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Reference:
Getgood Alan, Brow n Charles, Lording Timothy, Amis Andrew , Claes Steven, Geeslin Andrew , Musahl Volker, Van Dyck Pieter, et al..- The anterolateral complex of the knee : results from the International ALC Consensus Group Meeting
Knee surgery, sports traumatology, arthroscopy - ISSN 0942-2056 - 27:1(2019), p. 166-176
Full text (Publisher's DOI): https://doi.org/10.1007/S00167-018-5072-6
To cite this reference: https://hdl.handle.net/10067/1523120151162165141

The Anterolateral Complex of the Knee: Results from the International ALC Consensus Group Meeting

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Abstract

The structure and function of the anterolateral complex (ALC) of the knee has created much controversy since the 're-discovery' of the anterolateral ligament (ALL) and its proposed role in aiding control of anterolateral rotatory laxity in the anterior cruciate ligament (ACL) injured knee. A group of surgeons and researchers prominent in the field gathered to produce consensus as to the anatomy and biomechanical properties of the ALC. The evidence for and against utilization of ALC reconstruction was also discussed, generating a number of consensus statements by following a modified Delphi process.

Key points include that the ALC consists of the superficial and deep aspects of the iliotibial tract with its Kaplan fibre attachments on the distal femur, along with the ALL, a ligamentous structure within the anterolateral capsule. A number of structures attach to the area of the Segond fracture and hence it is not clear which is responsible for this lesion. The ALC functions to provide anterolateral rotatory stability as a secondary stabilizer to the ACL. Whilst biomechanical studies have shown that these structures play an important role in controlling stability at the time of ACL reconstruction, the optimal surgical procedure has not yet been defined clinically. Concern remains that these procedures may cause constraint of motion, yet no clinical studies have demonstrated an increased risk of osteoarthritis development. Furthermore, clinical evidence is currently lacking to support clear indications for lateral extra-articular procedures as an augmentation to ACL reconstruction.

The resulting statements and scientific rationale aim to inform readers on the most current thinking and identify areas of needed basic science and clinical research in order to help improve patient outcomes following ACL injury and subsequent reconstruction.

Introduction

Since the 2013 publication by Claes et al. regarding the anatomy of the anterolateral ligament (ALL)[7], there has been a great deal of controversy surrounding the presence of the ALL, and its potential role in the control of anterolateral rotatory laxity of the knee following anterior cruciate ligament (ACL) injury. Numerous anatomical and biomechanical studies have followed, with conflicting results. While some studies have been promoting the importance of the ALL[4, 7, 12, 25], others have been refuting it[15, 40, 53]. Journal editorials have been written, some favouring[31] and others questioning the significance of the ALL[35], and orthopaedic meetings are filled with varying opinions and interpretations of the published data. Clinical studies have been published, with members of the orthopaedic community developing new ways to address the 'rediscovered ligament', whilst others have focused on the anterolateral soft tissues as a complex that may or may not need to be addressed in the face of ACL injury.

With such controversy comes the need for clarity of thought, and a focus on those specific areas where evidence is lacking. With good resources at hand, evidence should be utilized to guide treatment paradigms; and where such evidence is lacking, the need for studies investigating specific research questions should be identified. To this end, an international consensus group was convened, with the task of producing a position statement on the current evidence in terms of the anatomy and function of the anterolateral complex (ALC), and the assessment and treatment of ALC injuries in association with an ACL injury.

Thirty-six international researchers and clinicians in the field were invited to join a meeting to discuss the below points pertaining to the ALC and anterolateral rotatory laxity. The group met in London, UK, in October 2017 with the specific aims of:

1. Developing a consensus in terms of the anatomical terminology utilized for structures within the ALC.
2. Producing position statements as to the kinematic role of key structures in the knee, pertaining specifically to anterolateral rotatory laxity and ACL deficiency.
3. Providing clinical guidance on when to utilize an anterolateral procedure in the ACL deficient knee.

Methods

Thirty-six researchers and clinicians were initially contacted via email and asked to complete an online survey compiled by the Chairs of the meeting (AG and CB). The questions posed and collated responses may be found in the supplementary material. Based on the responses of 33 participants, 22 statements were generated pertaining to the three main aims of the meeting. A modified Delphi consensus discussion was then held during a one-and-a-half-day meeting in London UK, attended in person by 26 individuals, with two individuals providing prerecorded presentations and a further two calling in via teleconference. Each structured session included a summary of the published literature, as well as time in the cadaveric laboratory for dissections of the ALC and associated structures and demonstration of reconstructive techniques. Following each structured session, a consensus discussion was held, moderated by the two chairs of the meeting (AG & CB). Each statement generated from the results of the survey was discussed and revised, until an acceptable level of consensus was achieved. A majority of 80% was determined *a priori* as being a satisfactory level of consensus. Opposing views were documented. Statements that did not reach the required majority, or those that were felt to not be relevant were discarded from the final paper (see supplementary material).

Consensus Statements and Discussion

Following discussion of the available evidence 13 statements were accepted and are presented below. These are accompanied by a summary of the pertinent evidence and rationale supporting each statement.

