Current Concepts of the Anterolateral Ligament of the Knee

Anatomy, Biomechanics, and Reconstruction

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In 1879, Paul Segond described an avulsion fracture (now known as a Segond fracture) at the anterolateral proximal tibia with the presence of a fibrous band at the location of this fracture. Although references to this ligament were occasionally made in the anatomy literature after Segond's discovery, it was not until 2012 that Vincent et al named this ligament what we know it as today, the anterolateral ligament (ALL) of the knee. The ALL originates near the lateral epicondyle of the distal femur and inserts on the proximal tibia near Gerdy's tubercle. The ALL exists as a ligamentous structure that comes under tension during internal rotation at 30°. In the majority of specimens, the ALL can be visualized as a ligamentous structure, whereas in some cases it may only be palpated as bundles of more tense capsular tissue when internal rotation is applied. Biomechanical studies have shown that the ALL functions as a secondary stabilizer to the anterior cruciate ligament (ACL) in resisting anterior tibial translation and internal tibial rotation. These biomechanical studies indicate that concurrent reconstruction of the ACL and ALL results in significantly reduced internal rotation and axial plane tibial translation compared with isolated ACL reconstruction (ACLR) in the presence of ALL deficiency. Clinically, a variety of techniques are available for ALL reconstruction (ALLR). Current graft options include the iliotibial (IT) band, gracilis tendon autograft or allograft, and semitendinosus tendon autograft or allograft. Fixation angle also varies between studies from full knee extension to 60° to 90° of flexion. To date, only 1 modern study has described the clinical outcomes of concomitant ALLR and ACLR: a case series of 92 patients with a minimum 2-year follow-up. Further studies are necessary to define the ideal graft type, location of fixation, and fixation angle for ALLR. Future studies also must be designed in a prospective comparative manner to compare the clinical outcomes of patients undergoing ACLR with ALL reconstruction versus without ALL reconstruction. By discovering the true effect of the ALL, investigators can elucidate the importance of ALLR in the setting of an ACL tear.

Keywords: anterolateral ligament; anterior cruciate ligament reconstruction; allograft; autograft; biomechanics

In 1879, Paul Segond described an avulsion fracture (now known as a Segond fracture) at the anterolateral proximal tibia.[13] At the location of this fracture, Segond noted the presence of a "pearly, resistant, fibrous band which invariably showed extreme amounts of tension during forced internal rotation (of the knee)."[13] Although references to this ligament were occasionally made in the anatomy literature after Segond's discovery,[10] it was not until 2012 that Vincent et al[65] named this ligament what we know it as today, the anterolateral ligament (ALL). Interestingly, most credit for the "rediscovery" of the ALL has been given to Claes et al,[13] who in 2013 published a detailed anatomic description of the ALL as found in a series of cadaveric knees. Since this time, many authors have tested the biomechanics of the ALL in an effort to determine the anatomic function of the ALL, the effect of ALL rupture on knee kinematics, and the effect of ALL reconstruction using various graft sources. The purpose of this Current Concepts review is to highlight the findings of the current literature on the native anatomy of the ALL, the function and biomechanics of the ALL, and techniques for ALL reconstruction.

PREVALENCE

Debate exists as to the presence and prevalence of the ALL, enough that some authors have questioned whether

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One or more of the authors has declared the following potential conflict of interest or source of funding: R.F.L. receives IP royalties from Arthrex, Ossur, and Smith & Nephew; receives research support from Arthrex, Linvatec, Ossur, and Smith & Nephew; and is a paid consultant for Arthrex, Ossur, and Smith & Nephew. E.C.M. receives IP royalties from Biomet; receives research support from Biomet, Mitek, Smith & Nephew, and Stryker; and is a paid consultant for Biomet.

