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Research Article

The anterolateral ligament of the knee and the lateral meniscotibial ligament – Anatomical phantom versus constant structure within the anterolateral complex

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ABSTRACT

Background: Concerning the ongoing controversy about the existence and nature of the anterolateral ligament (ALL) of the knee joint, we reinvestigated the formation of the anterolateral part of its fibrous capsule in anatomic specimens. Furthermore, we wanted to clarify if the lateral meniscus has established a constant anchoring to the lateral tibial condyle via a lateral meniscotibial ligament (lmtl).
Methods: Forty paired embalmed lower extremities taken from 20 human body donors (15 men and five women) underwent exact macroscopic dissection. For the detailed evaluation of the lmtl, additionally 12 specially dissected joint specimens were used. In two of these specimens, the lmtl underwent further histological examination.
Results: In all specimens, the anterolateral part of the knee joint fibrous capsule was established by the iliotibial tract and the anterior arm of the aponeurosis of the biceps femoris muscle. According to their close connection and the fact that the anterolateral part of the fibrous capsule is exclusively assembled by these two aponeuroses, they do not leave any space for a distinct ALL connecting the lateral femoral epicondyle and the lateral tibial condyle.

The constantly present lmtl was identified as a flat, rectangular bundle of collagen and also elastic fibers reinforcing the inner aspect of the fibrous capsule. Following an oblique direction, it connected the lateral face of the lateral meniscus with the superolateral margin of the lateral tibial condyle. The lmtl measured, on average, 17.1 mm in longitudinal and 13 mm in anteroposterior direction.
Conclusion: Our results show that there is no evidence for the existence of an ALL in human knee joints. It is represented either by the iliotibial tract or – most likely – by the anterior arm of the short head of the biceps femoris muscle. On the other hand, the lmtl was found to be a constantly present structure.

1. Introduction

Since at least the description given in the first volume of the anatomy textbook of Tandler (1926) it is generally accepted that the formation of the fibrous capsule of the knee joint is unique in the human body. Beside the intracapsular tibial collateral and arcuate popliteal ligaments it is mainly established by the tendons of muscles acting on the knee joint. Thus, the anterior part is built up by the quadriceps femoris muscle forming a central tendinous (or ligamentous) part, i.e. the patellar tendon and an aponeurotic part surrounding the patella, i.e. the patellar retinacula. As already stated in the early work of Weitbrecht (1742), these are followed on the lateral aspect by the iliotibial tract and the insertion of the biceps femoris muscle. The latter is again bipartite and shows an aponeurotic part inserted into the lateral tibial condyle and a tendinous part which is attached to the fibular head (Munshi et al., 2003; Sneath, 1955).

Not any of the classical textbooks of human anatomy (Fick, 1911; Henle, 1872) report a distinct ligament as first hypothesized by Terry et al. (1986) and thereafter re-described by Vincent et al. (2012) and Claes et al. (2014a,b, 2013). However, these authors have identified different structures to represent what they call an “anterolateral ligament (ALL)”. Whereas Terry et al. (1986) state that the ALL is formed by fibers of the iliotibial tract connecting the lateral femoral epicondyle with the lateral tibial condyle, Vincent et al. (2012) as well as Claes et al. (2013) have considered collagenous fibers adjacent to the fibular collateral ligament to be the ALL. Moreover, Vincent et al. have even identified a third structure which may represent the ALL, i.e. the meniscofemoral (or better meniscopopliteal) and meniscotibial ligaments connecting the lat-

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eral meniscus with the adjoining parts of the lateral femoral and tibial condyles (Vincent et al., 2012). Therefore, Claes et al. (2013) have already conceded that there is "confusion about the precise anatomy of . . .this presumed ligament". Moreover and even to increase the proverbial babel on the structures forming the lateral part of the fibrous capsule of the human knee joint, in between even a fourth structure, namely the short posterior genual ligament (Pretterklieber et al., 2012) has been said to represent the ALL (Cianca et al., 2014). On the other hand, hitherto published data do not really verify that the so-called ALL is constantly present during pre- and postnatal human development (Sabzevari et al., 2017; Shea et al., 2017, 2016; Toro-Ibarguen et al., 2017) or in other vertebrates (Ingham et al., 2017; Vallois, 1914).

Hence we want to elucidate the formation of the anterolateral part of the knee joint fibrous capsule based on a series of exact anatomical dissections and to clarify which structure can best represent the ligamentous fragment shown in the work of Segond (1879) on which all discussion is based upon. In addition, we wanted to prove if the lateral meniscotibial ligament (lmtl) first described in extension by Vallois (1914) and re-evaluated by Jost (1921) and Bezerra et al. (2007) is a constant structure at the inner aspect of the knee joint capsule.

2. Materials and methods

2.1. Sample

The lateral part of the fibrous capsule of the knee joint was studied by careful stratigraphic macroscopic dissection of forty knees from 20 body donors. They were 15 male and five female individuals with a mean age at death of 82 years and were part of student dissection courses held at the Division of Anatomy of the Medical University of Vienna, Austria. As a routine for our student dissection courses, all specimens were embalmed by perfusion via the right femoral artery using a solution of 1.6% formaldehyde and 4% phenol. All of these individuals had donated their bodies to medical education and research at the Center of Anatomy and Cell Biology, Medical University of Vienna. In addition to the informed consent of the deceased individuals, the study was approved by the ethics committee of the Medical University of Vienna (ethics committee approval number 1069/2013). All of the specimens had an intact joint capsule and did not demonstrate any signs of previous surgery or severe deformities. As they were provided for further student dissection, for the more detailed inspection, in addition 12 specially dissected joint specimens (six from body donors of each sex) were used.

Furthermore, the right knee of a 79 years old man was used to perform an additional dissection done by the senior author. This dissection was filmed and the video with live oral explanations is presented as supplementary material. In order to ascertain that none of the structures have been missed, the video remained in uncut version.

2.2. Stratigraphic macroscopic dissection

In all specimens, the subfascial structures within the anterolateral aspect of the knee region were identified by carefully dissecting them toward their bony attachments. Thus, the different layers of (mostly aponeurotic) tendinous structures (i.e. the lateral patellar retinaculum, the iliotibial tract, the tendons of the biceps femoris muscle) known to cover or also reinforce the fibrous capsule of the knee joint were separated. Finally, the fibrous capsule was split along the anterior margin of the upright limb of the arcuate popliteal ligament (Munshi et al., 2003) also named short lateral ligament (Resnick et al., 2007) or short posterior genual ligament (Pretterklieber et al., 2012) as this structure directly covers the lateral meniscotibial ligament (lmtl). The latter was defined as flat bundle of fibrous tissue reinforcing the innermost aspect of the fibrous capsule and connecting the lateral aspect of the lateral meniscus with the lateral tibial condyle. In addition, the longitudinal and the anterior–posterior extension of the lmtl was measured in 12 specially dissected knee joint specimens (equally distributed in terms of sex and side) with a slide-gauge (HM HELU-2, Herber Müllner Werkzeuggroßhandel GmbH, Eugendorf, Austria). In order to avoid any squeezing of the lmtl, the beams of the scale were applied without any pressure.

2.3. Histological analysis

From two of the specially dissected joint specimens (one right knee of a female, one left knee of a male individual) presenting a strong lmtl, the ligament underwent histological analysis. Thus, it was cut out, embedded into paraffin, and serial transverse cross-sections were obtained on a rotary microtome (Leica RM 2255, Leica Biosystems Nussloch GmbH, Nussloch, Germany) at a slice thickness of 3 μm. The sections were mounted on chrome-alum-subbed glass slides and stained with a modified Masson-Goldner trichrome method (Mulisch and Welsch, 2010) using a commercially available kit (Masson-Goldner staining kit, Merck KGaA, Darmstadt, Germany). For counterstaining, ferrous hematoxyline (Weigerts ferrous hematoxyline, Merck KGaA, Darmstadt, Germany) was applied. Microphotographs were taken at different enlargements using a transmitted light microscope (Nikon Eclipse 80i, Nikon Instruments Inc., Melville, USA) equipped with a digital camera (Nikon DS-Fi 1, Nikon Instruments Inc., Melville, USA).