Anatomy

1. The ALL exists as a structure within the anterolateral complex.

2. The structures of the anterolateral complex, from superficial to deep, are:
    - Superficial IT band and iliopatellar band
    - Deep IT band incorporating
        - Kaplan fiber system
            - Supracondylar attachments
                - Proximal
                - Distal
            - Retrograde (Condylar) attachment continuous with the Capsulo-osseous layer of the IT band
    - ALL and capsule

3. The ALL is a capsular structure within Seebacher Layer 3[42] of the anterolateral capsule of the knee.

4. The ALL has variable gross morphology between individuals in terms of size and thickness.

5. The ALL predominantly attaches posterior and proximal to the lateral femoral epicondyle and the origin of the LCL, runs superficial to the LCL, and attaches on the tibia midway between the anterior border of the fibular head and the posterior border of Gerdy's Tubercle.

6. There is an attachment of the ALL to the lateral meniscus.

Numerous historical studies have investigated the structures on the anterolateral side of the knee, from Segond's description of the eponymous fracture of the anterolateral tibia[43], to Kaplan's original work in 1958 describing the layers and attachments of the iliotibial band (ITB) to the femur[24], and then on to the paper by Terry et al., breaking down the lateral fascia lata into its component parts[51]. It was Terry et al., in fact, who first described the iliotibial tract as the 'true anterolateral ligament of the knee'. Further work by Lobenhoffer et al. in 1987 documented the existence of a retrograde fiber tract, providing a static stabilizer of the lateral side of the knee via its connection from the deep fibers of the IT tract to the lateral tibial plateau[29]. In this article, they commented that this was the same structure that Werner Müller had previously called the 'lig. Femoro-Tibiale laterale anterius'[33].

Descriptions of the anterolateral complex anatomy are confused by overlapping nomenclature. Vieira et al. are often attributed to being the first to describe the ALL[54], although this was same name that Terry et al. used to describe the capsule-osseous layer of the iliotibial tract. Vincent et al. further described a structure that was more anterior to the lateral collateral ligament (LCL)[55], with Caterine et al. suggesting that the new ALL was in fact the same structure that had previously been described by Hughston, namely the mid third capsular ligament[4]. Following the initial description by Claes et al. in 2013, Dodds et al.[12] and then Kennedy et al.[25] have provided the most distinct descriptions of this structure that we now refer to as the ALL. Histologically, this structure has been characterized by dense and well-organized connective tissue collagen bundles consistent with ligamentous tissue[16]. Furthermore, it has been demonstrated that the ALL has significantly different biomechanical properties to adjacent capsule and similar properties to other capsular ligaments such as the inferior glenohumeral ligament[45].

Seebacher et al. described Layer 3 of the anterolateral capsule as splitting into a superficial and deep lamina anterior to the LCL, and enveloping it[42]. Based on this information, the group concluded that the ALL is a ligamentous structure within Layer 3 of the anterolateral capsule, and that the superficial lamina is the ALL with the deep lamina being the true capsule of the knee at this level.

The present lack of consensus in terms of the nomenclature used to describe the various structures of the ALC stems from a number of issues, including:

- Lack of clear photographs and corresponding diagrams in historical papers
- Description of anatomy on both embalmed and fresh specimens
- Differences in dissection technique that may introduce 'dissection artifact'

Following demonstration of a number of dissection protocols[4, 9, 27], the group was able to identify and describe the key structures of the anterolateral complex, as illustrated in the attached figures (Figures 1-7).

Segond Fracture

7. Multiple structures (ALL, deep ITB, and biceps aponeurosis) attach in the region of the Segond fracture and it remains unclear which may be responsible for this lesion

In regard to the Segond fracture, much debate ensued in regard to the cause of this bony avulsion. Paul Segond originally described a 'fibrous pearly band' attached to the bony avulsion that we now call the Segond fracture, which is pathognomonic of an ACL injury [43]. Whilst there is little objective evidence as to the cause of this injury pattern, several authors have demonstrated that the previous literature has probably underestimated the incidence of this injury pattern. Specifically, Klos et al.[28] and Cavaignac et al.[5] demonstrated that the incidence on ultrasound (30-50%) is higher than visualized with either plain radiographs or MRI. More recent studies suggest that it is not only the ALL that attaches in this region[6], but also the capsulo-osseous layer of the IT tract as well as an expansion of the short head of biceps fascia[1].

Biomechanics of the Anterolateral Structures

8. The primary soft tissue stabilizer of coupled anterior translation and internal rotation near extension is the ACL. Secondary passive stabilizers include:
   - The ITB including the Kaplan fiber system
   - The lateral meniscus
   - The ALL and the anterolateral capsule

9. The ALL is an anisometric structure

A number of important cadaveric biomechanical studies have been published investigating the kinematics of the knee following sectioning of the ACL and the anterolateral structures. Spencer et al. demonstrated that sectioning of the ALL resulted in a statistically significant increase in anterior translation and internal rotation during an early-phase pivot shift[50]. Similar findings were also published by Rasmussen et al.[39], clearly showing an increase in internal rotation following ALL sectioning using a 6-degree of freedom robot. Sonnery-

Cottet et al.[47] and Monaco et al.[32], both utilizing navigation, demonstrated increased internal rotation laxity during a dynamic pivot shift test following an ACL/ITB deficient and ACL/ALL deficient setting respectively.

