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Anterior Cruciate Ligament Injury and the Anterolateral Complex of the Knee—Importance in Rotatory Knee Instability?

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Abstract

Purpose of Review In the setting of rotatory knee instability following anterior cruciate ligament (ACL) reconstruction, there has been a resurgence of interest in knee's anterolateral complex (ALC). Reconstruction or augmentation of the ALC with procedures such as a lateral extra-articular tenodesis (LET) has been proposed to reduce rotatory knee instability in conjunction with ACL reconstruction. The current review investigates the recent literature surrounding the role of the ALC in preventing rotatory knee instability.

Recent Findings The knee's anterolateral complex (ALC) is a complex structure composed of the superficial and deep portions of the iliotibial band, the capsulo-osseous layer, and the anterolateral capsule. Distally, these various layers merge to form a single functional unit which imparts stability to the lateral knee. While the iliotibial band and the capsule-osseous layer have been shown to be primary restraints to rotatory motion after ACL injury, the biomechanical role of the anterolateral capsule remains unclear. Biomechanical studies have shown that the anterolateral capsule and the anterolateral thickening of this capsule act as a sheet of fibrous tissue which does not resist motion around the knee as other longitudinally oriented ligaments do.

Summary Augmentation of the ALC, with LET, has been performed globally for over 30 years. This procedure can decrease rotatory knee instability, but long-term studies have found little difference in patient-reported outcomes, osteoarthritis, or ACL reconstruction failure with the addition of LET. Further research is needed to clarify indications for the clinical use of ALC-based procedures.

Keywords ACL · Rotatory stability · Anterolateral capsule · Extra-articular tenodesis

Introduction

There has been increasing focus on the anterolateral structures of the knee following the re-discovery of a discrete anatomical ligament along the lateral aspect of the knee capsule [7, 56]. There is conflicting literature for the proposed anterolateral ligament (ALL) with regard to its existence, significance, and the role for its reconstruction in the setting of injury [12, 16, 50]. There is currently consensus among international ACL reconstruction experts that the proposed ALL is a structure within the anterolateral capsule of the knee. The iliotibial band (ITB) with its superficial, deep, and Kaplan fibers and

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the anterolateral capsule make up the anterolateral complex (ALC). The ALC will be discussed for the remainder of this review [12]. The purpose of the current review is to present the recent literature on the ALC and its role in rotatory knee instability of the knee.

Anatomy

Meticulous layer-by-layer anatomical dissections on adult fresh frozen cadavers showed an identifiable thickening of the ALC in 35% of specimens with no adult specimens having a discrete ligamentous structure (Fig. 1) [17]. Anatomical assessment of fetal knee tissue revealed no distinct ligamentous structure along the anterolateral capsule between the fibular collateral ligament and the patellar tendon, and confirmed via histology that only loose disorganized collagen, consistent with capsular tissue, was present in this region of the fetal anterolateral capsule [43].