2.4. MR-imaging and computer-aided three-dimensional reconstruction

In order to correlate the anatomic findings with radiographic imaging, a series of routine T1-weighted MR-images obtained from the left knee of one 37 years old healthy male volunteer was included. The scans were taken at a 1.0 T scanner type T10-NT (Philips Medical Systems, Eindhoven, Netherlands) using a slice thickness of 4.0 mm with 0.4 mm gap. Based on the axial MR-images, a computer-aided three-dimensional (CAD-3D) reconstruction was performed using the simple, but reliable technique developed by Keri and Ahnelt (1991) and further adopted by the senior author (Pretterklieber, 1999; Rand et al., 2000). Additionally, the software Render for Sculpt® Alpha ST Version 0.04 (Lexicor Software Corp., Fairfax, CA, USA) was applied for final surface rendering.

3. Results

3.1. Stratigraphic macroscopic dissection

In all specimens, the lateral part of the fibrous capsule of the knee joint was formed as a monolayer by two adjoining structures anteriorly and by five layers posteriorly. Closely following the lateral patellotibial ligament as part of the lateral patellar retinaculum, the anterior monolayer was formed by the iliotibial tract and the aponeurosis of the biceps femoris muscle. The most anterior fibers of the aponeurosis arising from the short head of the biceps femoris muscle were attached to the superior margin of the lateral tibial condyle. They run closely adjacent to the posterior border of the iliotibial tract and were attached to the lateral tibial condyle as far anterior as the lateral border of the tibial tuberosity. Posterolateral, the aponeurosis of the biceps femoris muscle formed the most superficial layer. Together with the tendon of the biceps femoris muscle inserting into the fibular head, it covered

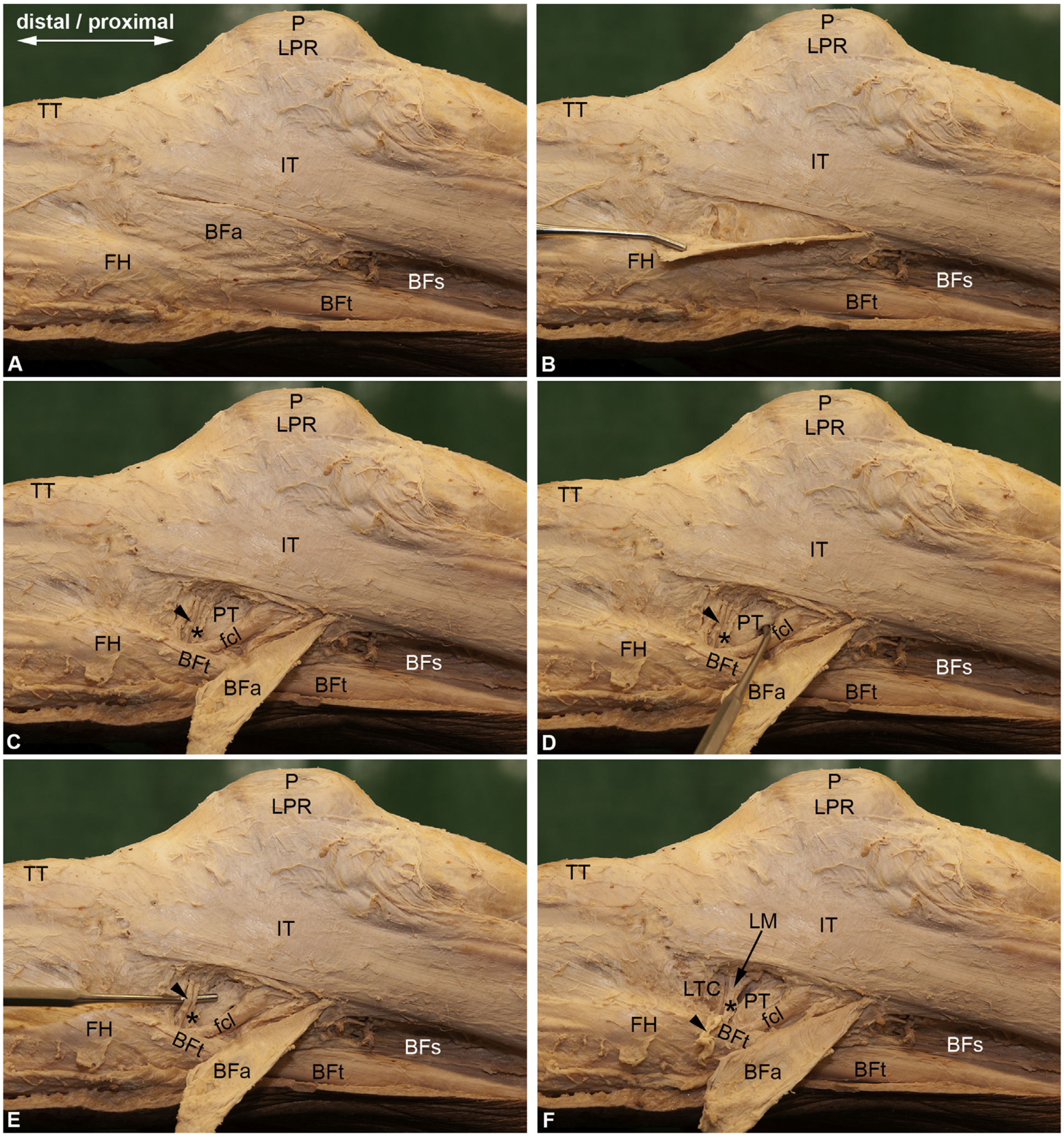

Fig. 1. Stratigraphic dissection of the lateral part of a left knee joint from a female individual. In (A), the different structures forming the anterolateral part of the joint capsule, i.e. iliotibial tract (IT) and the aponeurotic tibial insertion of the biceps femoris muscle (BFa) are shown in situ. Note that this aponeurosis represents a direct continuation of the short head of the biceps femoris muscle (BFs) lacking any attachment to the lateral femoral epicondyle. In (B), the BFa has been detached from its bony insertion on the lateral tibial condyle and also separated from the already exposed synovial membrane. In (C), also the loose areolar tissue surrounding the neurovascular bundle formed by the inferior lateral genicular artery (asterisk) and the articular sensory branch of the common peroneal nerve (arrowhead) and the synovial layer have been removed and the tendon of the biceps femoris muscle (BFt) has been mobilized. Therefore, the fibular collateral ligament (fcl) and the tendon of the popliteus muscle (PT) became visible. In (D), a probe has been inserted between the fcl and the PT to show the direct admittance to the synovial cavity of the knee joint. In (E), the neurovascular bundle has been separated from the lateral meniscus (LM) which is finally exposed in F by cutting and reflecting the articular branch of the common peroneal nerve. FH: fibular head; LPR: lateral patellar retinaculum; P: patella; TT: tibial tuberosity.

the fibular collateral ligament forming the second layer. Tendon and ligament were separated from each other by a small bursa and together covered the third layer. This, in turn, was represented by loose areolar tissue embedding the inferior lateral genicular artery, a branch of the popliteal artery and an articular sensory branch of the common peroneal nerve. This neurovascular bundle passed toward the anterior aspect of the knee joint. Deep and dorsal to it, the fibrous capsule of the knee joint was established and reinforced by the arcuate popliteal ligament and its upright part, i.e. the short posterior genual ligament. The innermost layer was formed by the tendon of the popliteus muscle and the flat and rectangular formed lmtl (Figs. 1 and 2 as well as the video provided in supplementary material). The lmtl was attached to the lateral face of the lateral meniscus and descended oblique dorsally to reach the superolateral margin of the lateral tibial condyle. There it was attached just posterior to the attachment of the posterior ligament of the fibular head. Anthropometry performed in 12 knee joint specimens revealed that – regardless of sex and side – the lmtl measured, on average, 17.1 mm in longitudinal (range, 10–22 mm) and 13 mm in anteroposterior direction (range, 6–17 mm).

