physical characteristics were performed. The origin of the ALL was determined by placing tension on its proximal fibres in order to see its attachment point relative to the FCL on the lateral femoral epicondyle [4, 36]. If visualization of the origin was difficult (often the proximal fibres of the ALL and FCL were integrated), then the ALL and FCL were both cut midbody and separated to see where the main body of each structure attached on the lateral femoral epicondyle. Identification of the ALL insertion was done by placing tension on its distal fibres and visualizing their insertion point. Following the identification of the ALL along with its origin and insertion, anatomical measurements (including length, width, and thickness) were taken in 14 specimens with a Procise digital caliper (model no. 210-2373), which has a 150 mm capacity and accuracy of 0.01 mm. In addition, the width of the femoral and tibial attachment sites were recorded, along with measurements describing the ALL's position relative to other relevant lateral anatomical landmarks. Additional verification of the ALL's anatomical position and relevant anatomy was also carried out by an orthopaedic fellow from the Fowler Kennedy Sport Medicine Clinic (AR) following dissection.

Histology

Histological analysis was performed to classify the tissue type of the ALL and determine whether its microscopic structure was characteristic of ligamentous tissue. Following anatomical dissection, the ALL was isolated and removed for histological analysis from four knees [three males; one female; median age 68 (range 53–81)]. Tissue samples were taken from the ACL and lateral knee joint capsule for control comparison. Each specimen was fixed in 10 % formaldehyde and embedded in paraffin wax. Sections were cut with a Microm HM-325 microtome at a thickness of 5 μm and stained with haematoxylin and eosin using standard procedures [25] to reveal tissue morphology. Three of the specimens were used for histological analysis to investigate the microscopic structure of the body of the ALL. The fourth specimen was used to histologically investigate the bony attachments of the ALL. This was done by maintaining the ALL's proximal attachment point by removing a circular piece of bone from the lateral femoral epicondyle which contained the origin of the ALL, FCL, and popliteus. This procedure allowed for comparison of all three attachment points to ascertain whether the ALL origin mimicked that of other ligamentous structures. Distally, a circular piece of bone with a length of 10 mm and width of 5 mm was taken from the tibia, which contained the insertion of the ALL. Bone decalcification was achieved by first submerging the specimen for 48 h in Calex decalcification solution (Fisher Scientific) following fixation, then placing the specimen in a series of increasing alcohol solutions starting at 70 % to 95 %, then finishing in 100 % ethanol before being embedded in paraffin wax.

Immunohistochemistry

Immunohistochemical analysis was performed on one specimen (one female; age 70) containing an ALL to investigate the ALL's peripheral nervous innervation. The ALL was harvested, embedded in paraffin wax, and sectioned into 5-μm-thick sections for staining with monoclonal mouse anti-human neurofilament protein (NFP) [2] (Dako Canada; cat. no. M-0762). Antigen retrieval was performed in a de-cloaking chamber submersed in citrate buffer. Nonspecific antigenic sites were blocked using 10 % horse serum before incubation with anti-NFP at a dilution of 1:800 determined by preliminary titrations experiments. Sections were then incubated with a secondary antibody ImmPRESS Anti-Mouse Ig Peroxidase Polymer Detection Kit (Vector Laboratories; cat. no. MP-7402) followed by incubation with DAB (DAB Peroxidase Substrate Kit, 3,3′-diaminobenzidine, Vector Laboratories, cat. no. SK-4100) and taken through a standard sequence of solutions to xylene. Qualitative analysis was performed on a Zeiss Scope A.1 microscope linked to a Zeiss AxioCam MRc camera to identify NFP immunolocalization. Longitudinal and cross-sectional slides were both analysed to determine the general distribution of peripheral nervous innervation throughout the ALL.

The IRB approval for the use of cadaveric material was given by the Committee for Use of Cadaveric Material, Division of Clinical Anatomy, Western University in accordance with the Anatomy Act of Ontario, Canada (Approval No. 03012013).