The American Journal of Sports Medicine, Vol. XX, No. X
DOI: 10.1177/0363546517701920

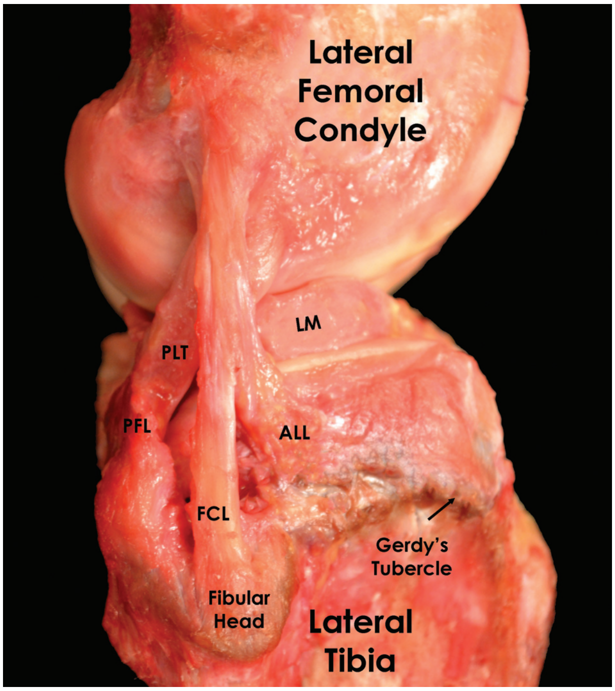

Figure 1. Anatomy of the anterolateral ligament (ALL). Note the origin of the ALL near the lateral epicondyle of the femur and inserting on the proximal tibia between the fibular head and Gerdy's tubercle. The ALL overlaps with the fibular collateral ligament (FCL) near its femoral origin. LM, lateral meniscus; PFL, popliteofibular ligament; PLT, popliteus tendon.

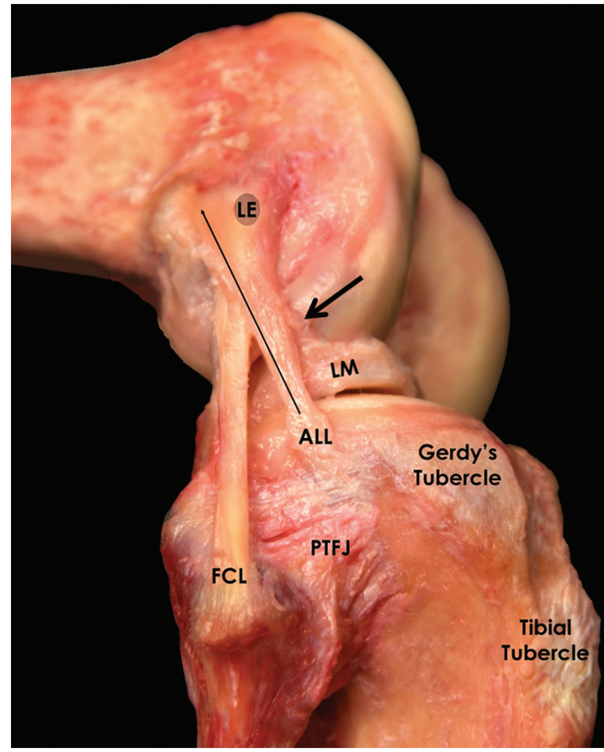

Figure 2. Lateral meniscal insertion of the anterolateral ligament (ALL). Thin black line represents the ALL. Black arrow points to collagen fibers of the ALL inserting onto the lateral meniscus (LM). FCL, fibular collateral ligament; LE, lateral epicondyle; PTFJ, proximal tibiofibular joint.

the ALL is fact or fiction.[43] Ingham et al[29] performed knee dissections on 58 specimens from 24 different animal species and did not find the ALL in any of the specimens. In studies of human specimens, the ALL has been identified as a distinct anatomic structure in 12% to 100% of specimens.[14,23,49,58,68] Given the results of these studies, there has been a call for a better understanding of the anterolateral knee anatomy,[36] with some authors suggesting that through careful dissection with a clear knowledge of the anatomic insertions of the ALL, this ligament can be identified in all human cases.[55]

