High risk of tunnel convergence during combined anterior cruciate ligament and anterolateral ligament reconstruction.

Peer-reviewed author version

SMEETS, Kristof; BELLEMANS, Johan; Lamers, G.; Valgaeren, B.; BRUCKERS, Liesbeth; GIELEN, Ellen; VANDEVENNE, Jan; VANDENABEELE, Frank & TRUIJEN, Jan (2018) High risk of tunnel convergence during combined anterior cruciate ligament and anterolateral ligament reconstruction.. In: Knee surgery, sports traumatology, arthroscopy, 27 (2), p. 611-617.

DOI: 10.107/s00167-018-5200-3
Handle: http://hdl.handle.net/1942/27584

High risk of tunnel convergence during combined anterior cruciate ligament and anterolateral ligament reconstruction.

K. Smeets[1,2], J. Bellemans[2,3], G. Lamers[3], B. Valgaeren[3], L. Bruckers[4], E. Gielen[5], J. Vandevenne[5], F. Vandenabeele[3], J. Truijen[2,3]

[1]Doctoral School for Medicine and Life Sciences, Hasselt University, Diepenbeek, Belgium
[2]Department of Orthopedic Surgery, Ziekenhuis Oost-Limburg, Genk, Belgium
[3]Faculty of Medicine and Life Sciences, Hasselt University, Diepenbeek, Belgium
[4]I-BioStat, Hasselt University, Diepenbeek, Belgium
[5]Department of Radiology, Ziekenhuis Oost-Limburg, Genk, Belgium

Corresponding Author:
Kristof Smeets, MD
Orthopaedic Department
Schiepse Bos 6
3600 Genk
Belgium
kristofsmeets@yahoo.com
Phone: 0032474879934

Acknowledgement The authors thank Senne Van de Bempt and Maarten Verheyden for their help with the drilling of femoral tunnels on human cadavers.

Conflict of interest All authors declare that they have no conflict of interest

ABSTRACT

Purpose

To assess the risk of femoral tunnel convergence in combined anterior cruciate ligament (ACL) and anterolateral ligament (ALL) reconstructions. The hypothesis was that a more proximal and anterior orientation of the ALL femoral tunnel should reduce the risk of convergence with the ACL femoral tunnel.

Methods

Fifteen fresh-frozen cadaver knees were examined. An anatomic ACL femoral tunnel was drilled arthroscopically in each specimen and ALL tunnels were made in two directions: 1) 0° coronal angulation and 20° axial angulation , 2) 30° coronal angulation and 30° axial angulation. Computed tomography scans were performed to investigate tunnel convergence and to measure the minimal distance between tunnels, tunnel length and the LFC width.

Results

Tunnel convergence occurred in 20 of 30 cases (67%). Convergence was significantly reduced when tunnels were drilled at 30° coronal and 30° axial angulation ($P<0.05$). The mean length of the ALL tunnel was 15.9mm (95% CI [13.6; 18.1]) and was independent of ALL tunnel angulation. The mean minimal distance between the ALL and ACL tunnel was 3.1 mm (95% CI [2.1; 4.1]). The odds ratio for tunnel convergence was 3.5 for small LFC, relative to large LFC *(n.s.)*

Conclusion

A high risk of tunnel convergence was observed when performing combined ACL and ALL reconstructions. The clinical relevance of this work is that the occurrence of tunnel conflicts can be reduced by aiming the ALL tunnel in a more proximal and anterior direction. Surgeons should be aware of this, since tunnel convergence could jeopardize the ACL reconstruction and fixation.

Keywords: knee, anterior cruciate ligament, anterolateral ligament, reconstruction, tunnel convergence

INTRODUCTION

An anterior cruciate ligament (ACL) tear is one of the most common sports injuries, and frequently requires surgical reconstruction. [25,26] When performing a state-of-the-art intra-articular ACL reconstruction (ACLR), a remaining pivot shift has been reported to persist in 11% to 60% of patients [17,18,43] and failure of the graft is seen in approximately 1.7% to 18% of patients. [25,45] This high failure rate has led to the combination of an intra-articular ACLR and lateral extra-articular tenodesis (LET) in an attempt to control anterolateral instability and to reduce tension on the ACL graft. [8,16,30,32,41]

Recent studies pretend that the anterolateral ligament (ALL) functions as a secondary stabilizer to the anterior cruciate ligament (ACL) in resisting anterior tibial translation and internal tibial rotation [21,22,38,42,44]. Therefore, ALL reconstructions (ALLR) becomes increasingly popular among orthopaedic surgeons as a LET procedure to augment an ACLR. Several authors agree on performing ALLR in revision cases, patients with a high-grade pivot shift and high-level athletics. [15,20,35,36] Since the rediscovery of the ALL [6], clinical outcome studies of ALLR are showing promising results and a reduced failure rate. [39-41]

The current trend in ACLR is to position the femoral tunnel relatively oblique through the anteromedial portal, in order to better reproduce the native ACL anatomy and orientation for controlling tibial rotation. [2,3,46,47] The femoral insertion of the ALL varies [4-7,19] but the ALL Expert Group reached a consensus that the femoral attachment is posterior and proximal to the lateral epicondyle. [37] This implies that the femoral ACL tunnel is in closer proximity of the ALL origin , and so there is theoretically more chance to interfere with the ALLR. Despite the increasing number of studies on anatomic ALLR, to our knowledge no studies exist on the risk of tunnel convergence.