Results

MRI

The ALL could be identified as a distinct, distinguishable structure in all 10 specimens using MRI (Fig. 1a). Coronal plane images revealed that the boney proximal attachment

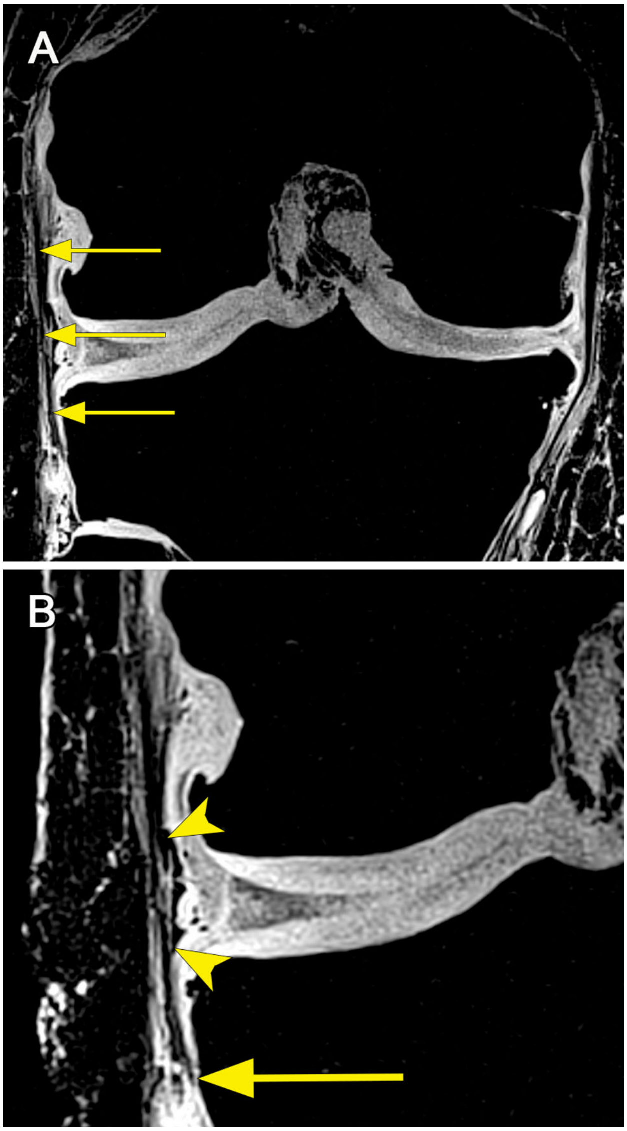


Fig. 1 MRI in the coronal plane fully depicting the ALL which is shown as a *dark*, dense band (left-hand side represents the lateral knee). **a** A full view of the ALL with *arrows* pointing to its body above, at, and below the lateral meniscus. **b** An enhanced view with the large *arrow* pointing to the ALL insertion onto the lateral tibia, and fibres of the ALL extending towards the lateral meniscus shown by the *arrow heads*

is not clearly visible in many of the specimens due to the ALL's close relationship with the other ligamentous structures; however, the ALL's tibial attachment could be easily identified on the lateral tibial plateau (Fig. 1b). In addition, a close relationship with the lateral meniscus was also identified and can be seen (Fig. 1b) by the presence of fibres between the two structures, which has been previously described macroscopically by Vincent and Claes [4, 36]. When comparing different knee specimen scans, it was discovered that the body of the ALL would either be completely anterior to the FCL (Fig. 2a) or crossing over the proximal FCL (Fig. 2b).

Anatomical dissection

The ALL could be identified as a distinct anatomical structure in all nineteen specimens, but only once all of the layers of the ITB were fully reflected to their distal insertion point.

In all 19 cases, proximal fibres of the ALL fanned over the top of, and integrated with, the FCL origin as previously reported [4]. When trying to locate the specific origin of the ALL on the lateral femoral epicondyle, it was often difficult due to confluence of fibres between the proximal fibres of the ALL and FCL. However, the main body of both the ALL and FCL was easily separable at the level of the lateral tibial plateau, and when following these main portions proximally, it was evident that both had their own separate attachment points to the femur. When specifically looking at the relationship between the ALL and FCL origin on the femoral epicondyle, the ALL inserted into bone either anterior–distal or posterior–proximal to the FCL origin contradicting previous reports [4, 36]. This resulted in the discovery of three anatomical variations of the ALL (Table 1). Regarding the three sets of paired knees, each individual pair had the same anatomical variation between the left and right knee.