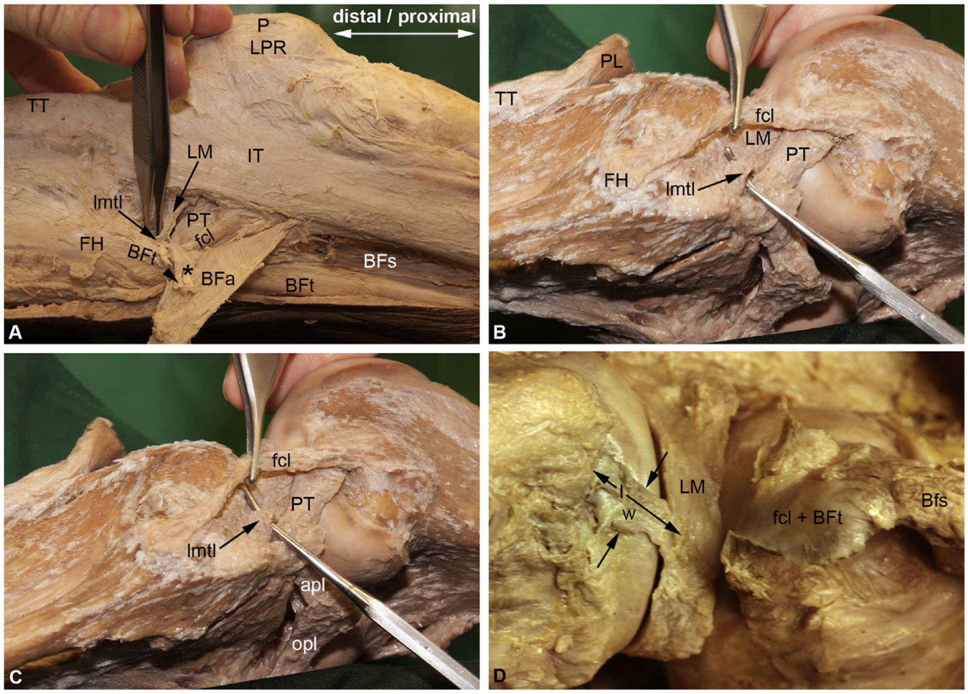

Fig. 2. Identification and macroscopical analysis of the lateral meniscotibial ligament (lmtl). In (A), the lmtl has been identified in the same specimen as shown in Fig. 1. In (B) and (C), its total course is shown in one of the additional joint specimens (again a left knee). The probe is inserted between the lateral meniscus (LM) and the lateral tibial condyle. Note the arcuate popliteal ligament (apl) crossing over the tendon of the popliteus muscle (PT) and continuing into the oblique popliteal ligament (opl). In (D), the fibular collateral ligament together with the tendon of the biceps femoris muscle (fcl + BFt) have been detached from the fibular head to give a better insight on the lmtl and to show the measurements performed on it, i.e. its length (l) and width (w). Due to the lack of both supporting structures, the femur together with the LM is slightly drawn backwards. Thus, the lmtl fixed to the LM follows a different course from that shown in (C), i.e. it courses upwards in a more posterior direction. BFs: short head of the biceps femoris muscle; BFt: tendon of the biceps femoris muscle; fcl: fibular collateral ligament; FH: fibular head; IT: iliotibial tract; LPR: lateral patellar retinaculum; P: patella; PL: patellar ligament; TT: tibial tuberosity.

3.2. Histological analysis

On the axial cross-sections, the lmtl showed a cone-shape with a thick posterior part gradually tapering toward its anterior margin. It was mainly formed by parallel oriented bundles of collagen fibers with cork-screw like appearance (Fig. 3). In its proximal part, the lmtl was additionally rich of elastic fibers and in its posterior part small blood vessels were found to be present.

3.3. MR-imaging and CAD-3D reconstruction

The formation of the anterolateral part of the fibrous capsule covering the knee joint by the iliotibial tract and the aponeurosis of the biceps femoris muscle is also visible in routine T1-weighted MR images and best represented in the axial cross-sections (Fig. 4). Moreover, parallel and deep to the fibular collateral ligament, the lmtl could also be identified. The three-dimensional arrangement of these structures is further illustrated by the CAD-3D reconstructions (Fig. 5).

4. Discussion

4.1. General arrangement of the knee joint fibrous capsule

Despite of the high number of publications dealing with the existence and nature of the so-called ALL (Terry et al., 1986) and against a recently published consensus paper (Sonnery-Cottet et al., 2017), there is obviously still dissidence about its morphological appearance. The main reason is that Segond (1879), to whom many authors refer to, has given a rather poor and thus potentially misleading description of structures establishing the anterolateral part of the knee joint fibrous capsule. He stated that forced internal rotation of the flexed knee results in tensioning that part of the fibrous capsule which is formed by fibers of the iliotibial tract inserting into Gerdy's tubercle. These fibers are further described as "pearly, resistant fibrous band" [translation given by Cavaignac

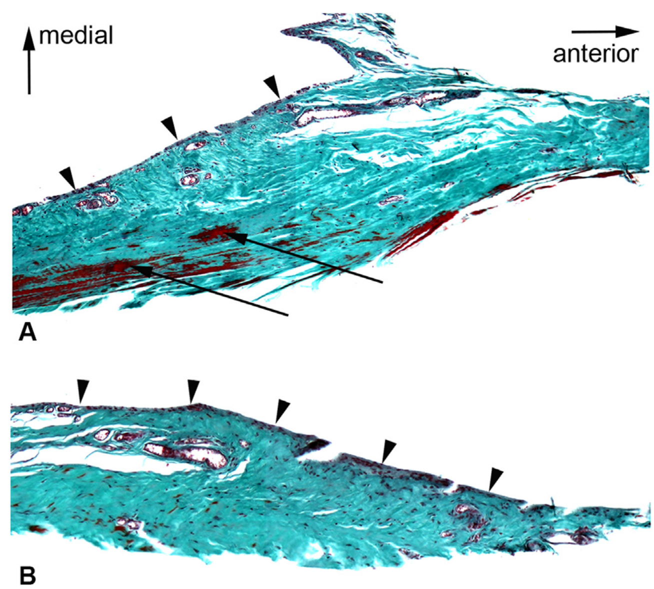

Fig. 3. Histologic axial cross-sections through the right lateral meniscotibial ligament (lmtl) of a female individual (original magnification 100×). (A) shows a representative cross-section through the proximal and (B) through the central part of the lmtl. Note that the medial aspect of the ligament is covered by synovial membrane (arrowheads) and the thick bundle of elastic fibers found to be present in its proximal part (A; arrows).