Kittl et al. examined the effect of ALL sectioning, as well as division of the superficial and deeper layers of the iliotibial tract[26]. Using a 6 degree of freedom robot, they found the ALL to have only a minor role in controlling internal rotation in the ACL deficient knee. The IT tract, in particular the deep and capsulo-osseous layers, made a greater contribution to internal rotation control at larger flexion angles, with the ACL having its greatest contribution closer to extension.

Conversely, Guenther et al. examined the anterolateral capsule during anterior translation and internal rotation by means of optical tracking analysis and strain mapping[15]. These researchers observed the anterolateral capsule to behave more like a fibrous sheet rather than a distinct ligamentous structure, disputing the existence of a discrete ALL. Thein et al. published their findings in a serial sectioning study showing that the ALL only engaged in load sharing beyond the physiological limits of the ACL[53]. As such they concluded that the ALL was a secondary stabilizer to anterolateral translation only after loss of the ACL, rather than a co-stabilizer.

Similar conclusions were made by Noyes's group in Cincinnati, who further examined the role of the ALC structures during a simulated pivot shift[20]. This was the first study to utilize a combination of anterior translation, valgus and internal rotation. During this study, they demonstrated that an isolated ALL sectioning in the ACL intact knee resulted in no increase in tibial internal rotation during the pivot shift, concluding that injury to the ALL does not behave as a primary restraint to anterolateral rotation [20]. However, In a further study, the same group observed that sectioning of the ALL and the ITB in ACL deficient knees converted 71% of the specimens to a grade 3 pivot shift as measured by composite tibiofemoral translations and rotations[37]. In contrast, Inderhaug et al. demonstrated that when a combined ACL and anterolateral injury exists, isolated ACL reconstruction fails to restore normal knee kinematics. Specifically, Inderhaug et al. demonstrated that only combined ACL and lateral extra-articular procedures (ALL reconstruction or lateral tenodesis) were able to restore normal kinematics in this scenario[23].

The lateral meniscus also pays a role in the control of anterolateral rotation. Two studies [30, 44] have both shown increased lateral compartment anterior translation and internal rotation in the setting of lateral meniscus posterior root tears. The role of the ALL as a peripheral anchor of the lateral meniscus has been questioned. Corbo et al. observed that the infra-meniscal ALL fibers were significantly stiffer and stronger than the supra-meniscal fibers[8]. The clinical significance of the infra-meniscal fibers is yet to be determined.

Biomechanics of Lateral Extra-Articular Procedures

10. Time zero biomechanical studies show lateral extra-articular procedures used as an augmentation to ACL reconstruction have the potential to over-constrain normal motion of the lateral compartment compared to the intact knee. The clinical significance of this is as yet unknown.

11. Causes of over-constraint of lateral extra-articular procedures may include:
    - Fixation of the graft with the tibia in external rotation
    - Over-tensioning of the graft

12. Despite concerns often being raised, to date the group is not aware of any

clinical evidence that lateral extra-articular procedures used as an augmentation to ACL reconstruction lead to accelerated progression of OA

A number of studies have now examined the biomechanics of ALC reconstruction, most of them acknowledging the difficulties with extrapolating artificially created injury patterns and laboratory results to the clinical scenario. Spencer et al. studied the effect on anterior translation and internal rotation in an ACL deficient knee of both a Lemaire type lateral extra-articular tenodesis (LET) compared with an ALL reconstruction as described by Claes et al[50]. The ALL reconstruction had little effect on controlling rotation or translation; however, we now know that the anatomical description that formed the basis of this reconstruction was incorrect as the femoral graft position was anterior and distal to the lateral epicondyle, not posterior and proximal. The LET produced a composite reduction of rotation and translation with the latter reaching statistical significance.

Kittl et al. studied the length change patterns of ALC reconstructions based upon graft attachment site [27]. The most isometric position was a proximal and posterior attachment on the femur, attached distally to Gerdy's tubercle and with the graft passed deep to LCL. They therefore concluded that a LET would be the most efficient form of reconstruction.

Dodds et al. demonstrated that a femoral attachment posterior and proximal to the origin of the LCL resulted in minimal length change during the flexion cycle[12]. Conversely, if using the femoral attachment described by Claes et al.[7], a number of authors have shown that the ALL does lengthen with flexion, and as such would cause the ALL to tighten in higher degrees of flexion [3, 27, 57]. From these studies, it is clear that if an ALL reconstruction is to be of benefit in controlling the pivot shift, then an attachment posterior and proximal to the LCL, and hence posterior to the center of rotation of the knee, should be chosen, so that the ALL graft is tight near knee extension.