In each of the 19 specimens, attachment of the ALL to the lateral meniscus could be anatomically identified. Manipulating the lateral meniscus in all directions also showed attaching fibres, as the ALL moved in unison to the direction in which the lateral meniscus was pulled.

Mean measurements of the ALL (Table 2) are taken along with a comparison to three other previously published studies [4, 9, 36]. In our current study, the width of the ALL varied, beginning as a more tubular, narrow structure at the femoral origin, then widening distally to insert on the tibia. This was shown by a mean femoral attachment width of 4.8 mm ± 1.4 mm and a mean tibial insertion width of 11.7 mm ± 3.3 mm. The mean thickness of the ALL was 1.4 mm ± 0.6 mm, indicating it as a flat, broad structure compared with other ligaments of the knee.

The ALL insertion onto the tibia was on average approximately halfway between the midpoint of Gerdy's tubercle and the FCL insertion onto the fibular head. On average, the insertion point was more likely to be closer to Gerdy's tubercle than to the fibular head. The initial five specimens did not undergo anatomical measurements as the ALL is a difficult structure to visualize, and a firm understanding of the ALL's anatomical structure was obtained before measurements were taken.

Histology

In all three specimens stained with H&E, the body of the ALL had a dense regularly organized collagenous structure, similar to that of other ligamentous tissue.