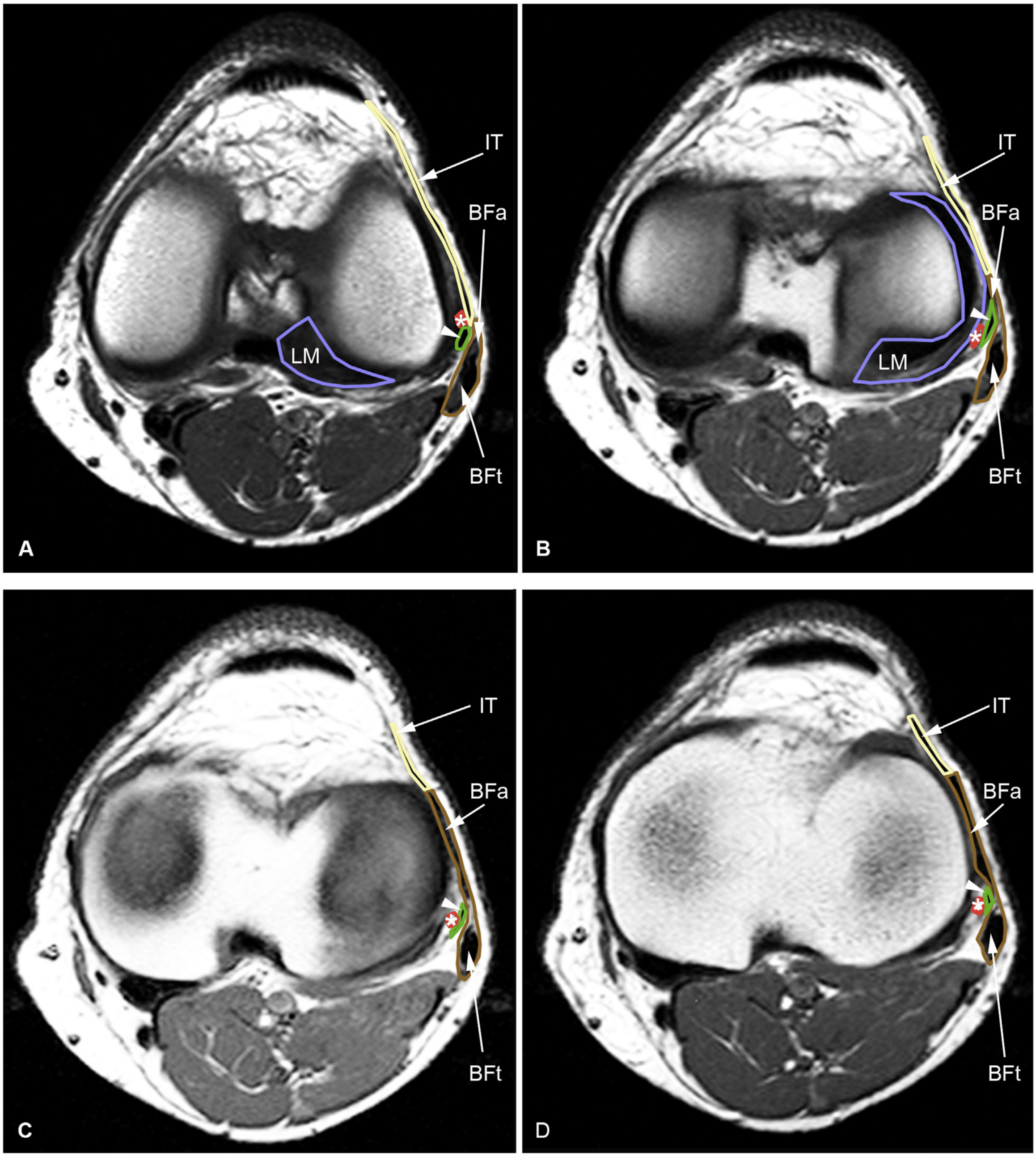

Fig. 4. Axial T1-weighted MR-images of the left knee showing the formation of the anterolateral part of the fibrous capsule by the iliotibial tract (IT) and the aponeurotic insertion of the biceps femoris muscle (BFa) as well as the course of the lateral meniscotibial ligament (asterisk) and its correlation to the adjoining fibular collateral ligament (arrowhead). The figures are arranged in proximodistal sequence with (A) being the most proximal and (D) the most distal cross-section. BFt: biceps femoris tendon; LM: lateral meniscus.

et al. (2017)]. Later on, the same structure is said to establish anyway – without any further description by Segond – the anterolateral part of the fibrous capsule (Segond, 1879). And as already stated by Cavaignac et al. (2017), Segond has also failed to add any information about the femoral and tibial attachments of these fibers. The anterolateral part of the fibrous capsule is formed by two closely adjacent structures, i.e. the iliotibial tract and the aponeurosis formed by the anterior arm of the short head of the biceps femoris muscle. Both structures insert into that part of the tibia prone to lateral rim or Segond fractures (Resnick et al., 2007). For centuries, anatomists (Henle, 1872; Munshi et al., 2003; Salmons, 1995; Sneath, 1955; Tandler, 1926; Weitbrecht, 1742) have well known that the aponeurosis of the biceps femoris participates in forming the fibrous capsule of the knee joint. And looking at the original drawing by Segond (1879), this part of the fibrous capsule fits best to be involved in lateral tibial rim fractures. This fact has been obviously overlooked by Claes et al. (2013) and also most of the succeeding authors. Thus, as can be gathered from their description and – if available – dissection photographs, they have isolated a part of the anterior arm of the short head of the biceps femoris muscle and interpreted it to be of ligamentous nature, i.e. the ALL (Albright, 2017; Daggett et al., 2016; De Maeseneer et al., 2015; Dombrowski et al., 2016; Mathew et al., 2018; Nitri et al., 2016; Olewnik et al., 2019; Parker and Smith, 2018; Patel et al., 2017; Pomajzl et al., 2015; Porrino et al., 2015; Rasmussen et al., 2016; Runer et al., 2016; Shea et al., 2017, 2016; Taneja et al., 2015; Thein et al., 2016; Van der Watt et al., 2015). Only one of the most recent publications (de Lima et al., 2019) clearly shows