ANATOMY

The ALL exists as a ligamentous structure that comes under tension during internal rotation at 30°.[31] In the majority of specimens, the ALL can be visualized as a ligamentous structure, whereas in some cases it may only be palpated as bundles of more tense capsular tissue when internal rotation is applied.[60] The ligament originates on the femur and inserts on the tibia, with a mean length at full extension of 33 to 37.9 mm, a mean width of 7.4 mm, a mean thickness of 2.7 mm, and a mean cross-sectional area of 1.54 mm^2.[23,25,71] The ALL is not an isometric ligament.[25,33,63,72] The length of the ligament increases with knee flexion, to a degree which depends on the relationship of the femoral origin of the ALL and lateral collateral ligament (LCL).[33,63] The length of the ALL also increases with internal tibial rotation.[72]

The ALL originates on the femur either directly on the lateral epicondyle or posterior and proximal to the lateral epicondyle (Figure 1).[14,16] The ligament attaches to the femur in a fanlike shape with an average attachment area at its femoral origin of 67.7 mm^2.[14,31] The ligament may attach posterior and proximal or anterior and distal to the attachment site of the LCL.[23,31,63] The ALL overlaps with the LCL near its femoral origin. At the femoral origin, the mean diameter of the ALL is 11.85 mm.[14]

Between the femur and tibia, dense collagen fibers of the ALL insert onto the external surface of the lateral meniscus (Figure 2). The site of meniscal insertion is between the anterior horn of the lateral meniscus and the lateral meniscus body, with a mean attachment length of 5.6 mm.[22] Four types of meniscal attachment may be appreciated: complete, central, bipolar, or inferior-only.[35]

At the tibia, the ALL has an average attachment area of 53.0 to 64.9 mm^2 and attaches an average of 24.7 mm posterior to the center of Gerdy's tubercle and 26.1 mm proximal to the anterior margin of the fibular head.[8,31] The tibial insertion site of the ALL can be found an average of 9.5 mm distal to the joint line and just proximal to the tibial insertion of the biceps femoris.[8,31]

BIOMECHANICS

Several studies have tested the biomechanical properties of the ALL, with a mean ultimate load to failure measured between 50 and 205 N, a mean stiffness of 20 to 42 N/mm, and a mean ultimate strain of 36%.[21,31,71] Through biomechanical testing, failure of the ALL has been shown to occur by a variety of mechanisms, including ligamentous tear at the femoral or tibial insertions, intrasubstance tears, and complete detachment from the tibia with an associated bony avulsion (Segond fracture).[31]

FUNCTION

The ALL functions as a secondary stabilizer to the anterior cruciate ligament (ACL) in resisting anterior tibial translation and internal tibial rotation and in preventing the knee pivot-shift phenomenon.[34,54,57,60,61] Most biomechanical studies[54,57,60] have demonstrated a significant effect of the ALL in providing rotational control of the knee during the simulated pivot shift, although at least one study[34] has suggested that the ALL makes only small contributions to restraining internal tibial rotation and that the iliotibial tract is the primary restraint during the pivot-shift test.

The function of the ALL is most important in ACL-deficient states, with most biomechanical studies demonstrating that in the presence of ACL insufficiency, detaching or sectioning the ALL in cadaveric knee specimens results in a significant effect on anteroposterior (AP) stability as well as a significant increase in internal rotation.[7,46,47,54,60] However, Tavlo et al[60] found that after ACL reconstruction (ACLR), there was no significant difference between an intact and a detached ALL in terms of AP knee stability. In addition, detaching the ALL had a significant effect on internal rotational stability in ACL-insufficient knees but a nonsignificant effect in knees after ACLR.

With regard to ALL reconstruction (ALLR), Spencer et al[57] found that in an ACL-deficient state, ALLR did not significantly reduce internal rotation or anterior translation compared with an ALL-deficient state. However, concomitant ACLR and ALLR have been shown to significantly reduce internal rotation and axial plane tibial translation (ie, pivot-shift translation) compared with isolated ACLR in the presence of ALL deficiency.[44] Nevertheless, the long-term clinical effects of ALL insufficiency are unknown at this time.

INJURY

Injury to the ALL is most commonly associated with a concomitant tear of the ACL.[12] In a clinical case series of 60 patients undergoing ACLR, Ferretti et al[18] exposed the lateral knee compartment and found various lesion types of the ALL, including macroscopic hemorrhage involving the area of the ALL extending to the anterolateral capsule (32%), macroscopic hemorrhage involving the area of the ALL extending to the posterolateral capsule (27%), complete transverse tear of the ALL near its tibial insertion (22%), and a bony tibial avulsion, that is, Segond fracture (10%).