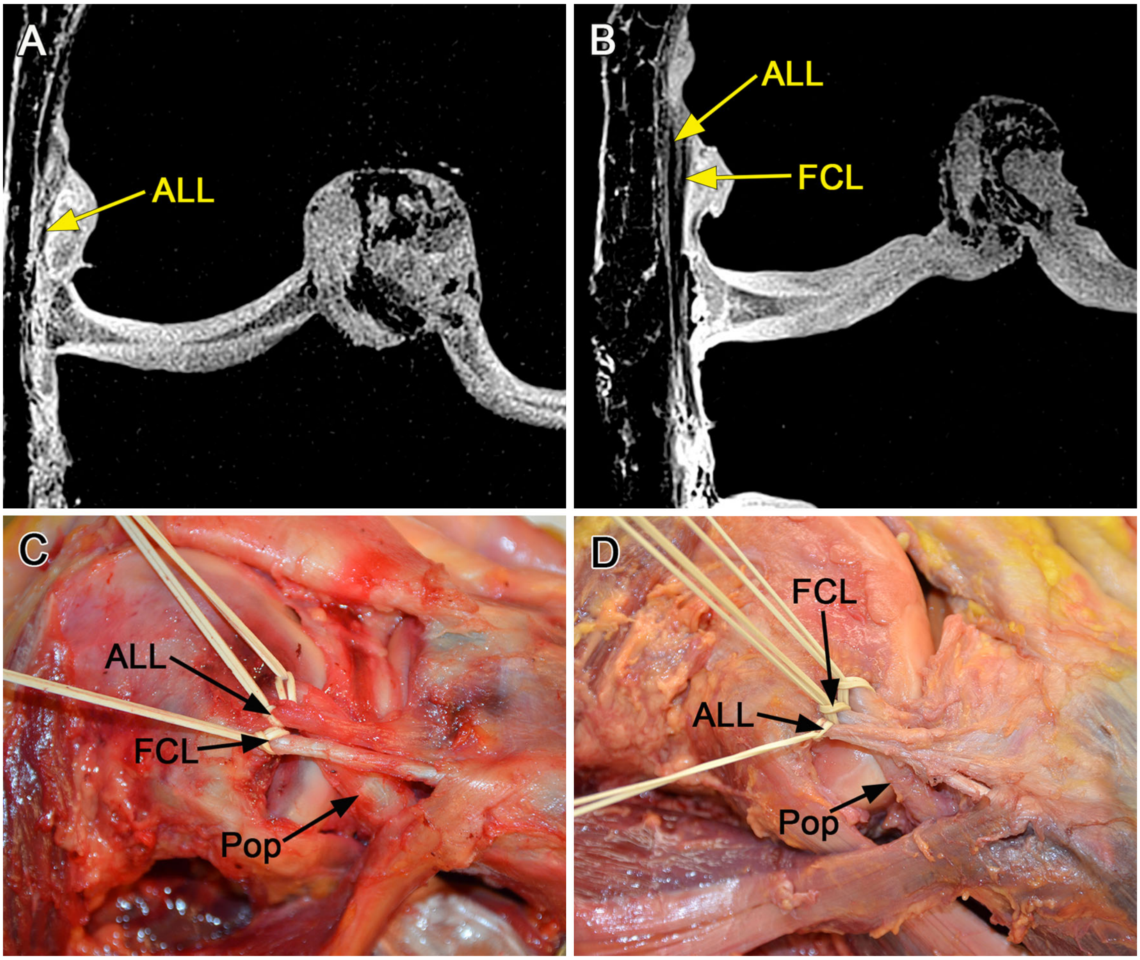


Fig. 2 Two MRI scans of the ALL in different specimens with their corresponding anatomical dissections beneath them. **a** MRI scan with full visualization of the ALL only when completely anterior to the FCL. The ALL is shown as a *thin*, *dark* band with difficulty visualizing the proximal attachment point. With the ALL completely anterior to the FCL, this MRI is classified as anatomical variation 1. **b** MRI scan showing a crossing orientation between the proximal fibres of the ALL and FCL. This crossing orientation shows the ALL inserts posterior–proximal to the FCL, making this MRI classified as anatomical variation 2. **c** Anatomical dissection corresponding with the anatomical variation seen in its corresponding MRI above, showing that the ALL originates completely anterior to the FCL, then continues distally to insert onto the lateral tibia. **d** Anatomical dissection corresponding with the anatomical variation seen in its corresponding MRI above, showing that the ALL crosses proximally over the FCL and inserts posteriorly, then continues distally to insert onto the lateral tibia. *ALL* anterolateral ligament, *FCL* fibular collateral ligament, and *Pop* popliteus tendon

In longitudinal section, the body of the ALL is comparable with that of the ACL (Fig. 3a). The ALL body shows prominent parallel collagen bundles with a crimping pattern, and fibroblast nuclei arranged in rows indicative of dense regular connective tissue (Fig. 3b). The collagen pattern of the ALL seemed to be organized into individual 'bundles', indicating that the structure may be a combination of multiple thickenings of the lateral joint capsule rather than a homogenous entity such as the ACL. Though this pattern was seen most often, there were still portions of the ALL in which a consistent collagenous pattern was observed; specifically, near the femoral and tibial attachment points, which had a very dense, homogenous morphology.

In cross section, the ALL is again comparable with the ACL (Fig. 3c), though it greatly differs in comparison with the lateral joint capsule (Fig. 3d). Both the ACL and ALL show fascicular organization in cross section, with the ALL having smaller collagenous bundles of various size. In contrast, there is a clear distinction of the ALL in cross section compared with the joint capsule, as the joint capsule resembles a loose connective tissue.

Analysis of the FCL, ALL, and popliteus tendon insertion on the lateral femoral epicondyle showed that all three attachment points had almost identical morphologies. Because all three attachment points can be easily distinguished from each other, it provides evidence that the ALL origin is anatomically distinct compared with the surrounding FCL or popliteal origin. Similar to the femoral insertion of the FCL (Fig. 3e), the ALL's femoral attachment shows a transition from ligamentous tissue to mineralized cartilage and to bone (Fig. 3f). This transition is indicative of ligamentous tissue, strengthening the notion that the ALL can be considered ligamentous.

At the tibial attachment, a piece of bone 10 mm in length and 5 mm in width showed that the ALL broadly attaches at all points of the bone sample taken (Fig. 3g). These sections depict that the tibial insertion is not a small circular area, but a large, broad expansion where the fibres of the ALL appear to run in a parallel orientation to the tibia over the course of the entire bone sample sectioned (Fig. 3h).

Immunohistochemistry

Antibodies to NFP have been reported to accurately identify peripheral nervous tissue by staining neurofilaments found in axon cylinders. They can also be used as a tool to morphologically identify mechanoreceptors [2]. This study found that NFP was detected in the ALL, indicating the ALL has a peripheral nervous innervation. Serial sectioning revealed circular structures that were positively stained for NFP and that can be identified as either small peripheral nerves (Fig. 4a) or mechanoreceptors (Fig. 4b). Mechanoreceptors were identified by the presence of previously described morphological characteristics [10], as well as serial sectioning to determine their endpoint. Peripheral nerves were identified by monitoring their course through the serial sections, as well as their axonal density.

