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Anterolateral rotatory instability of the knee

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Abstract Recent publications have generated renewed interest in the anatomy of the anterolateral capsule. Knowledge of the biomechanical function of the anterolateral components is lacking. Further research is required to evaluate the influence of the anterolateral capsule on rotatory laxity of the knee. The role of surgical procedures, such as an extra-articular tenodesis or lateral plasty, has to be defined based on quantification of the injury. This article seeks to summarize the current literature and discusses the role of the anterolateral capsule and reconstructive techniques in combined ligamentous knee trauma.
Level of evidence V.

Keywords Anterolateral capsule · Anterolateral ligament · Rotatory laxity · Rotatory instability · Knee

Introduction

The interplay between the dynamic and static stabilizers of the knee joint is complex. The lateral side of the knee is especially reliant on these stabilizers due to its inherent bony instability from the opposing convex surfaces [56]. Beyond the collateral and cruciate ligaments of the knee, there are significant strength and stabilizing effects from the lesser-known ligaments of the knee. The first description of an injury to the lateral capsular ligaments was an avulsion fracture [46]. The Segond fracture is said to result from an avulsion of the lateral proximal tibia due to the insertion of a ligamentous structure. Recently, there have been an increased number of publications on the static stabilizers of the anterolateral knee [10].

The nomenclature has varied in the literature including the mid-third lateral capsular ligament [18, 26, 28, 31, 39, 51, 52, 58], anterior oblique band of the fibular collateral ligament (FCL) [6, 27], the capsulo-osseous layer of the iliotibial band [29, 50, 53, 54], or the anterolateral ligament [10, 54, 55]. For the purpose of this article, we will refer to this lateral stabilizing structure as the anterolateral capsule (ALC). The anatomy of the ALC is controversial given that it has interdigitating fibres with the iliotibial band. Often, a capsular thickening rather than a distinct ligament, such as the anterior cruciate ligament (ACL), is present.

Significant clinical interest exists whether ALC injuries in anterior ACL-deficient knees should be surgically addressed at the time of ACL surgery. Some have postulated that a combined intra- and extra-articular reconstruction can achieve improved post-operative stability and may result in a decreased incidence in post-traumatic arthritis. However, biomechanical studies regarding the function of the ALC are lacking. So far, determination of rotatory laxity is mainly based on subjective grading using the pivot shift test. Even though a standardized pivot shift test has been proposed [22], the clinical grading and the tibial translation still vary between examiners.

A better method to test rotatory knee laxity is by quantitative pivot shift testing. An image analysis method, which tracks markers on the lateral knee, was found to

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accurately calculate lateral compartment translation during the pivot shift [2, 3, 24]. Subsequently, an iPad application was developed to aid in processing of the image capture as well as calculation of translation [23]. An inertial sensor strapped non-invasively to the anterior tibia is another quantitative pivot shift tool [34]. This device is able to calculate acceleration of the proximal tibia during the reduction movement of the pivot shift test and is sensitive to rupture of the ACL [33]. The importance of quantitative pivot shift testing does not only provide objective laxity parameters but more importantly provide side-to-side comparison of the healthy and injured knee.

The purpose of this article was to summarize the current knowledge on the ALC. The clinical relevance is to rationalize the current applications for surgical reconstruction of the ALC structures for anterolateral rotatory instability of the knee.

Material and methods

A comprehensive review of the MEDLINE database was carried out to identify relevant articles using different keywords (e.g. “anterolateral ligament”, “anterolateral capsule”, “anterolateral rotatory laxity”, “lateral structures of the knee”, “Segond fracture”). Our search strategy yielded 1062 articles. Two authors screened the articles and excluded 1020 articles. Articles not written in English, not pertaining to the knee, or not specifically addressing the area of interest or directly associated structures were excluded. The reference lists of the reviewed articles were searched for additional relevant articles. The references were divided into history, anatomy, histology, imaging, biomechanics, and treatment. However, biomechanical, histological, and prospective randomized studies were rare.