ALL reconstruction and LET have now been compared in ACL reconstructed knees. Inderhaug observed that an LET graft tensioned at 20N and passed deep to the LCL was effective at controlling rotation with minimal over constraint of internal rotation[23]. Furthermore, they demonstrated that by passing the graft deep to LCL, the graft could be tensioned at a number of different flexion angles with no detrimental effect. In the same study, the ALL reconstruction described by Sonnery-Cottet et al. only controlled knee laxities when tensioned in full extension [23]. Studies by Schon et al. observed that an ALL reconstruction using a single graft tensioned with 88N caused significant over constraint of internal rotation, no matter what angle of fixation was used[41]. The high graft tension in this study has been questioned and may explain the over-constraint observed, with later studies suggesting 20N to be the optimal. A further study by the same group compared their ALL reconstruction (based on the anatomy described by Kennedy et al.[25]) to the modified Lemaire technique, utilizing varying knee flexion and graft tension parameters at fixation. In this study, they found that the Lemaire LET resulted in greater reduction in anterior translation and internal rotation during a simulated pivot shift manoeuvre compared to the ALL reconstruction; however, both reconstructions caused an element of over constraint [14].

Noyes et al. demonstrated that, at time zero in a knee with combined ACL and ALC injury, an anatomically placed bone-patellar tendon-bone (BTB) ACL reconstruction secured in 25 degrees of knee flexion adequately controlled knee kinematics without the need for an additional ALL reconstruction during a simulated pivot shift [36].

Similarly, Herbst at el. investigated the role of LET in both an isolated ACL injury and ACL plus ALC injury[18]. These researchers concluded that the addition of an LET had no additional benefit to knee stability in the isolated ACL deficient knee when an ACL reconstruction was performed. However, the LET was required in the combined injury to restore normal knee kinematics. The question raised by this work is whether an isolated ACL injury is often seen, or if a concomitant ALC injury occurs at the time of ACL rupture. Based on a number of other studies, it is clear that in a knee demonstrating a high-grade laxity pattern, an isolated ACL injury is rarely seen. Instead, concomitant meniscus and lateral soft tissue injuries are often observed, which may further support the need for an anterolateral procedure in combination with an ACL reconstruction[34]. The prevalence of concomitant anterolateral structure lesions in acute ACL injuries have been reported to vary from 40% to 90% depending on the chosen method of detection.[5, 13, 17].

At present, it is not possible to ascertain which reconstruction technique is superior to another, as the experimental set up and associated testing protocols differ between studies. If using an LET type procedure, it is recommended to pass the graft deep to the LCL prior to femoral fixation[23, 27]. Passing the graft deep to the LCL appears to provide a more optimal direction of action throughout the flexion cycle, as well as providing a more forgiving position of fixation, in terms of avoiding over constraint, as the LCL attachment serves as a fulcrum. If instead performing a combined ACL and ALL reconstruction, the technique described by Sonnery-Cottet, tensioned in full extension, would appear to provide the optimal ALL reconstruction kinematics[23].

Concerns relating to over-constraint of the lateral compartment remain an issue. Inderhaug et al. have looked at lateral compartment contact pressures following LET[22]. They demonstrated that a small increase in lateral compartment contact pressure was observed after LET. However, the increased pressure was found to be insignificant compared with the contact pressure seen in the lateral compartment during normal physiological loading [22]. The clinical importance of over constraint of internal rotation is currently unknown, but to date there is no known evidence supporting lateral extra-articular procedures causing or accelerating the development of osteoarthritis[11].

Clinical Evidence

13. Clinical evidence is currently lacking to support clear indications for lateral extra-articular procedures as an augmentation to ACL reconstruction. Appropriate indications may include:
    - Revision ACL
    - High Grade Pivot Shift
    - Generalized ligamentous laxity/Genu recurvartum
    - Young patients returning to pivoting activities

Lateral extra-articular tenodesis has a long clinical history. Having been the stand-alone procedure of choice to address anterolateral knee laxity in the first half of the 20th Century by Strickler, Lemaire and later Macintosh, it soon became apparent that intra-articular ACL reconstruction would provide a better control of knee stability. Surgeons reported the results of their lateral reconstruction, which was developed to aid in the control of anterolateral rotatory stability, later to be added to intra-articular ACL reconstruction. Lemaire, Losee, Andrews, Ellison and later versions of the Macintosh to name but a few were reported in a variety of publications. Recent meta-analyses have shown that these combined procedures performed extremely well at reducing rotatory laxity, but no differences in anterior translation nor patient-reported outcomes were observed[10, 19, 46].