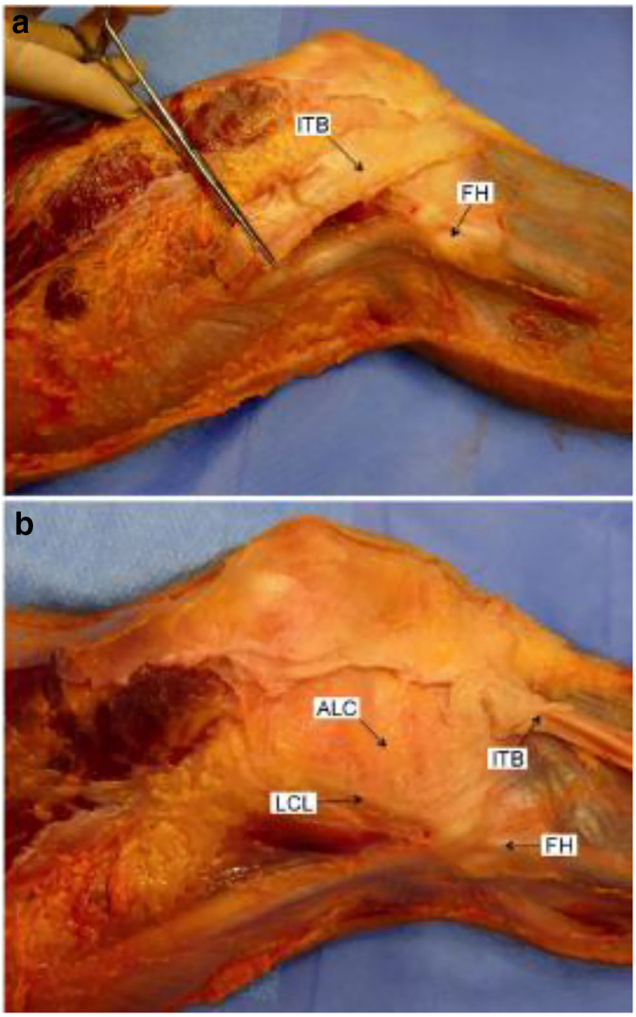

Fig. 1 Lateral view on a left knee of a 46-year-old specimen. To enable visualization of the anterolateral structures, the iliotibial band was carefully dissection from the underlying tissue, **a** starting proximally and **b** ending with the transection from the Gerdy tubercle. ALC, anterolateral capsule; FH, fibula head; ITB, iliotibial band; LCL, lateral collateral ligament. (Adapted from Guenther D et al. The Anterolateral Capsule of the Knee Behaves Like a Sheet of Fibrous Tissue. *The American Journal of Sports Medicine*. 2012; 45(4), 849–855. https://doi.org/10.1177/0363546516674477)

There is variability in the recently published literature about the anatomical characteristics of the ALC. Careful anatomical dissection of fresh frozen human cadavers has revealed multiple distinct layers of the ALC (from superficial to deep): the superficial and deep iliotibial band, the capsulo-osseous layer of the iliotibial band, and the anterolateral capsule of the knee [17]. A systematic review found that most anatomic studies determined the thickening of the anterolateral capsule had its femoral origin anterior and distal to the origin of the lateral collateral ligament on the lateral epicondyle, but some finding variation in the thickening with the origin posterior to the lateral collateral ligament [1, 32, 42, 55]. The tibial insertion of thickening in the ALC is consistently noted to be between Gerdy's tubercle and the fibular head [1].

Biomechanics of the ALC and Residual Rotatory Knee Instability

The primary goal of ACL reconstruction is to restore function to the knee, reducing the anterior tibial translation and rotatory knee instability seen in the ACL-deficient knee. While in most cases, anatomic reconstruction of the ACL reduces rotatory knee instability, the etiology of residual rotatory knee instability following anatomic ACL reconstruction remains unclear [62]. In this regard, residual rotatory knee instability or a high-grade pivot shift pre-operatively have been proposed as indications for ALC reconstruction [53, 57].

When rotatory knee instability is encountered following ACL reconstruction, it remains unclear whether ALC injury plays a contributing role [35]. While some cadaveric biomechanical studies analyzing a simulated pivot shift maneuver demonstrated increased rotatory knee instability in the setting of concomitant ALC injury, other have failed to demonstrate significant increases in rotatory knee instability or other changes to knee kinematics (Fig. 2) [20, 24, 27, 35, 39, 44, 51, 54, 58]. Ex vivo biomechanical studies have demonstrated that, in cases of ACL deficiency with known concomitant injury to the ALC, ACL reconstruction alone may not fully restore knee stability [18, 22].