History

The structures of the ALC were subjects of multiple research projects during the last century. Segond originally described a pearly, resistant, fibrous band in this area [46]. Hughston later described a lateral capsular ligament as a thickening of the capsule which is divided into anterior, middle, and posterior thirds as well as a division into menisco-femoral and menisco-tibial components [25]. The mid-third lateral capsular ligament was the most structurally important and attached to Segond fragments [51, 57]. The mid-third lateral capsular ligament description has been supported in other anatomic descriptions [29, 39, 52], identified on MRI scans [18, 29], and associated with injuries causing anterolateral laxity [26, 31]. Other studies described an anterior oblique bundle of the FCL, which originated from the FCL in an oblique fashion and inserted at the lateral mid-portion of the tibia and blending with posterior fibres of the iliotibial tract [6, 27]. This description is similar to Hughston’s description of the mid-third capsular ligament stated above. Additionally, the recent literature described an anterolateral ligament to attach anteriorly to the socket from which the FCL originated [10]. This description is also similar since the FCL is known to attach only millimetres away from the lateral femoral epicondyle [30]. The insertion of the ligamentous structure into the tibia was consistent in all of the above papers. It was described as posterior to the insertion of the iliotibial band at Gerdy’s tubercle [6, 18, 26, 27, 29, 31, 39, 51, 52, 55].

The intimate relationship between the anterolateral capsule and the iliotibial band was frequently mentioned in the previous literature. In fact, the capsulo-osseous layer has been called the “true knee anterolateral ligament” and was described to have attachments and orientation similar to Hughston [54]. Attachments between the capsulo-osseous layer of the iliotibial band and the ACL create an inverted horseshoe sling around the posterior femoral condyle preventing the anterolateral tibial subluxation that occurs in the pivot shift test [50]. Because of similar descriptions of the attachment sites and interdigitating fibres [28] between a ligamentous structure in the ALC and the capsulo-osseous layer of the iliotibial band, it is worthwhile to consider that these two structures may be synonymous.

The anterolateral ligament

Recently, there have been a number of new studies dedicated to the anatomy of the ALC. Each article was unique in its surgical approach to identify a ligamentous structure and as a result, the anatomic findings differed. Table 1 lists the number of specimens used, the anthropometric data, and the proposed origins and insertions of the structure for all recent anatomy articles included in this article. Table 2 lists quantitative measurements from these studies for the anatomy of the structure. After resection of the skin, subcutaneous fat tissue, and iliotibial band, different approaches were proposed for visualization. In one approach, the knee was flexed to 60° and an internal torque was applied. All visible distinct fibres were isolated at the proximal tibia, posterior and proximal to Gerdy’s tubercle, and on the lateral femur [10]. In another approach, varus and internal rotational forces were applied between 30° and 60° flexion to highlight any structure coming under tension. Any tissue in the anterolateral region of the knee that did not come under tension was resected, leaving only a ligamentous structure [7]. Other authors placed a Hohmann retractor between the femur and the tibia tightening

Table 1 Anthropometric data of the included specimen and the proposed origins and insertions of the described structures for the respective studies

	Amount of specimen	Gender (m/f)	Mean age (years)	Identified ALL	Origin	Insertion	State
Claes et al.	41	22m/19f	79 (range 61–93)	40 (97 %)	Lateral femoral epicondyle Anterior to the origin of the FCL, proximal and posterior to the insertion of the popliteus tendon	Middle of the line connecting Gerdy's tubercle and the tip of the fibular head	Embalmed
Vincent et al.	10	2m/8f	85.3 ± 5.1	10 (100 %)	Lateral femoral condyle Closely associated with the popliteus tendon	Posterior to a line drawn vertically from the posterior border of Gerdy's tubercle to the joint line	Fresh
Dodds et al.	40	21m/19f	75 (range 58–90)	33 (83 %)	Capsule (no direct attachment to the femur)	Posterior to Gerdy's tubercle and anterior to the head of the fibula	Fresh-frozen
Stijak et al.	14	6m/8f	78	7 (50 %)	Lateral femoral condyle In front of the FCL	Lateral tibial condyle Midway between Gerdy's tubercle and the head of the fibula	Formalin fixed
Caterine et al.	19	13m/7f	70 (range 51–94)	19 (100 %)	Lateral femoral epicondyle Anterior–distal to FCL ($n = 11$) Lateral femoral epicondyle Posterior and proximal to FCL ($n = 8$)	Tibia Posterior to Gerdy's Tubercle ($n = 18$) Medial to the fibular head ($n = 1$)	Fresh-frozen
Helito et al.	20	16m/4f	61.5 ± 11.2 (range 37–67)	20 (100 %)	Lateral femoral epicondyle Anterior and distal to the FCL	Posterior to Gerdy's tubercle and anterior to the head of the fibula	Not described
Sonnery-Cottet et al.	1	Not described	Not described	1 (100 %)	Not described	Not described	Not described