Whilst remaining popular in Europe, the addition of an LET fell out of favor in North America following publications from O'Brien et al. [38] and Anderson et al. [2]. The former paper was a retrospective comparison of BTB ACL reconstruction with or without a lateral tenodesis in 80 patients. Whilst there were significant methodological flaws of this study, in particular its underpowered nature to elicit a difference in clinical outcome, the lack of differences in outcome and the concern of over-constraint in these patients led to the recommendation from an AOSSM consensus group to abandon the lateral-based procedures. A commentary from James Andrews in the AJSM following publication of the O'Brien paper suggested that whilst good results can be achieved with an isolated BTB ACL reconstruction, there are likely to be individuals who may still benefit from a lateral procedure. The latter paper of Anderson compared three surgical techniques, concluding that similar results could be found with either a hamstrings or patellar tendon autograft ACL reconstruction, with a lateral tenodesis offering very little benefit. Of note, they cautioned about the risk of over-constraint of internal rotation, and hence the concern for the development of OA, although this was not specifically studied.

With recent studies showing a high failure rate in young patients [56], there is likely room for improvement in ACL reconstruction methods. However, these failures cannot all be attributed to the technique itself, as there are many reasons for ACL reconstruction failure. These include poor neuromuscular rehabilitation, early return to sport and participation in high risk pivoting sports. However, at the time of surgery, there are still many areas where surgeons can influence outcome. Good surgical technique is paramount, including avoidance of the technical error of improper graft placement. Failure to address meniscal tears, concomitant soft tissue laxity patterns and issues of alignment may all contribute to a higher risk of ACL failure.

Systematic reviews with meta-analyses of comparative studies [10, 19, 46] [46] [10] have all demonstrated that the addition of a lateral based procedure to an ACL reconstruction improves rotational laxity control, but has no impact on anterior translation nor patient reported outcomes. Importantly, no studies have demonstrated an increased risk of osteoarthritis with the addition of an LET. A more recent meta-analysis did not find any evidence of OA in the knee in 11 years of follow up, contrary to reports of isolated LET procedures which clearly showed an increased prevalence of OA when the ACL was not addressed concomitantly[11].

At present, there is no high-level evidence to guide clinicians as to when a lateral based procedure should be added to an ACL reconstruction. Historic studies have tended to include 'all-comers', and were generally based upon small numbers of patients. Sub-group analyses in meta-analyses have therefore not been possible due to the significant heterogeneity of inclusion and exclusion criteria.

The more recent studies by Sonnery-Cottet et al. have demonstrated the potential benefit of adding an ALL graft to a standard ACL reconstruction. In 2015, two year outcomes of 92 patients were reported demonstrating only a 1% re-rupture rate with only 7 patients having a grade one pivot shift[49]. This was followed in 2017 by a comparative cohort study of 502 young patients engaging in pivoting sports, and therefore exposed to a high risk of graft rupture, undergoing ACL reconstruction[48]. In the largest comparative series of any type of extra-articular reconstruction to date, the data has demonstrated significantly lower ACL graft rupture rates in the combined ACL and ALL group (4%) when compared to isolated patellar tendon (16%) and hamstrings tendon autograft (10%) groups, with a further study observing low complication rates[52].

In contrast, a recent study by Ibrahim et al. has shown minimal differences in the outcome following addition of an ALL graft to a standard hamstrings autograft ACL reconstruction[21]. However, this study utilized a non-anatomic ALL reconstruction technique (femoral insertion proximal and anterior to LCL, instead of posterior and proximal), was underpowered and did not select out patients who would be at a higher risk of failure, such as young patients returning to pivoting sport or those with high grade laxity.

Based on the current evidence, the consensus group was unable to make definitive recommendations as to when a lateral procedure should be added to an ACL reconstruction.

Conclusions

The 13 consensus statements generated from the ALC Consensus group are intended to provide some clarity of anatomical nomenclature and a better understanding of pertinent biomechanics associated with the ALC. Strategies to address persistent anterolateral rotatory laxity and ACL reconstruction failure are warranted due to the high rates of graft failure that we continue to see in young active individuals. There has been controversy over the 're-emergence' of the ALL and associated anterolateral reconstructive procedures. It is, however, evident from this consensus that there is still considerable clinical research to be performed to determine the optimal scenarios for augmentation of a primary ACL reconstruction with an anterolateral procedure in order to improve outcomes for patients.

Acknowledgements

The ALC Consensus Group would like to acknowledge the generous support from Smith and Nephew PLC to enable this meeting.

Figure Legend

Figure 1. Lateral structures of the right knee showing the superficial IT band, iliopatellar band and the attachment to Gerdy's tubercle. The line of asterisks (*) represents the deep IT band corresponding to the capsule-osseous layer

Figure 2. The superficial ITB is reflected posteriorly, demonstrating the Kaplan fibre system. The Proximal and distal (supracondylar) fibres are shown, continuing distally from the intermuscular septum.

Figure 3. The retrograde (condylar) Kaplan fibres are shown to be continuous with the capsule-osseous layer of the ITB, as marked by the line of asterisks (*) attaching distally to Gerdy's tubercle.

Figure 4. A) The FCL (*) is shown with the knee at 90^{o}, neutral tibial rotation; B) An internal tibial rotation torque is applied to the tibia demonstrating the ALL (#) tensioned across the FCL, running from posterior and proximal to the lateral femoral epicondyle to a position midway between the fibular head and Gerdy's tubercle.