The differences in rotatory knee instability may be in part due to differing levels of resection of the iliotibial band during simulated ALC injury, with the iliotibial band consistently acting as a primary stabilizer to tibial internal rotation [24, 34]. At greater than 30° of flexion, where the pivot shift is measured during clinical examinations, the superficial, deep, and capsulo-osseous layers of the iliotibial band act as the primary stabilizers

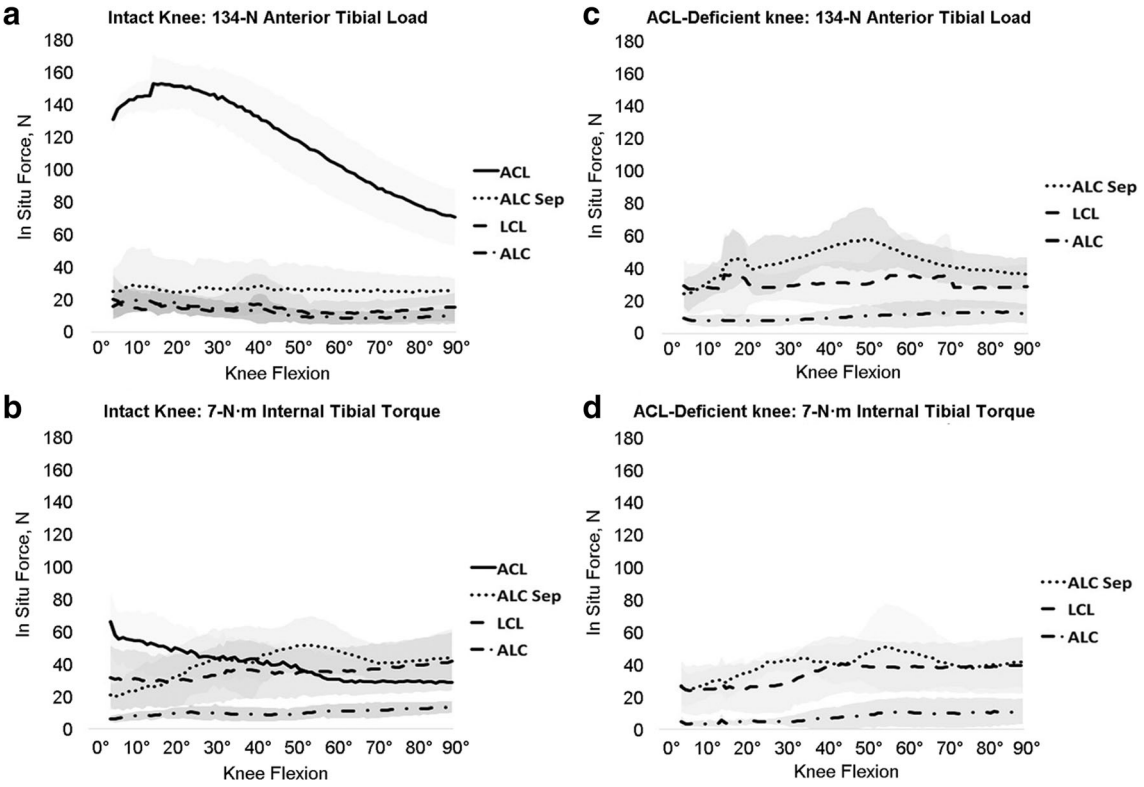

Fig. 2 In situ forces in response to **a** a 134-N anterior tibial load and **b** a 7-Nm internal tibial torque in the intact knee and in response to **c** a 134 anterior tibial load and **d** a 7-Nm internal tibial roque in the ACL-deficient knee. ACL, anterior cruciate ligament; ALC, anterolateral capsule; ALC Sep, anterolateral capsule separation (forces transmitted between anterolateral capsular regions); LCL, lateral collateral ligament. The areas shaded represent the SDs. (Adapted from Guenther D et al. The Anterolateral Capsule of the Knee Behaves Like a Sheet of Fibrous Tissue. *The American Journal of Sports Medicine*. 2012; 45(4), 849–855. https://doi.org/10.1177/0363546516674477)

of rotatory stability. Additionally, following ACL injury, the iliotibial band is the primary restraint to tibial internal rotation during a simulated pivot shift [24]. Similar biomechanical studies have found that the ALC experiences the highest in situ forces and resists rotatory knee instability at 90° of flexion and insignificant in situ force at 30° of flexion where rotatory knee instability is normally assessed [4, 60].