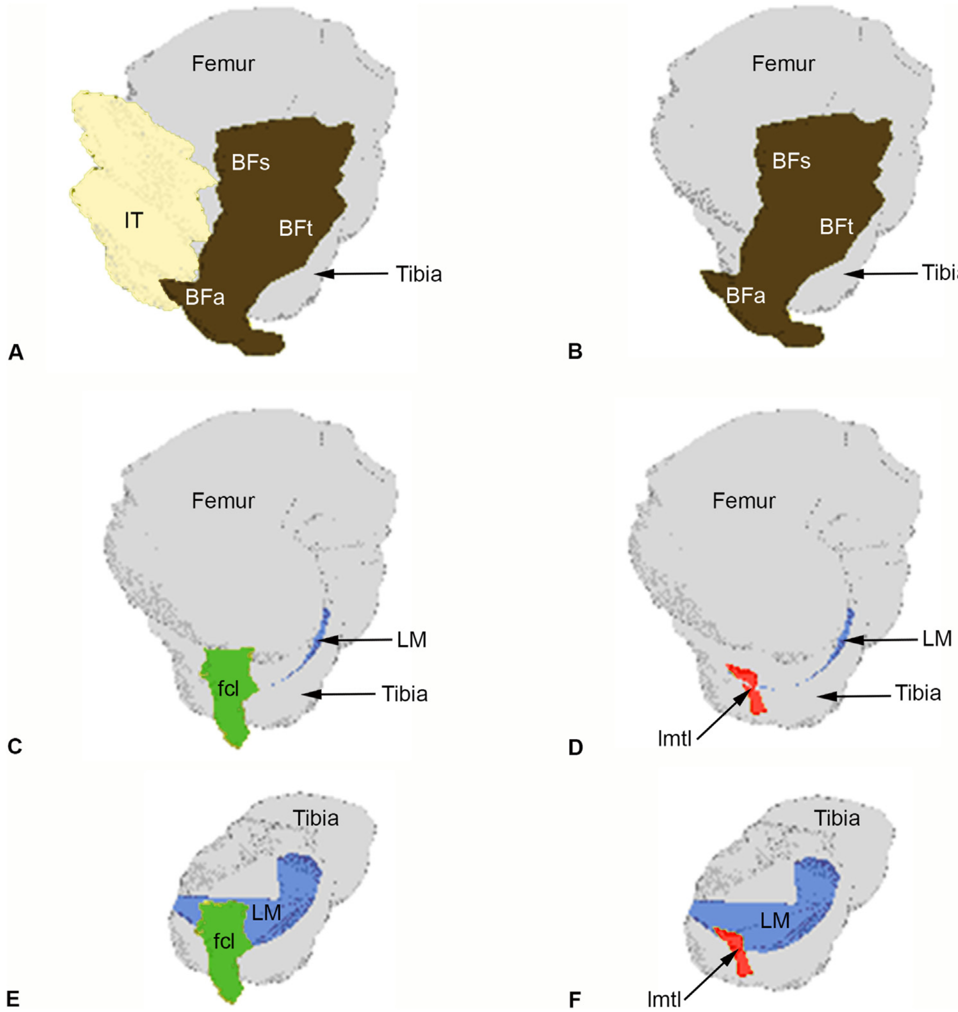

Fig. 5. CAD-3D-reconstruction of the different structures forming the anterolateral part of the knee joint capsule using the series of axial MR-images partly shown in Fig. 4. The models are oriented in an oblique view from proximal and posteromedial. In (A) and (B), the most superficial layer built up by the iliotibial tract (IT) and the aponeurosis of the biceps femoris muscle (BFa) is presented. Note the formation of this aponeurosis by the short head of the biceps femoris muscle (BFs) and the adjoining tendon (BFt) as well as the close contact between the IT and BFa. In (C), the course of the fibular collateral ligament (fcl) and in (D) of the lateral meniscotibial ligament (lmtl) is shown. To further illustrate the different position of these two structures, in (E) and (F) the femur has been removed. Especially in (F), the connection between the lmtl and the lateral meniscus (LM) is depicted.

that the so-called ALL is represented by the aponeurotic attachment of the biceps femoris muscle on the lateral tibial condyle; unfortunately, it is again interpreted as an isolated ligamentous structure. The aponeurotic nature of the so-called ALL has already been described by Terry et al. (1986). Interestingly, in a consecutive article (Terry and LaPrade, 1996), they obviously followed the original verbal description of Segond (1879) differing from the accompanying illustration and thus localized the ALL within the iliotibial tract. This localization has also been chosen in the recently published consensus paper (Sonnery-Cottet et al., 2017). In addition, Viera et al. (2007) have attributed both, the biceps aponeurosis and the iliotibial band, as representing the ALL. Disregarding the existence of different layers of the fibrous capsule, other authors have interpreted a combination of outer and inner strata, i.e. ligaments connecting the lateral meniscus with femur and tibia together with either the biceps aponeurosis (Brockmeyer et al., 2017, 2019; Patel and Brophy, 2018; Rustagi et al., 2019; Toro-Ibarguen et al., 2017; Van Dyck et al., 2016) or the iliotibial tract (Vincent et al., 2012) as being the ALL. Perhaps this again misleading view is based upon an illustration in Henle's textbook indicating an insertion of the fibular collateral ligament (sic!) into the lateral meniscus (Cavaignac et al., 2017; Henle, 1872). As this ligament is completely extracapsular and surrounded by the tendon of biceps femoris, an attachment to the lateral meniscus has to be attributed to the fibrous capsule formed by the anterior arm of the short head of the biceps femoris muscle again (Munshi et al., 2003).

4.2. Nature of the so-called anterolateral ligament

Our results show that the so-called ALL as defined by Claes et al. (2013) is represented by the most anterior fibers of the anterior arm of the short head of the biceps femoris muscle which have been artificially isolated by resecting the remaining part of the tibial insertion of the biceps femoris muscle. The present results are further confirmed by developmental studies revealing the non-existence of an ALL in human fetuses (Sabzevari et al., 2017) and also in other vertebrates from reptiles to primates (Ingham et al., 2017; Vallois, 1914). Quite to the contrary, Toro-Ibarguen et al. (2017) as well as Helito et al. (2017) reported a constant presence of the ALL in human fetuses. But the first study unfortunately suffers from a principal shortcoming, i.e. an inconsistent definition of the ALL which on one hand is said to be definitely extracapsular and on the other hand should be attached to the lateral meniscus. In the second study, the authors have again isolated a part of the biceps aponeurosis and hence presented an artificially created ligament. Moreover, Shea et al. have reported a highly variable incidence of the ALL in children ranging from 14 to 64% (Shea et al., 2017, 2016), but again show up with the same type of artifact.

4.3. MRI-appearance of the anterolateral part of the knee joint fibrous capsule

Reports on the MR-anatomy of the so-called ALL are mainly based on the hitherto published anatomical studies. Thus, they reduce the insertion of the biceps femoris to its tendinous attachment on the fibular head and again identify its aponeurotic insertion into the lateral tibial condyle as ALL (Patel et al., 2017; Patel and Brophy, 2018; Taneja et al., 2015; Van Dyck et al., 2016). As shown in the present study, this aponeurosis covers the whole space between the posterior border of the iliotibial tract and the fibular collateral ligament enwrapped by the biceps tendon. This is best described by Dombrowski et al. (2016) as “lateral capsular thickening”, but again without referring to the anatomic structure behind, i.e. the biceps aponeurosis.

4.4. Functional aspects concerning the anterolateral part of the knee joint fibrous capsule

According to Fuss (1991), the “fibrous side-structures”, i.e. the biceps tendon together with the fibular collateral ligament form a “fibrous cylinder which is torqued in rotation” and assist the anterior cruciate ligament in restricting internal rotation of the flexed knee. The increased tension of the biceps tendon and aponeurosis in the fully internal rotated knee can be even easily felt in the living. As already observed by Duchenne (1867) and recapitulated by Kaplan (1957, 1962) and Jagodzinski et al. (2016), the more moveable lateral half of the knee joint urges for the principle of dynamic stabilization. This may not be fulfilled by ligaments but only by muscles acting on their tendons which, in turn, build up and reinforce the fibrous capsule. Thus, Jagodzinski et al. (2016) have subdivided the lateral supporting structures of the knee joint into more passive and active elements. While the lateral collateral ligament together with the iliotibial tract and the arcuate popliteal ligament represent the more passive elements, the active part is taken over by the biceps tendon and aponeurosis, the popliteus muscle, the lateral head of the gastrocnemius muscle and again the iliotibial tract. The dynamic function of the latter is exerted by the attachments of the tensor fasciae latae and gluteus maximus muscles. These authors especially stress that the biceps femoris muscle is highly relevant in stabilizing the extended knee against varus stress and – as already stated above – the flexed knee against internal rotation. They again confirm our own results by stating that the biceps is not only attached to the fibular head but also on the lateral tibial condyle (Jagodzinski et al., 2016). In addition Filli et al. (2018) have reported that the biceps tendon is frequently torn in patients suffering from anterior cruciate ligament injury. The tendinous nature of the anterolateral part of the knee joint fibrous capsule is further illustrated by the fact that the aponeurotic fibers insert into the tibia via non-calcified fibrocartilage, thus forming an enthesis (Nasu et al., 2018; Neri et al., 2017). Classically, entheses are said to be typical for epiphyseal insertions of muscles (thus also as for the biceps aponeurosis) and show a morphology similar to joint facets (Schneider, 1956). All these facts underline that the so-called ALL cannot be either a ligament or a “simple thickening of capsular structure” (Neri et al., 2017) but is represented by the aponeurotic insertion of the biceps femoris muscle.