On the basis of magnetic resonance imaging (MRI) of 206 patients undergoing ACL reconstruction, Claes et al[12] described radiological abnormalities in 78.8% of knees, with the majority seen in the distal (tibial) portion of the ligament. In a similar study, van Dyck et al[64] found ALL abnormalities in 46% of 90 knee MRIs of patients with an acute ACL rupture. Furthermore, van Dyck et al[64] found that patients with an abnormal ALL on MRI were significantly more likely to have a lateral meniscal tear (P = .008), collateral ligament injury ($P \leq .05$), and osseous injury (P = .0037) compared with patients with an intact ALL.

Bony contusions seen on MRI may also lead one to suspect injuries of the ALL and ACL. On the basis of retrospective review of 193 MRIs of patients who underwent ACLR, Song et al[51] found that bony contusions of the lateral femoral condyle and lateral tibial plateau (but not the medial femoral condyle or medial tibial plateau) were significantly associated with ALL injury.

Ruptures of the ALL are particularly associated with a Segond fracture, or a bony avulsion near the lateral tibial plateau often found in the presence of an ACL tear. De Maeseneer et al[15] retrospectively reviewed the MRIs of 13 cases of a Segond fracture and found that the ALL inserted on the Segond bone fragment in 10 of 13 (77%) cases. Similarly, Porrino et al[45] evaluated 20 knee MRIs with a Segond fracture and found that the ALL was attached to the fracture fragment in all but one case limited by anatomic distortion. On the basis of these data, it is likely that a Segond fracture may be classified as an "ALL equivalent injury." However, as described above, injury to the ALL may occur in the absence of a Segond fracture.[18]

RECONSTRUCTION

The history of ALL reconstruction is closely intertwined with first attempts at restoring stability to an ACL-deficient knee. In the 1970s and 1980s, the aim of ACLR was to alleviate the anterior subluxation and rotational instability caused by insufficiency of the ACL.[19,62] The surgical focus was on controlling anterolateral tibial subluxation and, to this end, the first popular reconstruction technique was a lateral extra-articular tenodesis: that is, using a strip of the patient's iliotibial band and maintaining the graft's distal insertion on Gerdy's tubercle.[37,41] As such, early ACLR in effect also attempted to restore native anterolateral stability. While these techniques initially stabilized internal rotational laxity, over time they were found to stretch out, yielding residual instability, graft failure, and poor outcomes.[2,5,6,59] The aims of surgical reconstruction were thus refined, not only to focus on restoration of stability but also to reconstruct the intra-articular ACL structure itself. Consequently, ACLR techniques became combined extra- and intra-articular surgical procedures.[4,30,39] These combined surgeries also had mixed outcomes and in many series were not able to demonstrate superiority over isolated intra-articular reconstruction alone.[3,59] As a result, focus continued to shift to reconstruct the ACL intra-articularly, and thus reconstruction of the ALL was for the most part removed from the surgical repertoire of orthopaedic surgeons until the early 2000s.

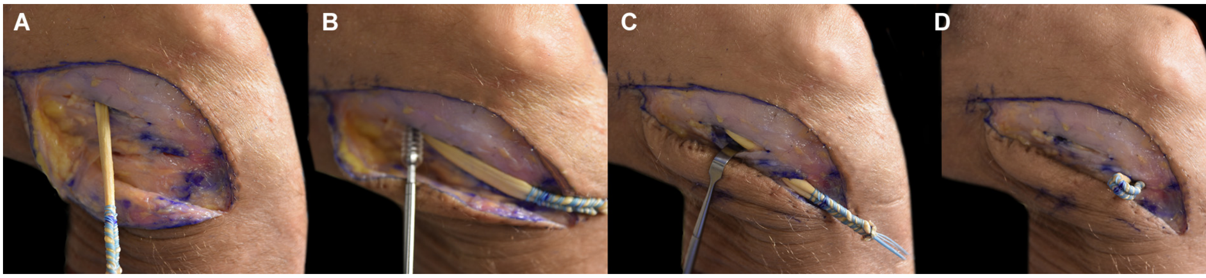

Figure 3. Anterolateral ligament reconstruction sequence. (A) The graft is inserted into the femoral tunnel with the help of the previously placed passing suture and (B) secured with a 7 × 23–mm biointerference screw. (C) The graft is then passed between the superficial layer of the iliotibial band and fibular collateral ligament. (D) The graft is passed through the tibial tunnel and fixed in the tibial tunnel with a 7 × 23–mm biointerference screw on a left knee.