Residual rotatory knee instability following anatomic ACL reconstruction may be addressed via different anterolateral procedures, of which a lateral extra-articular tenodesis (LET) represents one option. Biomechanically, in the setting of confirmed ALC injury, the addition of a LET has been demonstrated to play a role in restoring pre-injury kinematics [18, 22]. However, concerns regarding potential over-constraint exist following the results of recent biomechanical studies which demonstrated decreased tibial internal rotation with a LET procedure [18].

Biomechanical studies have demonstrated that the ALC may not function as a ligamentous structure. In a systematic dissection of the anterolateral knee, only negligible longitudinal forces were noted within the anterolateral capsule [14]. This suggests that the anterolateral capsule responds biomechanically like a sheet of tissue rather than a longitudinally oriented ligamentous structure.

Although the proposed role of a discrete ligamentous structure within the ALC is variable in recent biomechanical literature, the role of the ALC (iliotibial band, lateral capsule, lateral meniscus) has been reported as preventing rotatory knee instability [12, 20, 31, 34]. When injury or insufficiency of the ALC is present, surgical fixation or reconstruction might be performed to prevent rotatory knee instability by restoring native anatomy.

Residual Rotatory Knee Instability

Restoring translational and rotatory knee stability to the knee is the primary goal of ACL reconstruction. Non-anatomic ACL reconstruction can lead to residual rotatory knee instability or anterior laxity, and critical review of radiographs may reveal signs of non-anatomic tunnel placement [2, 3, 47]. Residual rotatory knee instability in the setting of anatomic ACL reconstruction may be secondary to injury to other ligamentous structures around the knee or may be related to the bony morphology of the individual patient, which has been associated with findings such as a high-grade pivot shift [30, 31, 37, 38, 49, 59]. In the setting of combined ACL and ALC injury where the patient experiences persistent rotatory knee

instability, biomechanical studies have suggested that the addition of LET may reduce rotatory knee instability to a greater degree than isolated ACL reconstruction [11, 28].

Multiple methods for performing LET have been described, including the Lemaire, modified Lemaire, MacIntosh, Zarins and Rowe, Müller, and Marcacci and Zaffagnini, and other techniques. The noted techniques do not encompass all described LETs, but represent multiple approaches, grafts, and tensioning techniques for performing an additional anterolateral procedure [6, 10, 25, 26, 29, 64]. Relatively few studies exist, which directly compare these various techniques. In a biomechanical comparison of a proposed ALL reconstruction with Lemaire, and Macintosh LET techniques, the proposed reconstruction was not found to result in increased stability, while Macintosh and Lemaire techniques were noted to prevent rotatory knee instability [22]. Similarly, cadaveric models have noted the addition of a Müller type LET to restore rotatory stability in the setting of combined ACL + ALC injury better than ACL reconstruction alone [45]. Finally, a systematic review of biomechanical literature on ACL reconstruction + LET suggested that several LET techniques restored or even over-constrained rotatory knee motion following ACL reconstruction. No significant biomechanical differences noted between specific techniques in this study [46].

Outcomes of LET and ALC Procedures

Multiple retrospective and prospective studies have looked at patient outcomes in ACL reconstruction and ACL + LET [9, 13, 36, 48, 63]. A meta-analysis of ACL reconstruction versus ACL + LET in human subjects found the LET decreased the pivot shift phenomenon, but did not result in changes in IKDC scores or KT-1000 measurements [19].

LET results in decreased rotatory knee motion suggestive of over-constraint in some biomechanical studies [11]. Biomechanical findings have raised concerns regarding whether LET may predispose the knee to degenerative changes. However, it is too early to report clinical findings of premature osteoarthritis. One examination with long-term follow-up of 421 patients did not note an increase in rates of osteoarthritis following LET. However, the authors did note that concomitant meniscal injury, common with ACL injury, may increase the risk for development of osteoarthritis at long-term follow-up [8, 15]. A second study with 10-year follow-up of patients undergoing combined ACL reconstruction and LET demonstrated reduced rates of rotatory knee instability, improved IKDC activity scores, and found no increased risk for arthritic changes compared with ACL reconstruction alone [9].