4.5. Lateral meniscofemoral and meniscotibial ligaments

As some authors even take lateral meniscofemoral and meniscotibial ligaments to represent the ALL in part, either combined with the biceps aponeurosis (Patel and Brophy, 2018; Toro-Ibarguen et al., 2017; Van Dyck et al., 2016) or the iliotibial tract (Vincent et al., 2012), we also wanted to re-evaluate these connections at the inner aspect of the joint capsule. In the early study of Vallois (1914), a meniscotibial connection (named “membrane méniscale”) has been found to exist in variable form and size in certain primates including humans. In the latter however, it has been seen as very reduced in size. In other primates, the meniscotibial ligament is replaced by a meniscofibular ligament anchoring the lower edge of the lateral meniscus to the fibular head. Obviously, this is caused by the broad communication between the knee and tibiofibular joints present in these animals (Vallois, 1914). Jost (1921) has found the lateral meniscofemoral ligament to be an inconstant structure, phylogenetically appearing together with the ability of voluntary rotating the flexed knee. Thus, he has diagnosed it in the horse, the rabbit, the squirrel and a first draft of it also in carnivores. It seems to become a constant structure in prosimians, simians and anthropoids and is said to be proximally attached to the lateral femoral epicondyle and the tendon of the popliteus muscle (Jost, 1921). Thus, it seems to be similar to the superior popliteomeniscal fascicle (Munshi et al., 2003) and also hardly to distinguish from the tendon of the popliteus muscle itself (Staeubli and Birrer, 1990).

The meniscotibial continuation (Jost, 1921) represented by the lateral meniscotibial ligament (lmtl) described herein, is an obviously phylogenetically younger structure. It is first manifested in cebidae (e.g., the ateles) and anthropoids, e.g. the gibbon (Jost, 1921). But even in humans, Jost has found it in only 33 of 40 knee joints examined, i.e. in 82.5% (Jost, 1921). More recently, Bezerra et al. (2007) in a series of 85 human knees, have found it far more seldom, i.e. in merely 20 specimens (23.5%). Interestingly, more than two third of these were left knees. Both studies are thus quite in contrast to our findings revealing that the lmtl is a constantly present structure in our series. Furthermore, our measured values for the length and anteroposterior extension of the lmtl are strikingly different from those given by Jost (1921). Whereas the lmtl in our study was 13.9 mm shorter in longitudinal direction, the anteroposterior extension is 9.6 mm longer than in his study. The difference of the first value can be explained by the fact that Jost has added also the proximal, meniscofemoral or popliteomeniscal connections. The smaller second values could be due to the fact that Jost had by chance used specimens with a broad communication between the knee and tibiofibular joints which – as discussed above – influences the size of the lmtl (Vallois, 1914). According to Pauzat (1895) and Jost (1921), the lmtl is able to limit the voluntary rotation of the flexed knee by restraining backward gliding of the lateral meniscus against the tibial condyle. Thereby, its tibial attachment acts as a fixed point. Via the popliteomeniscal fascicle, the popliteus muscle and tendon is said to further assist the lmtl in ensuring the lateral meniscus (Jost, 1921).

4.6. Surgical aspects concerning the anterolateral part of the knee joint fibrous capsule

Merely based on the fact that three different structures represent the ALL, there is also no consensus about the optimal surgical reconstruction in rotatory instable knee joints (Chahla et al., 2018). However, actually applied surgical techniques commonly replace the ALL in that part of the fibrous capsule which – in reality – is established by the anterior arm of the biceps aponeurosis (Chahla et al., 2016; Mathew et al., 2018; Nitri et al., 2016; Patel and Brophy, 2018; Schon et al., 2016). Interestingly, a majority of these authors have reported a postoperative overconstraint of the knee (Chahla et al., 2018; Nitri et al., 2016; Patel and Brophy, 2018), but have not given any explanation. Anatomically, a possible explanation seems to be that the femoral attachment of the reconstruction situated at its lateral epicondyle is far distally to the natural origin of the short head of the biceps femoris muscle. According to textbook notations and also to our long lasting dissection room experience the lowermost point of origin is from the lateral supracondylar line just above the lateral femoral condyle (Salmons, 1995). Therefore, attaching the graft to the lateral femoral epicondyle anterior to the fibular collateral ligament seems to create a wrong pivot and consequently an increased tension on the anterolateral part of the fibrous capsule resulting in limited movement. Thus, as already stated by Ingham et al. (2017), it is questionable how and why the ALL should be surgically reconstructed or replaced.

5. Conclusion

Our results have shown that in any case the so-called ALL is represented by one of the aponeuroses establishing the anterolateral part of the knee joint fibrous capsule. The still existing proverbial babel in defining the ALL has already been initiated by Segond (1879) providing an inconsistent description. Thus, based on his text, the structure named ALL is constituted by the iliotibial tract whereas his rather crude drawing suggests that it is formed by the most anterior fibers of the anterior arm of the short head of the biceps femoris muscle. As the anterolateral part of the fibrous capsule acts as an entity (Duchenne, 1867; Jagodzinski et al., 2016; Kaplan, 1962) including the artificially isolated ALL, we propose – like Ferrer et al. (2018) and Kowalczuk et al. (2018) – to name it the anterolateral aponeurotic complex of the knee joint.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.aanat.2019.06.005.

References

Albright, J.P., 2017. CORR insights: anterolateral ligament of the knee shows variable anatomy in pediatric specimens. Clin. Orthop. 475, 1592–1595.

Bezerra, F.S., Alves, J.N., Silva, M.A.S., Trajano, E.T.L., Ferreira, T.A., Vasconcellos, H.A., Valenca, S.S., 2007. Quantitative and descriptive analysis of the meniscotibial ligament in human corpses. Braz. J. Morphol. Sci. 24, 211–213.

Brockmeyer, M., Hofer, D., Schafer, K., Seil, R., Becker, K., Paulsen, F., Kohn, D., Tschernig, T., 2017. The anterolateral ligament (ALL) of the knee – part of the iliotibial tract or a truly separate structure? Ann. Anat. 212, 1–3.

Brockmeyer, M., Orth, P., Hofer, D., Seil, R., Paulsen, F., Menger, M.D., Kohn, D., Tschernig, T., 2019. The anatomy of the anterolateral structures of the knee – a histologic and macroscopic approach. Knee 22, 22.

Cavaignac, E., Ancelin, D., Chiron, P., Tricoire, J.L., Wytrykowski, K., Faruch, M., Chantalat, E., 2017. Historical perspective on the "discovery" of the anterolateral ligament of the knee. Knee Surg. Sports Traumatol. Arthrosc. 25, 991–996.

Chahla, J., Geeslin, A.G., Cinque, M.E., LaPrade, R.F., 2018. Biomechanical proof for the existence of the anterolateral ligament. Clin. Sports Med. 37, 33–40.

Chahla, J., Menge, T.J., Mitchell, J.J., Dean, C.S., LaPrade, R.F., 2016. Anterolateral ligament reconstruction technique: an anatomic-based approach. Arthrosc. Tech. 5, e453–e457.

Cianca, J., John, J., Pandit, S., Chiou-Tan, F.Y., 2014. Musculoskeletal ultrasound imaging of the recently described anterolateral ligament of the knee. Am. J. Phys. Med. Rehabil. 93, 186.