Table 1 Three anatomical variations found during anatomical dissection

Variations	Number of specimens (19)	Origin/insertion (full extension)
1	11*	*Origin* Lateral femoral epicondyle anterior–distal to FCL *Insertion* Tibia posterior to Gerdy's tubercle
2	7	*Origin* Lateral femoral epicondyle posterior–proximal to FCL *Insertion* Tibia posterior to Gerdy's tubercle
3	1	*Origin* Lateral femoral epicondyle posterior–proximal to FCL *Insertion* Medial fibular head

* All three paired knees had both the left and right knee classified as variation 1

Fig. 3 (All *scale bars* 100 μm) Multiple H&E sections of the **a** ACL in longitudinal section. **b** ALL in longitudinal section comparable with that of the ACL longitudinal section, though the ALL is slightly more coarse and 'bundle' like. **c** ACL in cross section. **d** ALL in cross section comparable with the ACL in cross section, though the bundles are smaller and more variable in size. Lateral joint capsule is seen in the bottom right corner, having a much different morphology then the ALL, indicating the ALL is not joint capsule. **e** FCL femoral insertion. **f** ALL femoral insertion similar to the FCL femoral insertion. The ALL starts inferiorly as dense collagenous tissue (*1*), turning into mineralized cartilage (*2*), and then finally merging into the periosteum of the femoral epicondyle (*3*). **g** Tibial attachment of the ALL spanning over a large area indicated by the *arrow heads*. **h** Parallel fibre orientation of the ALL to tibial bone spanning over an extensive area indicated by the three arrows. Attachment of the ALL parallel fibres at all points is indicated by the *arrow heads* ▶

Discussion

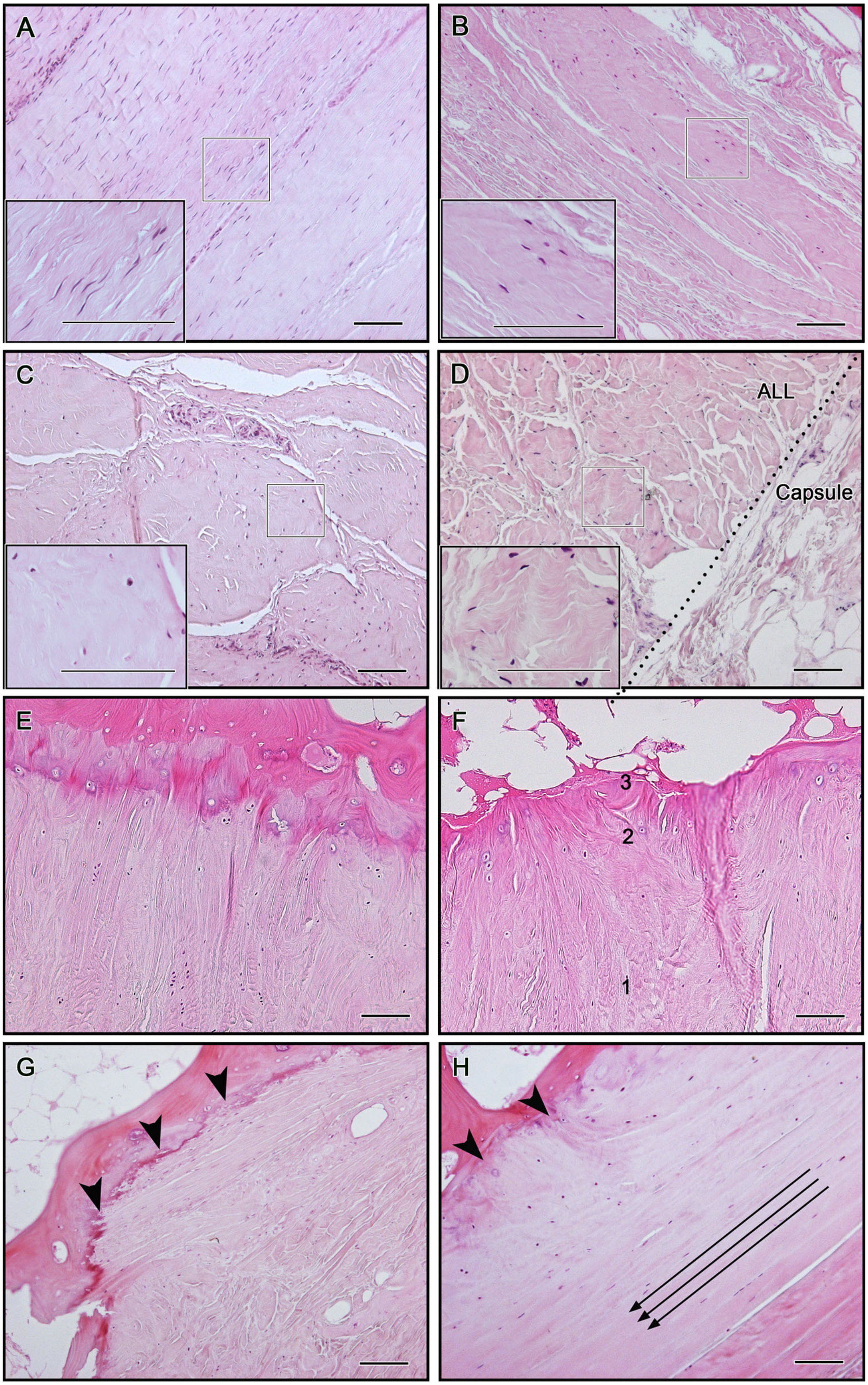
The most important finding of the present study is the confirmation that the ALL is a distinct ligamentous structure present on the anterolateral aspect of the knee, as demonstrated by three different modalities: MRI, anatomical dissection, and histological analysis. The femoral