LET may help to reduced rotatory knee instability and forces experienced by graft tissue following ACL reconstruction; therefore, it has been theorized that ACL reconstruction with LET could reduce re-rupture rates. However, a meta-analysis of eight randomized control trials between ACL reconstruction and ACL + LET did not demonstrate a significance decreased in re-rupture rates with only isolated clinical trials noting reduced rates of graft failure with combined ACL + LET [33, 40].

There is a lack of high-quality evidence with long-term (> 5 year) follow-up regarding ALL reconstruction procedure. Further, recently published results of such studies are often conflicting. In a single-surgeon, prospective cohort of 502 patients undergoing ACL reconstruction with bone-patellar tendon-bone autograft, hamstring autograft, or hamstring autograft with concomitant ALL reconstruction, there was significantly lower graft failure in the hamstring + ALL reconstruction group (4.1% failure) compared with the isolated ACL reconstructions [52]. However, in this study, the reported rates of failure for isolated ACL reconstruction (11% hamstring, 17% bone-patellar tendon-bone) were higher than reported in previous literature, suggesting a secondary factor may have played a role in the difference in failure rates between treatment groups in this cohort [23, 61].

A similar study retrospectively reviewed professional athletes undergoing combined ACL reconstruction and proposed ALL reconstruction [41]. In this study, ALL reconstruction again was noted to decrease side-to-side laxity and pivot shift findings, with a reported return to sport rate of 85.7% at 1 year. However, at 4-year follow-up, greater than 20% of subjects were noted to have retired from professional sport participation [41]. In a randomized controlled trial of ALL reconstruction, 110 patients with a minimum grade 2 pivot shift were randomly assigned to either isolated ACL reconstruction or combined ACL and ALL reconstruction [21]. At 27 months average follow-up, patients demonstrated similar pivot shift, Lachman, and anterior drawer findings. The combined reconstruction group was superior to the isolated ACL group only in instrumented laxity as measured on the KT-1000 and no clinical differences noted between groups [21]. In summary, some authors have noted short-term benefits to LET or ALL reconstruction in the setting of persistent rotatory knee instability following treatment of an ACL injury. However, the noted effect of extra-articular procedures have been reported with a great degree of variability, offering little generalizability of results from single-surgeon studies.

In an effort to better study the effects of LET, a large multicenter trial is ongoing aimed at determining the difference between ACL reconstruction and ACL + LET [5]. In this study, patients 25 years or younger with noted “high-risk” criteria are randomized to either isolated ACL hamstring reconstruction versus ACL reconstruction with a Lemaire-type LET procedure. LET is performed with a strip of IT band passed deep to the lateral collateral ligament. High-risk criteria for patient enrollment include a pivot shift of grade II or

greater, clinical evidence of ligamentous laxity (i.e., a medium to high Beighton's score), and plan to return to higher risk activity such as participation in cutting sports. While the study is still ongoing, interim reports have suggested a benefit to the addition of LET in this subset of patients, with lower rates of graft failure noted in those randomized to receive both an ACL reconstruction and Lemaire-type LET.

Conclusion

In conclusion, the anterolateral complex (ALC) of the knee is a complex structure comprised of a confluence of the knee's lateral stabilizers, which function to provide rotatory stability to the knee. While not completely understood, reports suggest a role for surgical management of the ALC in certain situations where persistent rotatory knee instability is encountered following ACL reconstruction. However, until more concrete indications for such procedures can be identified by high-level studies, management of rotatory knee instability likely will continue to emphasize the need for a well-performed, anatomic ACL reconstruction. Further, with regard to non-anatomic procedures, concerns for over-constraint have been documented historically, warranting further investigation of long-term outcomes. Though still in their infancy, several such high-level studies are ongoing, which may help to elucidate the true role of ALC reconstruction in the management of rotatory knee instability.

Compliance with Ethical Standards

Conflict of Interest Volker Musahl, Elan Golan, Robert Tischman, Theresa Diermeier, Ravi Vaswani, and Kevin Byrne declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- •• Of major importance

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