Despite our improved knowledge and surgical abilities in restoring ACL anatomy and function, rotational instability and failure of ACLR are still seen in approximately 1.7% to 7.7% of patients.[27,28,38,42,67] This failure rate has led the orthopaedics community to reconsider the ALL in restoring knee stability, and new techniques specific to ALLR have emerged (Figure 3).

Indications

As with most evolving surgical procedures, the indications and techniques described for ALLR are varied, but common themes do exist. Several authors agree that ALLR should be considered in revision cases and those with a high-grade pivot shift (grade 2-3),[11,17,20,32,50,52,66] despite previous studies[1,70] demonstrating no effect of pivot shift on revision rate or postoperative instability after primary ACLR. Smith et al[50] reported that they will only perform ALLR after ruling out LCL and posterolateral corner laxity during examination under anesthesia. Some authors advocate for ALLR based on patient activities, such as participation in pivoting sports or in high-level or "elite" athletics, and in patients demonstrating attributes of hypermobility.[50,52] Some authors also describe imaging parameters that are indicators for ALLR.[17,52] These include MRI consistent with ALL substance injury, a Segond fracture, and presence of a "lateral femoral notch sign" or an impaction of the lateral femoral condyle due to a pivot-shift injury mechanism.[26]

Graft Type

The ideal graft to use for reconstruction has not been clearly established, and many described options exist. Lutz et al[40] describe a technique with certain similarities to the Macintosh lateral extra-articular tenodesis technique from 1980[30] in that the ipsilateral iliotibial (IT) band is harvested, keeping the distal insertion on Gerdy's tubercle intact and using the proximal portion of the graft to recreate the intra-articular ACL. This technique in effect allows for combined reconstruction of the ALL and ACL using the same IT band autograft. Kernkamp et al[32] also describe a technique using a slip of the iliotibial band, although it is a free graft and is anchored distally on the tibia at the anatomic location of the ALL insertion.

Several authors have published technique descriptions of ALLR using a gracilis graft.[17,20,50,52] Helito et al[20] recommend using a gracilis auto- or allograft in conjunction with a tripled semitendinosus auto- or allograft for a combined ACL and ALL reconstruction. The quadrupled ACLR thus consists of a tripled semitendinosus and single gracilis with the ALLR consisting of a single or doubled portion of the gracilis, depending on the length of the latter. A tripled semitendinosus graft for ACLR and a doubled gracilis graft for ALLR also have been described.[17] Sonnery-Cottet et al[52] use a doubled gracilis tendon graft, although their technique differs in that the graft is placed as an inverted V-shape, such that two points of fixation are made on the tibia instead of one point, in an effort to mimic the broad-based tibial attachment of the native ALL. Smith et al[50] perform an all-inside quadrupled semitendinosus ACLR with a minimally invasive approach to reconstruct the ALL with a single gracilis graft. Other graft types are a minimally invasive technique using polyester tape[66] or a single-bundle semitendinosus auto- or allograft.[11]

Although several graft options have been described for use in ALLR, no graft appears to perfectly match the properties of the native ALL. Wytrykowski et al[69] performed a cadaveric study to compare the biomechanical properties of the ALL, gracilis, and IT band. The gracilis was found to have 6 times the stiffness of the ALL (131.7 vs 21 N/mm) and had the highest maximum load to failure (200.7 vs 141 N). Overall, the mechanical properties of the IT band (stiffness, 39.9 N/mm; maximum load to failure, 161.1 N) most closely resembled those of the ALL.