Figure 5. The ALL is dissected free from the FCL, shown to be within layer 3 of Seebacher's layers of the lateral retinaculum.

Figure 6. The close relationship of the ALL, FCL and popliteus tendon is demonstrated.

Figure 7. The relationship of the ALL and lateral meniscus is demonstrated, with the scissor demonstrating the course of the lateral inferior geniculate artery. Meniscofemoral and meniscotibial attachments of the ALL can be observed.

References

1. Albers M, Shaikh H, Herbst E, Onishi K, Nagai K, Musahl V, et al. (2017) The iliotibial band and anterolateral capsule have a combined attachment to the Segond fracture. Knee Surg Sports Traumatol Arthrosc;10.1007/s00167-017-4549-z
2. Anderson AF, Snyder RB, Lipscomb AB, Jr. (2001) Anterior cruciate ligament reconstruction. A prospective randomized study of three surgical methods. Am J Sports Med 29:272-279
3. Bell KM, Rahnemai-Azar AA, Irarrazaval S, Guenther D, Fu FH, Musahl V, et al. (2017) In situ force in the anterior cruciate ligament, the lateral collateral ligament, and the anterolateral capsule complex during a simulated pivot shift test. J Orthop Res;10.1002/jor.23676
4. Caterine S, Litchfield R, Johnson M, Chronik B, Getgood A (2015) A cadaveric study of the anterolateral ligament: re-introducing the lateral capsular ligament. Knee Surg Sports Traumatol Arthrosc 23:3186-3195
5. Cavaignac E, Faruch M, Wytrykowski K, Constant O, Murgier J, Berard E, et al. (2017) Ultrasonographic Evaluation of Anterolateral Ligament Injuries: Correlation With Magnetic Resonance Imaging and Pivot-Shift Testing. Arthroscopy 33:1384-1390
6. Claes S, Luyckx T, Vereecke E, Bellemans J (2014) The Segond fracture: a bony injury of the anterolateral ligament of the knee. Arthroscopy 30:1475-1482
7. 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
8. Corbo G, Norris M, Getgood A, Burkhart TA (2017) The infra-meniscal fibers of the anterolateral ligament are stronger and stiffer than the supra-meniscal fibers despite similar histological characteristics. Knee Surg Sports Traumatol Arthrosc;10.1007/s00167-017-4424-y
9. Daggett M, Busch K, Sonnery-Cottet B (2016) Surgical Dissection of the Anterolateral Ligament. Arthrosc Tech 5:e185-188
10. Devitt BM, Bell SW, Ardern CL, Hartwig T, Porter TJ, Feller JA, et al. (2017) The Role of Lateral Extra-articular Tenodesis in Primary Anterior Cruciate Ligament Reconstruction: A Systematic Review With Meta-analysis and Best-Evidence Synthesis. Orthop J Sports Med 5:2325967117731767
11. Devitt BM, Bouguennec N, Barfod KW, Porter T, Webster KE, Feller JA (2017) Combined anterior cruciate ligament reconstruction and lateral extra-articular tenodesis does not result in an increased rate of osteoarthritis: a systematic review and best evidence synthesis. Knee Surg Sports Traumatol Arthrosc 25:1149-1160
12. Dodds AL, Halewood C, Gupte CM, Williams A, Amis AA (2014) The anterolateral ligament: Anatomy, length changes and association with the Segond fracture. Bone Joint J 96-B:325-331
13. Ferretti A, Monaco E, Fabbri M, Maestri B, De Carli A (2017) Prevalence and Classification of Injuries of Anterolateral Complex in Acute Anterior Cruciate Ligament Tears. Arthroscopy 33:147-154
14. Geeslin AG, Moatshe G, Chahla J, Kruckeberg BM, Muckenhirn KJ, Dornan GJ, et al. (2017) Anterolateral Knee Extra-articular Stabilizers: A Robotic Study Comparing Anterolateral Ligament Reconstruction and Modified Lemaire Lateral Extra-articular Tenodesis. Am J Sports Med;10.1177/0363546517745268363546517745268
15. Guenther D, Rahnemai-Azar AA, Bell KM, Irarrazaval S, Fu FH, Musahl V, et al. (2017) The Anterolateral Capsule of the Knee Behaves Like a Sheet of Fibrous Tissue. Am J Sports Med 45:849-855
16. Helito CP, Demange MK, Bonadio MB, Tirico LE, Gobbi RG, Pecora JR, et al. (2013) Anatomy and Histology of the Knee Anterolateral Ligament. Orthop J Sports Med 1:2325967113513546
17. Helito CP, Helito PV, Costa HP, Demange MK, Bordalo-Rodrigues M (2017) Assessment of the Anterolateral Ligament of the Knee by Magnetic Resonance Imaging in Acute Injuries of the Anterior Cruciate Ligament. Arthroscopy 33:140-146
18. Herbst E, Arilla FV, Guenther D, Yacuzzi C, Rahnemai-Azar AA, Fu FH, et al. (2017) Lateral Extra-articular Tenodesis Has No Effect in Knees With Isolated Anterior Cruciate Ligament Injury. Arthroscopy;10.1016/j.arthro.2017.08.258