Table 2 Anatomical measurements of the ALL compared with previous descriptions [4, 9, 36]

	Vincent (2012)	Claes (2013)	Dodds (2014)	Caterine
Length in extension (mm)	34.1 ± 3.4	38.5 ± 6.1	59 ± 4	40.3 ± 6.2
Width (mm)	8.2 ± 1.5	6.7 ± 3	6 ± 1	5.1 ± 1.8 (above meniscus) 8.9 ± 2.5 (below meniscus)
Thickness (mm)	2–3	1.2 ± 0.6		1.4 ± 0.6
Distance from tibial plateau (mm)	5	6.5 ± 1.4	11 ± 2	11.1 ± 2.4
Femoral origin width (mm)		8.3 ± 2.1		4.8 ± 1.4
Tibial insertion width (mm)		11.2 ± 2.5		11.7 ± 3.2
Distance to Gerdy's tubercle		21.6 ± 4.0	18 ± 3	23.4 ± 3.4*
Distance to FCL insertion		23.2 ± 5.7	17 ± 3	23.9 ± 5.5*

Dodds description that the ALL is 59 ± 4 mm in length differs from previous reports and the current study. This hints that he may be describing a different structure, likely the capsule-osseous layer of the ITB. Dodds description of the ALL has the proximal fibres extending posterior–proximal to the lateral femoral epicondyle and blending with surrounding soft tissue and not directly into bone. This description is similar to others who describe the capsule-osseous layer of the ITB [5, 26, 31–33]

* Exclude variation 3 due to fibular head insertion


A
B
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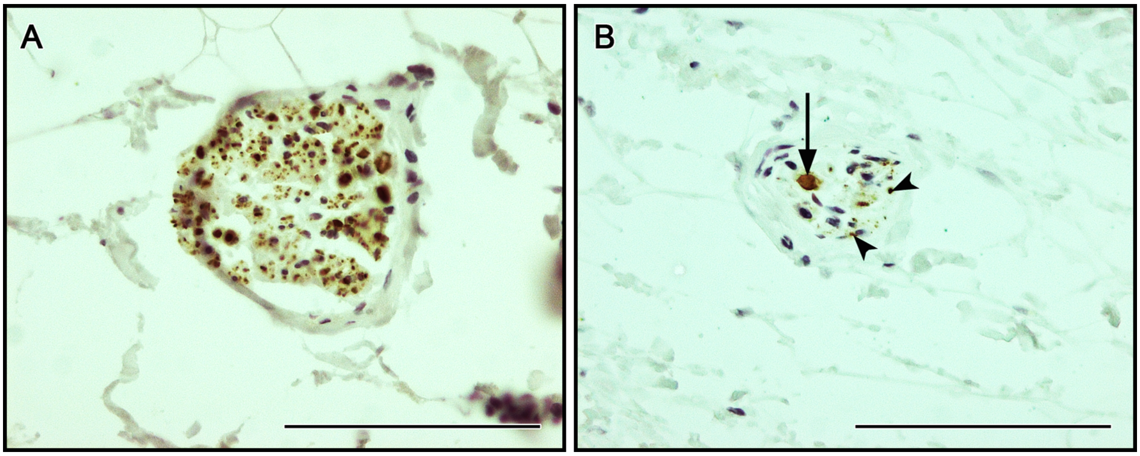