Claes, S., Bartholomeeusen, S., Bellemans, J., 2014a. High prevalence of anterolateral ligament abnormalities in magnetic resonance images of anterior cruciate ligament-injured knees. Acta Orthop. Belg. 80, 45–49.

Claes, S., Luyckx, T., Vereecke, E., Bellemans, J., 2014b. The Segond fracture: a bony injury of the anterolateral ligament of the knee. Arthroscopy 30, 1475–1482.

Claes, S., Vereecke, E., Maes, M., Victor, J., Verdonk, P., Bellemans, J., 2013. Anatomy of the anterolateral ligament of the knee. J. Anat. 223, 321–328.

Daggett, M., Busch, K., Sonnery-Cottet, B., 2016. Surgical dissection of the anterolateral ligament. Arthrosc. Tech. 5, e185–e188.

de Lima, D.A., Helito, C.P., de Lima, L.L., de Castro Silva, D., Cavalcante, M.L.C., Leite, J.A.D., 2019. Anatomy of the anterolateral ligament of the knee: a systematic review. Arthroscopy 35, 670–681.

De Maeseneer, M., Boulet, C., Willekens, I., Lenchik, L., De Mey, J., Cattrysse, E., Shahabpour, M., 2015. Segond fracture: involvement of the iliotibial band, anterolateral ligament, and anterior arm of the biceps femoris in knee trauma. Skeletal Radiol. 44, 413–421.

Dombrowski, M.E., Costello, J.M., Ohashi, B., Murawski, C.D., Rothrauff, B.B., Arilla, F.V., Friel, N.A., Fu, F.H., Debski, R.E., Musahl, V., 2016. Macroscopic anatomical, histological and magnetic resonance imaging correlation of the lateral capsule of the knee. Knee Surg. Sports Traumatol. Arthrosc. 24, 2854–2860.

Duchenne, G.B., 1867. Physiologie des Mouvements démontrée a l'aide de l'expérimentation électrique et de l'observation clinique et applicable al'etude des paralyses et des déformations. J.B. Bailliere et fils, Paris.

Ferrer, G.A., Guenther, D., Pauyo, T., Herbst, E., Nagai, K., Debski, R.E., Musahl, V., 2018. Structural properties of the anterolateral complex and their clinical implications. Clin. Sports Med. 37, 41–47.

Fick, R., 1911. Handbuch der Anatomie und Mechanik der Gelenke Dritter Teil: Spezielle Gelenk- und Muskelmechanik. In: Bardeleben, K. (Ed.), Handbuch der Anatomie des Menschen. G. Fischer, Jena.

Filli, L., Rosskopf, A.B., Sutter, R., Fucentese, S.F., Pfirrmann, C.W.A., 2018. MRI predictors of posterolateral corner instability: a decision tree analysis of patients with acute anterior cruciate ligament tear. Radiology 289, 170–180.

Fuss, F.K., 1991. Voluntary rotation in the human knee joint. J. Anat. 179, 115–125.

Helito, C.P., do Prado Torres, J.A., Bonadio, M.B., Aragao, J.A., de Oliveira, L.N., Natalino, R.J., Pecora, J.R., Camanho, G.L., Demange, M.K., 2017. Anterolateral ligament of the fetal knee: an anatomic and histological study. Am. J. Sports Med. 45, 91–96.

Henle, J., 1872. Handbuch der Bänderlehre des Menschen. In: Henle, J. (Ed.), Handbuch der systematischen Anatomie des Menschen. , 2nd ed. Vieweg und Sohn, Braunschweig, p. 144.

Ingham, S.J.M., de Carvalho, R.T., Martins, C.A.Q., Lertwanich, P., Abdalla, R.J., Smolinski, P., Lovejoy, C.O., Fu, F.H., 2017. Anterolateral ligament anatomy: a comparative anatomical study. Knee Surg. Sports Traumatol. Arthrosc. 25, 1048–1054.

Jagodzinski, M., Müller, W., Friederich, N., 2016. Das Knie, 2nd ed. Springer, Berlin.

Jost, A., 1921. La morphogènése et le ròle fonctionnel des ligamentes épiconylo-méniscaux du genou. CR Soc. Biol. LXXXIV, 667–669.

Kaplan, E.B., 1957. Factors responsible for the stability of the knee joint. Bull. Hosp. Joint Dis. 18, 51–59.

Kaplan, E.B., 1962. Some aspects of functional anatomy of the human knee joint. Clin. Orthop. 23, 18–29.

Keri, C., Ahnelt, P.K., 1991. A low cost computer aided design (CAD) system for 3D-reconstructions from serial sections. J. Neurosci. Methods 37, 241–250.

Kowalczuk, M., Herbst, E., Burnham, J.M., Albers, M., Musahl, V., Fu, F.H., 2018. A layered anatomic description of the anterolateral complex of the knee. Clin. Sports Med. 37, 1–8.

Mathew, M., Dhollander, A., Getgood, A., 2018. Anterolateral ligament reconstruction or extra-articular tenodesis: why and when? Clin. Sports Med. 37, 75–86.

Mulisch, M., Welsch, U., 2010. Romeis Mikroskopische Technik, 18th ed. Spektrum Akademischer Verlag, Heidelberg.

Munshi, M., Pretterklieber, M.L., Kwak, S., Antonio, G.E., Trudell, D.J., Resnick, D., 2003. MR imaging, MR arthrography, and specimen correlation of the posterolateral corner of the knee: an anatomic study. Am. J. Roentgenol. 180, 1095–1101.

Nasu, H., Nimura, A., Sugiura, S., Fujishiro, H., Koga, H., Akita, K., 2018. An anatomic study on the attachment of the joint capsule to the tibia in the lateral side of the knee. Surg. Radiol. Anat. 40, 499–506.

Neri, T., Palpacuer, F., Testa, R., Bergandi, F., Boyer, B., Farizon, F., Philippot, R., 2017. The anterolateral ligament: anatomic implications for its reconstruction. Knee 24, 1083–1089.

Nitri, M., Rasmussen, M.T., Williams, B.T., Moulton, S.G., Cruz, R.S., Dornan, G.J., Goldsmith, M.T., LaPrade, R.F., 2016. An in vitro robotic assessment of the anterolateral ligament. Part 2: Anterolateral ligament reconstruction combined with anterior cruciate ligament reconstruction. Am. J. Sports Med. 44, 593–601.

Olewnik, Ł., Gonera, B., Kurtys, K., Podgórski, M., Polguj, M., Topol, M., 2019. A proposal for a new classification of the fibular (lateral) collateral ligament based on morphological variations. Ann. Anat. 222, 1–11.

Parker, M., Smith, H.F., 2018. Anatomical variation in the anterolateral ligament of the knee and a mew dissection technique for embalmed cadaveric specimens. Anat. Sci. Int. 93, 177–187.

Patel, K.A., Chhabra, A., Goodwin, J.A., Hartigan, D.E., 2017. Identification of the anterolateral ligament on magnetic resonance imaging. Arthrosc. Tech. 6, e137–e141.

Patel, R.M., Brophy, R.H., 2018. Anterolateral ligament of the knee: anatomy, function, imaging, and treatment. Am. J. Sports Med. 46, 217–223.

Pauzat, J.E., 1895. Etudes sur le fonctionnement des ménisques interarticulaires du genou et les lésions qui peuvent en etre la conséquence. Revue de Chirurgie 15, 97–146.

Pomajzl, R., Maerz, T., Shams, C., Guettler, J., Bicos, J., 2015. A review of the anterolateral ligament of the knee: current knowledge regarding its incidence, anatomy, biomechanics, and surgical dissection. Arthroscopy 31, 583–591.