19. Hewison CE, Tran MN, Kaniki N, Remtulla A, Bryant D, Getgood AM (2015) Lateral Extra-articular Tenodesis Reduces Rotational Laxity When Combined With Anterior Cruciate Ligament Reconstruction: A Systematic Review of the Literature. Arthroscopy 31:2022-2034

20. Huser LE, Noyes FR, Jurgensmeier D, Levy MS (2017) Anterolateral Ligament and Iliotibial Band Control of Rotational Stability in the Anterior Cruciate Ligament-Intact Knee: Defined by Tibiofemoral Compartment Translations and Rotations. Arthroscopy 33:595-604

21. Ibrahim SA, Shohdy EM, Marwan Y, Ramadan SA, Almisfer AK, Mohammad MW, et al. (2017) Anatomic Reconstruction of the Anterior Cruciate Ligament of the Knee With or Without Reconstruction of the Anterolateral Ligament: A Randomized Clinical Trial. Am J Sports Med 45:1558-1566

22. Inderhaug E, Stephen JM, El-Daou H, Williams A, Amis AA (2017) The Effects of Anterolateral Tenodesis on Tibiofemoral Contact Pressures and Kinematics. Am J Sports Med;10.1177/0363546517717260363546517717260

23. Inderhaug E, Stephen JM, Williams A, Amis AA (2017) Anterolateral Tenodesis or Anterolateral Ligament Complex Reconstruction: Effect of Flexion Angle at Graft Fixation When Combined With ACL Reconstruction. Am J Sports Med;10.1177/0363546517724422363546517724422

24. Kaplan EB (1958) The iliotibial tract; clinical and morphological significance. J Bone Joint Surg Am 40-A:817-832

25. Kennedy MI, Claes S, Fuso FA, Williams BT, Goldsmith MT, Turnbull TL, et al. (2015) The Anterolateral Ligament: An Anatomic, Radiographic, and Biomechanical Analysis. Am J Sports Med 43:1606-1615

26. Kittl C, El-Daou H, Athwal KK, Gupte CM, Weiler A, Williams A, et al. (2016) The Role of the Anterolateral Structures and the ACL in Controlling Laxity of the Intact and ACL-Deficient Knee. Am J Sports Med 44:345-354

27. Kittl C, Halewood C, Stephen JM, Gupte CM, Weiler A, Williams A, et al. (2015) Length Change Patterns in the Lateral Extra-articular Structures of the Knee and Related Reconstructions. Am J Sports Med 43:354-362

28. Klos B, Scholtes M, Konijnenberg S (2017) High prevalence of all complex Segond avulsion using ultrasound imaging. Knee Surg Sports Traumatol Arthrosc 25:1331-1338

29. Lobenhoffer P, Posel P, Witt S, Piehler J, Wirth CJ (1987) Distal femoral fixation of the iliotibial tract. Arch Orthop Trauma Surg 106:285-290

30. Lording T, Corbo G, Bryant D, Burkhart TA, Getgood A (2017) Rotational Laxity Control by the Anterolateral Ligament and the Lateral Meniscus Is Dependent on Knee Flexion Angle: A Cadaveric Biomechanical Study. Clin Orthop Relat Res 475:2401-2408

31. Lubowitz JH, Provencher MT, Brand JC, Rossi MJ (2014) The knee anterolateral ligament. Arthroscopy 30:1385-1388

32. Monaco E, Fabbri M, Mazza D, Daggett M, Redler A, Lanzetti RM, et al. (2017) The Effect of Sequential Tearing of the Anterior Cruciate and Anterolateral Ligament on Anterior Translation and the Pivot-Shift Phenomenon: A Cadaveric Study Using Navigation. Arthroscopy;10.1016/j.arthro.2017.09.042

33. Muller W (1984) [Functional anatomy and clinical findings of the knee joint]. Helv Chir Acta 51:505-514

34. Musahl V, Rahnemai-Azar AA, Costello J, Arner JW, Fu FH, Hoshino Y, et al. (2016) The Influence of Meniscal and Anterolateral Capsular Injury on Knee Laxity in Patients With Anterior Cruciate Ligament Injuries. Am J Sports Med;10.1177/0363546516659649

35. Musahl V, Rahnemai-Azar AA, van Eck CF, Guenther D, Fu FH (2016) Anterolateral ligament of the knee, fact or fiction? Knee Surg Sports Traumatol Arthrosc 24:2-3

36. Noyes FR, Huser LE, Jurgensmeier D, Walsh J, Levy MS (2017) Is an Anterolateral Ligament Reconstruction Required in ACL-Reconstructed Knees With Associated Injury to the Anterolateral Structures? Am J Sports Med;10.1177/0363546516682233363546516682233

37. Noyes FR, Huser LE, Levy MS (2017) Rotational Knee Instability in ACL-Deficient Knees: Role of the Anterolateral Ligament and Iliotibial Band as Defined by Tibiofemoral Compartment Translations and Rotations. J Bone Joint Surg Am 99:305-314