Fig. 4 (All *scale bars* 100 μm) Peripheral nervous structures found within the ALL staining positive for NFP. **a** Small peripheral nerve identified by axonal density and serial sectioning. **b** Type 1 mechanoreceptor identified by large central axon indicated by the arrow, terminal nerve fibres indicated by the *arrow heads*, 1–3 layer capsule, and serial sectioning

origin is somewhat variable in position, inserting either posterior–proximal or anterior–distal to the femoral origin of the FCL. The insertion on the tibia is much more consistent, attaching midway between Gerdy's tubercle and the fibular head, with both attachment points clearly inserting into bone. This description is contrary to previous studies describing the ALL. Vincent et al. and Claes et al. both describe the ALL to originate anterior to the FCL [4, 36], while Dodds's et al. [9] state that the ALL does not insert directly into bone, but rather blends with locally adherent fibres of the capsule, posterior to FCL. Additionally, the results of this study have shown that the ALL can be classified as a capsular thickening opposed to a new structure altogether as previously claimed [4, 9] and that it can be characterized as ligamentous tissue similar to the glenohumeral ligaments of the shoulder [25]. In all nineteen anatomical dissections of fresh-frozen specimens in this study, superficial fibres originating from the investing fascia of the lateral gastrocnemius tendon insertion proximal to the lateral femoral condyle were found to overly the proximal portion of the ALL. It is believed that these fibres correspond to the previously described capsule-osseus layer of the IT band [5, 26, 31–33]. These superficial fibres were observed to continue distally and blend in with the overlying fascia covering the anterolateral proximal tibia, attaching to the posterior portion of Gerdy's tubercle only. As this layer had no attachments to the tibial bone posterior to Gerdy's tubercle, they were removed allowing complete visualization of the ALL, corroborating results reported by Claes et al. [4], indicating that the ALL and the IT band (specifically the capsule-osseus layer) are anatomically distinct structures. Due to these superficial fibres running in the same orientation as the ALL, it is understandable as to why others believed them to be synonymous structures [36]. In comparison with the capsule-osseous layer, the ALL is broader, comes under more tension during internal rotation, and has strong attachment from bone to bone.

The results from this study suggest that the ALL is the same structure described by many as the lateral capsular ligament [8, 14–22, 26, 28, 29, 37]. The lateral capsular ligament has been described to originate on the lateral femoral epicondyle and insert onto the tibial joint margin posterior to Gerdy's tubercle [15, 17–19]. This description of the lateral capsular ligament has the same origin and insertion points of the ALL found in this study, as well as previous descriptions of the ALL [4, 36]. In addition, the lateral capsular ligament has also been described to resist anterolateral rotary stress [8, 14, 17, 19, 30]. Placing the knee under anterolateral rotary stress in the present study caused the fibres of the ALL to come under tension. The ALL and the lateral capsular ligament have also been described to have attachments to the lateral meniscus [4, 7, 8, 15, 18, 19, 36]. It is unlikely that there are two separate structures sharing such a similar anatomical description. And though the lateral capsular ligament and ALL are believed to be synonymous, this study maintains that the structure be termed as the anterolateral ligament due to its location in the anterolateral compartment of the knee, in addition to preventing future confusion with those who refer to the FCL as the lateral collateral ligament (LCL).