Location of Fixation

More agreement appears to exist with regard to the location of tibial graft fixation, although the femoral fixation site has been heterogeneous in the literature. With the exception of one technique in which the IT band insertion on Gerdy's tubercle is kept as the point of distal fixation,[32] all other described techniques use the midpoint between Gerdy's tubercle and the fibula at approximately 5 to 10 mm below the lateral joint line as the location for distal fixation (Figure 4).[17,20,50,52] Most authors use direct visualization and palpation to guide them in determining this

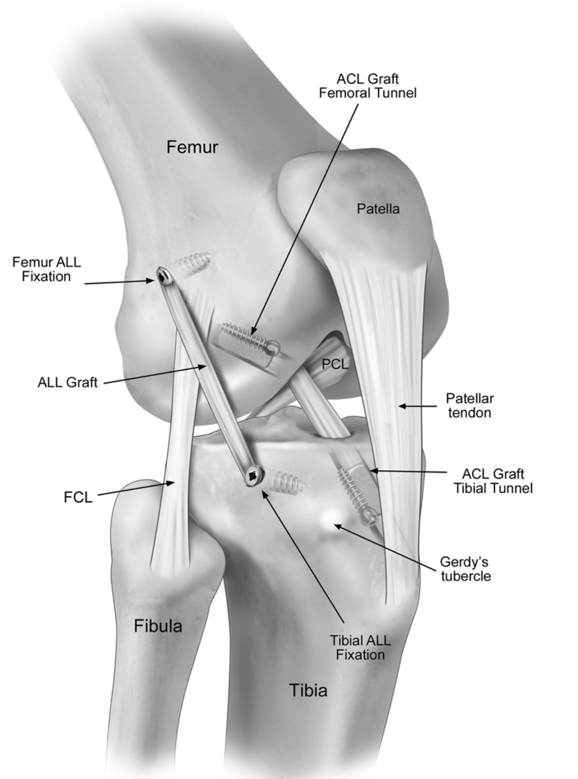

Figure 4. Anterolateral ligament (ALL) reconstruction. Example of ALL reconstruction demonstrating a common point of tibial fixation between Gerdy's tubercle and the fibula. Femoral fixation in this example is proximal and posterior to the fibular collateral ligament (FCL). ACL, anterior cruciate ligament.

location, although Helito et al[20] have described the use of radiographic landmarks to determine this location. Using fluoroscopy, the authors choose a point around 7 mm below the tibial plateau on the frontal view and around 50% of the plateau length on the lateral view.[20]

As the origin of the femoral insertion of the native ALL varies,[9,13,24,31] so does the location of femoral fixation during ALLR. Some authors[17,40,52] describe fixation at a point posterior and superior to the lateral femoral epicondyle. Chahla et al[11] use a point approximately 5 mm proximal and posterior to the LCL. However, several authors[32,50,66] perform femoral-sided fixation anterior to the lateral epicondyle or LCL.

Fixation Angle

No consensus is available on the proper angle at which fixation of the ALLR should occur. Several authors[11,40,50,66] perform fixation at 30° of flexion, although fixation in full extension,[52] fixation at 45° to 60° of flexion,[17] and fixation at 60° to 90° of flexion[20] have all been described. It is important to remember that the ALL is not an isometric ligament, with the length of the ligament increasing during knee flexion.[25,33,63,72] Surgeons should take this knowledge into account when considering the appropriate tensioning position during graft fixation.

In a biomechanical study, Schon et al[48] tested 10 fresh-frozen human cadaveric knees with intact ACL and ALL, anatomic single-bundle ACLR with intact ALL, ACLR with severed ALL, and ACLR with ALLR using graft fixation angles of 0°, 15°, 30°, 45°, 60°, 75°, and 90°. ACLR was performed with a bone–patellar tendon–bone (BPTB) allograft, and ALLR was performed with a semitendinosus allograft. The authors found that compared with the intact ALL, a sectioned ALL resulted in significantly increased internal rotation when subjected to a 5-N·m internal rotation torque. In addition, ALLR produced significant overconstraint of internal rotation when compared with the intact ALL at flexion angles of 30° or greater, except when fixed at 0° and tested at 30° of flexion. Although the results of this study bring into question the clinical utility of ALLR, Sonnery-Cottet et al[53] responded, stating that at a 5-year follow-up after several hundred combined ACLR and ALLR procedures, the authors have found no clinical evidence of overconstraint or stiffness, with no revision cases to cut a tight ALL graft. However, it should be emphasized that this is only anecdotal evidence. Thus, further clinical studies are necessary to fully define the effects of ALLR on internal rotation and knee stiffness.