Porrino Jr., J., Maloney, E., Richardson, M., Mulcahy, H., Ha, A., Chew, F.S., 2015. The anterolateral ligament of the knee: MRI appearance, association with the Segond fracture, and historical perspective. Am. J. Roentgenol. 204, 367–373.

Pretterklieber, M.L., 1999. Anatomy and arthrokinematics of the human ankle and intertarsal joints. Radiologe 39, 1–7.

Pretterklieber, M.L., Porta, J., Schamall, D., Zelenka, B., 2012. Anatomy. In: Kramer, J. (Ed.), MRI of the knee. University Publisher 2.0, Horn, pp. 13–42.

Rand, T., Frank, L., Pretterklieber, M.L., Muhle, C., Resnick, D., 2000. Intertarsal ligaments: high resolution MRI and anatomic correlation. J. Comput. Assist. Tomogr. 24, 584–593.

Rasmussen, M.T., Nitri, M., Williams, B.T., Moulton, S.G., Cruz, R.S., Dornan, G.J., Goldsmith, M.T., LaPrade, R.F., 2016. An in vitro robotic assessment of the anterolateral ligament. Part 1: Secondary role of the anterolateral ligament in the setting of an anterior cruciate ligament injury. Am. J. Sports Med. 44, 585–592.

Resnick, D., Kang, H.S., Pretterklieber, M.L., 2007. Knee. In: Resnick, D., Kang, H.S., Pretterklieber, M.L. (Eds.), Internal Derangements of Joints. , 2nd ed. Saunders Elsevier, Philadelphia, pp. 1561–2011.

Runer, A., Birkmaier, S., Pamminger, M., Reider, S., Herbst, E., Kunzel, K.H., Brenner, E., Fink, C., 2016. The anterolateral ligament of the knee: a dissection study. Knee 23, 8–12.

Rustagi, S.M., Gopal, P., Ahuja, M.S., Arora, N.C., Sood, N., 2019. The anterolateral ligament of the knee: descriptive anatomy and clinical correlation. Indian J. Orthop. 53, 89–93.

Sabzevari, S., Rahnemai-Azar, A.A., Albers, M., Linde, M., Smolinski, P., Fu, F.H., 2017. Anatomic and histological investigation of the anterolateral capsular complex in the fetal knee. Am. J. Sports Med. 45, 1383–1387.

Salmons, S., 1995. Muscle. In: Williams, P.L., Bannister, L.H., Berry, M.M., Collins, M., Dyson, M., Dussek, J.E., Ferguson, M.W.J. (Eds.), Gray's Anatomy. , 38th ed. Chruchull Livingstone, New York.

Schneider, H., 1956. Zur Struktur der Sehnenansatzzonen. Z. Anat. Entwicklungsgesch. 119, 431–456.

Schon, J.M., Moatshe, G., Brady, A.W., Serra Cruz, R., Chahla, J., Dornan, G.J., Turnbull, T.L., Engebretsen, L., LaPrade, R.F., 2016. Anatomic anterolateral ligament reconstruction of the knee leads to overconstraint at any fixation angle. Am. J. Sports Med. 44, 2546–2556.

Segond, P., 1879. Recherches cliniques et expérimentales sur les épanchenents sanguins du genou par entorse. Prog. Med. 7, 1–85.

Shea, K.G., Milewski, M.D., Cannamela, P.C., Ganley, T.J., Fabricant, P.D., Terhune, E.B., Styhl, A.C., Anderson, A.F., Polousky, J.D., 2017. Anterolateral ligament of the knee shows variable anatomy in pediatric specimens. Clin. Orthop. 475, 1583–1591.

Shea, K.G., Polousky, J.D., Jacobs Jr., J.C., Yen, Y.M., Ganley, T.J., 2016. The anterolateral ligament of the knee: an inconsistent finding in pediatric cadaveric specimens. J. Pediatr. Orthop. 36, e51–e54.

Sneath, R.S., 1955. The insertion of the biceps femoris. J. Anat. 89, 550–553.

Sonnery-Cottet, B., Daggett, M., Fayard, J.M., Ferretti, A., Helito, C.P., Lind, M., Monaco, E., de Padua, V.B.C., Thaunat, M., Wilson, A., Zaffagnini, S., Zijl, J., Claes, S., 2017. Anterolateral Ligament Expert Group consensus paper on the management of internal rotation and instability of the anterior cruciate ligament – deficient knee. J. Orthop. Traumatol. 18, 91–106.

Staeubli, H.U., Birrer, S., 1990. The popliteus tendon and its fascicles at the popliteal hiatus: gross anatomy and functional arthroscopic evaluation with and without anterior cruciate ligament deficiency. Arthroscopy 6, 209–220.

Tandler, J., 1926. Knochen – Gelenk und Muskellehre. In: Tandler, J. (Ed.), Lehrbuch der systematischen Anatomie. , 2nd ed. F.C.W. Vogel, Leipzig.

Taneja, A.K., Miranda, F.C., Braga, C.A., Gill, C.M., Hartmann, L.G., Santos, D.C., Rosemberg, L.A., 2015. MRI features of the anterolateral ligament of the knee [Erratum appears in Skeletal Radiol. 2015 Mar; 44(3): 411; PMID: 25520243]. Skeletal Radiol. 44 (3), 403–410.

Terry, G.C., Hughston, J.C., Norwood, L.A., 1986. The anatomy of the iliopatellar band and iliotibial tract. Am. J. Sports Med. 14, 39–45.

Terry, G.C., LaPrade, R.F., 1996. The posterolateral aspect of the knee: anatomy and surgical approach. Am. J. Sports Med. 24, 732–739.

Thein, R., Boorman-Padgett, J., Stone, K., Wickiewicz, T.L., Imhauser, C.W., Pearle, A.D., 2016. Biomechanical assessment of the anterolateral ligament of the knee: a secondary restraint in simulated tests of the pivot shift and of anterior stability. J. Bone Joint Surg. Am. 98, 937–943.

Toro-Ibarguen, A.N., Pretell-Mazzini, J., Perez, E., Pedrajas, I., Cano-Egea, J.M., Ramon Sanudo, J., 2017. The anterolateral ligament: a cadaveric study in fetuses. Clin. Anat. 30, 625–634.

Vallois, H.V., 1914. Etude anatomique de l'articulation du genou chez les primates, Laboratoire d'anatomie de la Faculté de médecine de Montpellier. Montpellier. Abeille.

Van der Watt, L., Khan, M., Rothrauff, B.B., Ayeni, O.R., Musahl, V., Getgood, A., Peterson, D., 2015. The structure and function of the anterolateral ligament of the knee: a systematic review. Arthroscopy 31, 569–582, e563.

Van Dyck, P., De Smet, E., Lambrecht, V., Heusdens, C.H., Van Glabbeek, F., Vanhoenacker, F.M., Gielen, J.L., Parizel, P.M., 2016. The anterolateral ligament of the knee: what the radiologist needs to know. Semin. Musculoskelet. Radiol. 20, 26–32.

Viera, E.L.C., Viera, E.A., daSilva, R.T., dosSantos Berlfein, P.A., Abdalla, R.J., Cohen, M., 2007. An anatomic study of the iliotibial tract. Arthroscopy 23, 269–274.

Vincent, J.P., Magnussen, R.A., Gezmez, F., Uguen, A., Jacobi, M., Weppe, F., Al-Saati, M.F., Lustig, S., Demey, G., Servien, E., Neyret, P., 2012. The anterolateral ligament of the human knee: an anatomic and histologic study. Knee Surg. Sports Traumatol. Arthrosc. 20, 147–152.

Weitbrecht, J., 1742. Syndesmologia sive historia ligamentorum corporis humani. Typographia Academiae Scientiarum, Sankt Petersburg.