FCL fibular collateral ligament

Table 2 Measurements of the particular structures for the respective studies

	Measurement tool	Length (mm)	Width (mm) Femoral origin	Width (mm) Joint line	Width (mm) Insertion	Thickness (mm)	Measured specimen
Claes et al.	Digital calliper	38.5 ± 6.1 (extension) 41.5 ± 6.7 (90° flexion)	8.3 ± 2.1	6.7 ± 3.0	11.2 ± 2.5	1.3 ± 0.6	41/41
Vincent et al.	Not described	34.1 ± 3.4	–	8.2 ± 1.5	–	2–3	Not described
Dodds et al.	Digital image analysis program	59 ± 4	–	6 ± 1	–	–	8/40
Stijak et al.	Not described	41 ± 3	–	4 ± 1	–	1	7/14
Caterine et al.	Digital calliper	40.3 ± 6.2	4.8 ± 1.4	5.1 ± 1.8 (above meniscus) 8.9 ± 2.5 (below meniscus)	11.7 ± 3.3	1.4 ± 0.6	14/19
Helito et al.	Digital calliper	37.3 ± 4.0	–	7.4 ± 1.7	–	2.7 ± 0.6	20/20
Sonnery-Cottet et al.	–	–	–	–	–	–	–

the lateral joint capsule until a ligament became visible. In addition, they examined 30 patients undergoing knee arthroplasty. In all 30 cases, they identified and dissected a ligamentous structure free from the lateral joint capsule [55]. Dodds et al. [13] disarticulated knees with only the anterolateral structures remaining intact. Then, using transillumination, they identified a potential capsular thickening above and below the lateral meniscus. Sonnery-Cottet et al. [47] arthroscopically identified a ligament both in vivo in patients undergoing treatment for iliotibial band syndrome, and in cadavers followed by an open dissection, to confirm the correct identification of the structure. Another study described the structure as a thickening of the knee joint capsule, which was not always clearly morphologically differentiated from the remainder of the joint capsule [48]. The authors describe a broad, translucent fibrous band connecting the lateral femoral epicondyle to a point on the proximal tibial midway between Gerdy's tubercle and the fibular head, whose fibres were continuations of the iliotibial band.

The attachments of the ligamentous structures are also controversial. Some studies describe an attachment between the ligament and the lateral meniscus [7, 10, 20, 48]. Other studies claim that the structure does not insert into the rim of the lateral meniscus, although there were branching attachments to it [13]. Still others mention that the majority of fibres came close to the meniscal tissue, but continued without interruption towards the tibial plateau [55].

Recently, a systematic review summarized the different approaches to provide and discuss a universal surgical course of action [43]. The authors conclude that anatomic variability should be taken into account when identifying a ligamentous structure in the area of the ALC.

Histology

In a histological analysis with haematoxylin and eosin, the ALC was compared to the ACL in four knees [7]. The collagen pattern of the structure was organized into individual bundles, indicating that the structure was a combination of multiple thickenings of the lateral joint capsule and not a homogenous entity such as the ACL. However, the femoral and tibial attachments contained more a consistent collagenous pattern, and the transition between the ALC and the mineralized cartilage and bone was indicative of ligamentous tissue. Furthermore, immunohistochemistry and serial sectioning indicated that this part of the ALC has a peripheral nervous innervation and mechanoreceptors [7]. Another study performed histological analysis using haematoxylin and eosin staining on ten specimens after removing the ALC structure en bloc. They concluded that a distinct fibrous structure is present in contact with the synovium [55]. The presence of dense connective tissue with arranged fibres and little cellular material was described in ten specimens [20].

A recent research study [14] performed histology on two specimens that were identified with a thickening of the anterolateral capsule in MRI (Fig. 1). The thickening appeared as a transition from loose connective tissue similar to the capsule to an organized structure similar to ligamentous tissue. In the area of the thickening, elongated nuclei were positioned between aligned collagen. However, the structural organization was not as regular as the FCL.

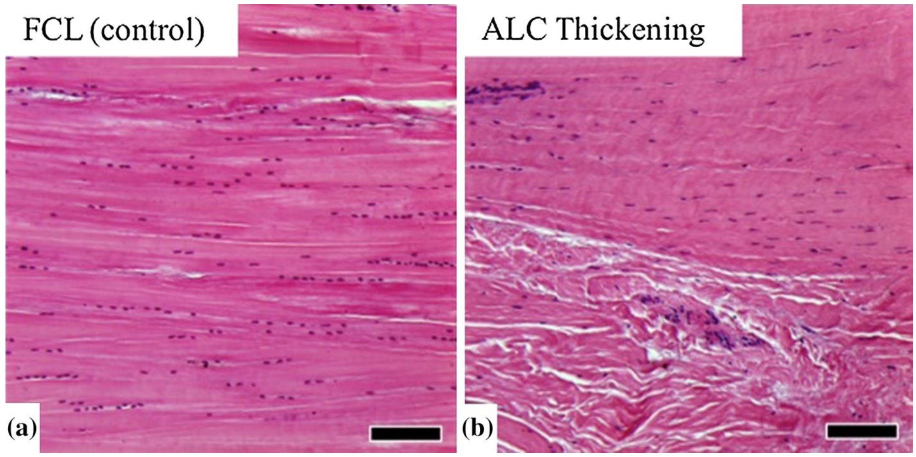

Fig. 1 Histological comparison of the fibular collateral ligament (FCL) (**a**) and a thickening of the anterolateral capsule (ALC) (**b**), which was confirmed by MRI prior to the dissection (*scale* 100 µm)