Clinical Outcomes

Before the rediscovery of the ALL, several studies[3,4,59] attempted to define the clinical effect of a combined intra-articular ACLR with an extra-articular procedure. Although these authors may not have been aware of the existence of the ALL, extra-articular augmentation was performed in an effort to limit pathologic motion and to protect the intra-articular ACL graft postoperatively.[3] In a randomized study performed by Anderson et al,[3] the authors compared the clinical outcomes of 3 surgical methods of ACLR using either a BPTB autograft (group 1), a hamstring tendon autograft with a combined extra-articular procedure (group 2), or a hamstring tendon autograft alone (group 3). At an average follow-up of 35.4 months, patients in group 2 had a higher incidence of patellofemoral crepitation and loss of motion compared with patients in group 3. No significant difference was found between groups with regard to the subjective International Knee Documentation Committee (IKDC) score, and most patients in each group returned to their preinjury activity level. The authors concluded that there appears to be no benefit to combining an intra-articular ACLR with an extra-articular procedure.

In a retrospective review of 127 patients with chronic ACL instability, Strum et al[59] compared the clinical outcomes of 84 patients treated with an intra-articular procedure alone (using a torn meniscus or a patellar tendon graft) and 43 patients treated with a combined intra- and extra-articular procedure. At an average follow-up of 45.2 months, no significant differences were found between groups with regard to radiographic changes, instrumented laxity, or a total knee score that was derived by summing subjective, functional, and objective scores. Similar to Anderson et al,[3] Strum et al[59] concluded that there is no demonstrable benefit to combining intra- and extra-articular stabilization for the treatment of chronic ACL instability.

To date, only one study[56] has described the clinical outcomes of ALL reconstruction since the rediscovery of this ligament. In a retrospective case series, Sonnery-Cottet et al[56] evaluated 92 patients at a minimum 2-year follow-up after concomitant ACLR and ALLR. Indications for ALLR were an associated Segond fracture, chronic ACL lesion, high level of sporting activity, participation in pivoting sports, and a lateral femoral notch sign on radiographs. A semitendinosus-gracilis autograft was used for ACLR, while an additional strand of the gracilis tendon autograft was looped in a Y-shape configuration for ALLR. At a mean follow-up of 32.4 months, 1 patient had experienced an ACL graft rupture (1.1%). Compared with the preoperative assessment, the follow-up showed significant improvements in Lysholm score, subjective IKDC score, and objective IKDC score (all P values $< .0001$). Pivot-shift results were also significantly improved, with all patients having either a negative (n = 76) or grade 1 (n = 7) pivot shift. The Tegner activity scale at follow-up (7.1 $\pm$ 1.8) had decreased to a statistically significant extent ($P < .01$) compared with baseline (7.3 $\pm$ 1.7).

Although the results of the study by Sonnery-Cottet et al[56] are promising, future studies must be designed in a prospective comparative manner to compare the clinical outcomes of patients undergoing ACLR with versus without ALLR. Such study designs will allow investigators to elucidate the true effect of ALLR in the setting of an ACL tear.

CONCLUSION

The anterolateral ligament was first named in 2012 by Vincent et al,[65] despite its initial discovery by Paul Segond in 1879 in association with a Segond fracture.[13] The ALL originates near the lateral epicondyle of the distal femur and inserts on the proximal tibia near Gerdy's tubercle. Biomechanical studies have shown that the ALL functions as a secondary stabilizer to the ACL in resisting anterior tibial translation and internal tibial rotation. Based on these studies, concurrent reconstruction of the ACL and ALL results in significantly reduced internal rotation and axial plane tibial translation compared with isolated ACLR in the presence of ALL deficiency. A variety of techniques for ALLR have been described. However, the ideal graft type, location of fixation, and fixation angle for ALLR remain to be determined. Further studies are necessary to define the clinical effect of concurrent ACLR and ALLR compared with isolated ACLR in patients with an ACL tear.

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