The clinical importance of the ALL is demonstrated in this study, and in a number of previous studies investigating the functional significance of the lateral capsular ligament. It has been found that the lateral capsular ligament may be the primary cause of anterolateral rotary instability, with an increase in instability when combined with primarily ACL rupture [18]. Numerous studies have also shown anterolateral instability resulting from an injury to the lateral capsular ligament and/or the ACL [14, 16, 19]. In a recent study, cutting both bundles of the ACL did not result in significant rotational instabilities of the knee; however, when cutting both bundles in conjunction with the lateral capsular ligament, a significant increase in combined rotation at 30°, 45°, and 60° knee flexion was found [22]. In addition, a Grade 3 pivot shift was only seen when the lateral capsular ligament was cut along with the ACL. In this present study, transection of the ACL revealed greater tension across the ALL indicating its possible role as a secondary stabilizer to varus and internal rotation of the lateral tibia.

Boney attachments, as well as the histological and immunohistochemical features of the ALL tissue, suggest that the ALL is indeed a ligamentous structure. Its broad tibial insertion is the only structure attaching to bone in this particular area; therefore, the ALL can be suggested as the cause of the Segond avulsion fracture. This is consistent with previous studies, as many have commented on the lateral capsular ligament causing the Segond fracture [6, 8, 14–16, 19, 20, 26, 29, 30, 37].

Immunohistochemistry revealed a network of peripheral nerves and structures reminiscent of mechanoreceptors present throughout the ALL, indicating that the ALL may play a proprioceptive role in normal knee mechanics. By using previously described methods of classification, type 1 mechanoreceptors were positively identified within the surrounding synovia of the ALL in the current study. In addition to mechanoreceptors, the ALL had a large number of peripheral nerves found throughout the tissue. These results have confirmed an active network of peripheral nerves and multiple mechanoreceptors within the ALL, indicating a potential proprioceptive role.

Lastly, the ALL was identified as a distinct dense structure by MRI. Following anatomical dissection of the MRI scanned knees, comparisons of MRI scans with their corresponding dissection showed similar results (Fig. 2a–d). This provides evidence that the use of MRI could be used as a future diagnostic tool to identify the ALL in ACL injured knees, though further validation is required in future studies.

It remains to be proven whether simultaneous reconstruction of the ACL and ALL can improve rotational stability and clinical outcome following ACL injury. Isolated anterolateral reconstruction was used in the past to address rotational stability [27]; however, this approach fell out of favour due to poor clinical results [12, 23] and a change in focus to intra-articular reconstruction [13]. A number of studies were published in which anterolateral reconstruction, in the form of a nonanatomical extra-articular tenodesis, was combined with ACL reconstruction (ACLR) [24, 35] and showed a reduction in graft failure and improved rotational stability. However, concerns related to over constraint of the lateral compartment were raised; therefore, in many centres, this approach was abandoned [1]. Even in the face of this evidence, the extra-articular procedure has remained common in Europe, with many French and Italian studies showing clinical benefit when combined with ACL reconstruction in both the primary [38] and revision scenarios [34].

Limitations of the current study include the relatively low number of specimens incorporated, of which the median age was 70. As younger athletes are at a higher risk of ACL injury [3], it will be important to try and locate the ALL in both young healthy and ACL injured individuals utilizing MRI. Furthermore, although the current findings of this study suggest a functional role of the ALL, this needs to be investigated via biomechanics and prospective clinical studies.

The strength of this study lies in the three different modalities (MRI, dissection, and histology) used to highlight the existence of the ALL as a distinct ligamentous structure. MRI verification provides evidence of the existence of the ALL in an unaffected, in vivo environment. Although the anatomy could not be clearly defined by MRI, all 10 MRI specimens corresponded with gross dissections, indicating the dissection method was valid. Finally, histological analysis suggests the ALL is ligamentous in nature with bone-to-bone attachment points and a network of peripheral innervation implicating a role in proprioception.

Conclusion

The current study showed that the ALL is a ligamentous thickening of the lateral joint capsule that can be referred to as an independent structure, synonymous with the lateral capsular ligament. The ALL has variable origins on the lateral femoral epicondyle and a broad attachment to the tibia midway between Gerdy's tubercle and the fibular head, attributing it to be the cause of the Segond fracture. Due to its tensioning pattern under internal rotation and varus stress, further investigation is required to determine the potential impact ALL reconstruction may have in controlling anterolateral rotatory instability of the knee.

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Conflict of interest The authors declare they have no conflict of interest.

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