Fig. 2 MRI with (**a**) and without (**b**) thickening of the lateral capsule (t2 fat sat sequence)

Imaging

Different qualities of imaging have been proposed to determine the structures of the ALC. What is the role they play in the evaluation of anterolateral laxity? The origin and insertion of a potential ligamentous structure in this area were described in radiographic studies [19, 44]. Historical literature stated that a Segond fracture correlates with an injury of the ALC. A recent study concluded that the avulsion resulted from the attachment of a ligamentous structure [9]. Others mention that the iliotibial band may be involved in the Segond avulsion as well [12]. Summing up, the presence of a Segond fracture on radiographs can be a hint that rotational instability is present.

The structures of the ALC can also be evaluated using ultrasound [8]. However, the gold standard is still evaluation by MRI [49]. A study revealed the presence of a 2–4 mm thickening of the central third of the lateral capsule in 3 of 10 specimens (Fig. 2) [14]. Other studies reported that a ligamentous structure was visualized in 97.4 [21] and 100 % [7]. So far, only one study correlated MRI findings with rotational stability using the iPad technology [23] as described before.

Biomechanics

Lateral instability of the knee is less frequent but more disabling than medial instability of a comparable amount [4]. It is known that similar to the menisci, the anterolateral capsule is a secondary stabilizer of anterior translation and rotation of the lateral compartment [37]. Increased anterior translation in flexion as well as in extension and increased internal rotation at 90° of flexion has been shown to be consistent with combined injury to the anterior cruciate ligament and the anterolateral structures [59]. Moreover, cadaveric navigation studies showed an increase in pivot shift grade after the section of lateral capsule or ALL compared to isolate ACL cut, suggesting its importance in the control of dynamic rotational laxity [37]. Given the previous literature documenting the role of a ligamentous structure in the ALC in anterolateral rotatory stability [6, 26, 28, 31, 46, 58], it seems as though the proposed structure and the capsulo-osseous layer of the iliotibial band are similar biomechanically.

However, there is a paucity of biomechanical studies on the ALC. A recent study measured changes in length of a ligamentous structure in eight knees from 0° to 90° of flexion during neutral, internal, and external rotation torque. Small metal eyelets were screwed into the bone at the origin and the insertion of the ligament. The changes in the distance between the eyelets were measured using a monofilament suture and a linear variable displacement transducer [13]. Another study measured the strain in the structure using polydimethylsiloxane gauges [62]. Both studies conclude that more work is needed to confirm the function.

Recently, a study evaluating the biomechanical function of the capsular structures using robotic technology showed that these structures are important stabilizers of internal rotation at higher knee flexion angles [41].

Quantification of injuries to the ALC is of high importance. The pivot shift test was performed in knees with different steps of injuries including the ACL and ALC and after surgical treatment (ACL reconstruction and extra-articular tenodesis). Tibial motion relative to the femur was tracked by an electromagnetic system during the physical examination. This study showed that either an isolated ACL reconstruction or a combined ACL reconstruction and extra-articular tenodesis restored intact knee kinematics in isolated ACL injury. However, an extra-articular tenodesis was necessary to restore intact kinematics when a lateral capsule lesion was present (unpublished data). A similar effect of the lateral plasty was demonstrated with an in vitro cadaveric study using a navigation system (unpublished data). A new approach to measure rotatory laxity of the knee is optical tracker fixation, which is non-invasive and validated by a commercial free navigation system that showed increased agreement compared with devices measuring tibial rotation by foot position alone [45].

Treatment

A combined intra- and extra-articular reconstruction may provide a more normal restoration of knee kinematics after ACL injury with concomitant anterolateral rotational laxity. Some authors advocate it, due to the longer lever arm of the lateral reconstruction, which may allows efficient control of tibial rotation [16]. Furthermore, the tenodesis may provide a "backup" since it persists in cases of intra-articular graft failure [15]. Finally, the extra-articular tenodesis has been found to decrease the stress on the intra-articular graft by more than 40 %, lending credence to the possible load-sharing role of the native structure [16, 17]. More recently, an extra-articular tenodesis as a minimally invasive anatomic reconstruction of the ALL was described [10] using a gracilis-tendon autograft.