38. O'Brien SJ, Warren RF, Wickiewicz TL, Rawlins BA, Allen AA, Panariello R, et al. (1991) The iliotibial band lateral sling procedure and its effect on the results of anterior cruciate ligament reconstruction. Am J Sports Med 19:21-24; discussion 24-25

39. Rasmussen MT, Nitri M, Williams BT, Moulton SG, Cruz RS, Dornan GJ, et al. (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

40. Saiegh YA, Suero EM, Guenther D, Hawi N, Decker S, Krettek C, et al. (2017) Sectioning the anterolateral ligament did not increase tibiofemoral translation or rotation in an ACL-deficient cadaveric model. Knee Surg Sports Traumatol Arthrosc 25:1086-1092

41. Schon JM, Moatshe G, Brady AW, Serra Cruz R, Chahla J, Dornan GJ, et al. (2016) Anatomic Anterolateral Ligament Reconstruction of the Knee Leads to Overconstraint at Any Fixation Angle. Am J Sports Med 44:2546-2556

42. Seebacher JR, Inglis AE, Marshall JL, Warren RF (1982) The structure of the posterolateral aspect of the knee. J Bone Joint Surg Am 64:536-541

43. Segond P (1879) Recherches cliniques et experimentales sur les epanchements sanguins du genou par entorse. . Progres Medical. (accessible from http://www.patrimoine.edilivre.com)/

44. Shybut TB, Vega CE, Haddad J, Alexander JW, Gold JE, Noble PC, et al. (2015) Effect of lateral meniscal root tear on the stability of the anterior cruciate ligament-deficient knee. Am J Sports Med 43:905-911

45. Smeets K, Slane J, Scheys L, Forsyth R, Claes S, Bellemans J (2017) The Anterolateral Ligament Has Similar Biomechanical and Histologic Properties to the Inferior Glenohumeral Ligament. Arthroscopy 33:1028-1035 e1021

46. Song GY, Hong L, Zhang H, Zhang J, Li Y, Feng H (2016) Clinical Outcomes of Combined Lateral Extra-articular Tenodesis and Intra-articular Anterior Cruciate Ligament Reconstruction in Addressing High-Grade Pivot-Shift Phenomenon. Arthroscopy 32:898-905

47. Sonnery-Cottet B, Lutz C, Daggett M, Dalmay F, Freychet B, Niglis L, et al. (2016) The Involvement of the Anterolateral Ligament in Rotational Control of the Knee. Am J Sports Med 44:1209-1214

48. Sonnery-Cottet B, Saithna A, Cavalier M, Kajetanek C, Temponi EF, Daggett M, et al. (2017) Anterolateral Ligament Reconstruction Is Associated With Significantly Reduced ACL Graft Rupture Rates at a Minimum Follow-up of 2 Years. Am J Sports Med;10.1177/0363546516686057363546516686057

49. Sonnery-Cottet B, Thaunat M, Freychet B, Pupim BH, Murphy CG, Claes S (2015) Outcome of a Combined Anterior Cruciate Ligament and Anterolateral Ligament Reconstruction Technique With a Minimum 2-Year Follow-up. Am J Sports Med 43:1598-1605

50. Spencer L, Burkhart TA, Tran MN, Rezansoff AJ, Deo S, Caterine S, et al. (2015) Biomechanical Analysis of Simulated Clinical Testing and Reconstruction of the Anterolateral Ligament of the Knee. Am J Sports Med 43:2189-2197

51. Terry GC, Hughston JC, Norwood LA (1986) The anatomy of the iliopatellar band and iliotibial tract. Am J Sports Med 14:39-45

52. Thaunat M, Clowez G, Saithna A, Cavalier M, Choudja E, Vieira TD, et al. (2017) Reoperation Rates After Combined Anterior Cruciate Ligament and Anterolateral Ligament Reconstruction: A Series of 548 Patients From the SANTI Study Group With a Minimum Follow-up of 2 Years. Am J Sports Med 45:2569-2577

53. Thein R, Boorman-Padgett J, Stone K, Wickiewicz TL, Imhauser CW, Pearle AD (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

54. Vieira EL, Vieira EA, da Silva RT, Berlfein PA, Abdalla RJ, Cohen M (2007) An anatomic study of the iliotibial tract. Arthroscopy 23:269-274

55. Vincent JP, Magnussen RA, Gezmez F, Uguen A, Jacobi M, Weppe F, et al. (2012) The anterolateral ligament of the human knee: an anatomic and histologic study. Knee Surg Sports Traumatol Arthrosc 20:147-152

56. Webster KE, Feller JA (2016) Exploring the High Reinjury Rate in Younger Patients Undergoing Anterior Cruciate Ligament Reconstruction. Am J Sports Med 44:2827-2832

57. Zens M, Niemeyer P, Ruhhammer J, Bernstein A, Woias P, Mayr HO, et al. (2015) Length Changes of the Anterolateral Ligament During Passive Knee Motion: A Human Cadaveric Study. Am J Sports Med 43:2545-2552