The effects of extra-articular tenodesis have been extensively evaluated with navigation studies. Bignozzi et al. acquired in vivo knee kinematics before and after the execution of lateral tenodesis in adjunct to single bundle "over the top" ACL reconstruction. They proved that the lateral plasty was able to reduce the anterior translation of the lateral compartment during the Lachman test, compared to isolated ACL reconstruction [5]. The same researchers performed also a randomized study aimed to compare single bundle plus lateral plasty with double-bundle reconstruction [61], showing that both techniques worked similarly for static knee laxity, while the lateral plasty technique better controlled tibial rotations and the displacement of lateral compartment during anterior drawer test. Similar biomechanical insights were reported also with different techniques of extra-articular tenodesis, suggesting the lateral tenodesis as a key element to reduce the tibial rotation and control the pivot shift phenomenon [11, 38].

Discussion

The most important finding of the present study was that knowledge regarding the biomechanical function of the anterolateral components of the knee is lacking. This article carefully analyses anterolateral rotatory instability in ligamentous knee trauma to determine the suitability for additional procedures, such as an extra-articular tenodesis.

Biomechanically and anatomically, the structures of the anterolateral capsule have held multiple names throughout history. Recently, there has been a dramatic increase in the number of articles related to these structures. While there is some disagreement in describing anatomy as indicated in Table 1, the majority of historical and current articles state that a ligamentous structure is present, whose origin is close to the lateral femoral epicondyle and whose insertion is slightly inferior to the tibial articular surface posterior to Gerdy's tubercle. However, there is still broad variation within the literature regarding the frequency with which the ligament can be identified and regarding its nature of capsular thickening or distinct ligament. Biomechanical studies regarding the function of the structure are lacking. Despite this, some authors already propose surgical treatment of ALC injuries. What is known at this time is that the ALC is an important secondary stabilizer to rotatory knee laxity [37]. In cases where anterolateral laxity remains despite an anatomic ACL reconstruction, an extra-articular tenodesis might be beneficial. However, it is important to note that this should be pursued in a minority of patients. The idea of an extra-articular reconstruction was first popularized in the 1970s, when open surgery with patellar tendon graft was the standard procedure for ACL reconstruction [36]. Lemaire in Europe [32], McIntosh in the USA [4], and others introduced extra-articular techniques with the aim of restoring rotatory stability of the knee. With the establishment and advancement of arthroscopic ACL reconstruction, extra-articular procedures became less common. Critics cited the higher pressure on the lateral compartment and the restricted range of motion due to the anterior position of the femoral insertion as disadvantages of the extra-articular tenodesis. Furthermore, in 2001, Anderson et al. [1] failed to show benefit of extra-articular tenodesis over intra-articular ACL reconstruction. However, in recent years, Neyret et al. and Marcacci et al. [35] were able to show excellent long-term results [42] with high satisfaction and few signs of osteoarthritis. Moreover, Zaffagnini et al. [60], through a randomized study, showed higher clinical results and faster return to sport at 5-year follow-up in patients treated with single-bundle ACL reconstruction plus lateral plasty compared to single-bundle four-strand hamstrings or patellar tendon. Moreover, an improved dynamic laxity behaviour of the extra-articular reconstructed knee was reported as well [56].

Advantages and disadvantages have to be considered when anterolateral instability is present. Individualized ACL surgery is the goal to maximize patient's outcome and functional return. The quantification of the individual injury is the first step to improve the outcome. Non-invasive assessment of pivot shift testing using software loaded on a tablet computer as before mentioned [23, 34] can be used pre-operatively to help grade ACL injury, intra-operatively to help adjust ACL reconstruction in real time, and post-operatively to track ACL graft function during rehabilitation [40].

Further research is required to evaluate the influence of ALC structures on rotatory laxity of the knee. It is of high clinical relevance to establish treatment algorithms and to define the role of additional procedures, such as the extra-articular tenodesis. However, this should be done cautiously and should be delayed until the function of the ALC has been better defined. When an extra-articular tenodesis is performed, the higher pressure on the lateral compartment and the restricted range of motion is a concern that should be discussed with the patients. The post-operative treatment and the physical therapy protocol have to be adapted or tailored to the specific procedure being performed.

Conclusions

Further research is required to evaluate the influence of the ALC on rotatory laxity of the knee. The role of additional procedures, such as an extra-articular tenodesis or lateral plasty, has to be defined based on quantification of the injury to the anterolateral capsule in combined ligamentous knee trauma.

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

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