Tunnel convergence is seen in combined ACL and posterolateral corner (PLC) reconstructions. [11,13,28,34] Because of the close proximity of the LCL and ALL femoral origin [7], it is reasonable to expect tunnel conflicts in ALLR. In case this is correct, during drilling potential damage could occur to the reconstructed ACL femoral attachment due to the conflicting tunnels.

The main objective of this study was therefore to assess the risk of femoral tunnel convergence in combined ACL and ALL reconstructions. The hypothesis was that a more proximal and anterior orientation of the ALL femoral tunnel should reduce the risk of convergence with the ACL femoral tunnel. The clinical relevance of this study is that it investigates potential complications of combined ACL-ALL reconstructions in order to reduce the risk of failure of the ACL reconstruction.

MATERIAL AND METHODS

Fifteen fresh-frozen cadaver knees (9 woman, 6 men) were studied with a median age of 74 years (ranged from 65 to 103 years). No donor had a history of knee injury or prior surgical intervention. All specimens were stored at -40°C and thawed at room temperature for 24 hours before testing.

Femoral Tunnel Drilling

All tunnels were drilled by the same orthopaedic surgeon (KS). The knees were placed in a custom-made rig in which they could move freely between 0° and 130°. A high parapatellar anterolateral portal was made as a viewing portal. A low anteromedial portal was established as the working portal for the femoral ACL drilling. An arthroscopic debridement of the anterior cruciate ligament and notch was performed in order to have a clear view on the medial wall of the LFC. A femoral offset guide (Arthrex) of 6mm was placed behind the LFC while the knee was flexed to 125°. Next a ACL tightrobe drill pin 4mm (Arthrex) was drilled at a 2 or 10 o'clock position and subsequently overreamed to 8 mm with a length of 25mm.

A lateral longitudinal incision of 8-10cm over the lateral epicondyle(LE) was made and subcutaneous tissue and fascia lata were removed. The ALL insertion point was identified, as described by the ALL Expert Group, just proximal and posterior of the LE. [37] From this position, two 2.4mm guidewires were drilled in 2 different orientations: 1) 0° coronal angulation and 20° axial angulation , 2) 30° coronal angulation and 30° axial angulation. (figure 1) In the coronal plane, the 0° angulation was perpendicular to the anatomical axis of the femur. In the axial plane, a 2 mm K-wire was reamed through the epicondylar axis and this was used to create the 20° or 30° axial directions with the help of a manual goniometer. The anatomical and epicondylar axis were used for a better reproducibility during real-life surgery. Both 2.4mm guidewires were overdrilled with a 4.5mm reamer until the second cortex was reached.

Computed Tomography Imaging

After the tunnels were completed, specimens were transported to the radiology department and imaged by computed tomography (CT) on a Siemens Somatom Force dual source 192-slice CT scanner (Siemens Healthineers, Erlangen, Germany) using tube voltage settings of Sn150kV and 300mAs and a bone kernel. 3D post processing of the thin slices (slice thickness 0.4 mm, isotropic voxels) was performed using bone window and level settings on Syngo.Via VB10B software (Siemens Healthineers, Huizingen, Belgium) and allowed for assessing tunnel convergence and measuring distances (figure 2).

All measurements were performed by an expert musculoskeletal imaging radiologist and confirmed by an experienced orthopaedic surgeon. To quantify variations between both investigators, the intra cluster correlation was determined. Drilling angles were measured and matched the intended angles. The potential variation in ACL tunnel orientation was investigated by measuring the angle between the ACL tunnel and the anatomical axis of the femur in the coronal and sagittal plane. To quantify the ACL tunnel position, a 2D reference plane was created and the position of the entry point was described. The occurrence of tunnel convergence between both ALL tunnels and the ACL tunnel was noted. If convergence was observed, the length of both tunnels from the entry point to the conflict was measured. If no tunnel interference was seen, the minimal distance between the ACL and ALL tunnel was calculated for data analysis. In addition, tunnel length was measured for both tunnels from their entry point to the point where the tunnel was at his shortest distance to the other tunnel. If the differences in results between the two observers were more than 1mm, measurements were done again. To determine the relationship between LFC width and tunnel convergence all knees were divided in two groups, depending if there were above or below the average LFC width.

This study was performed after ethical approval from the Institutional Review Board at the University of Hasselt (CME2016/670).

Statistical Analysis

For each knee, the outcomes are observed for both ALL tunnel angulations. As a result, the measurements cannot be treated as independent. A generalized estimating equations (GEE) model was used with an unstructured working correlation to take into account the dependency of observations. For the binary outcome (convergence of tunnels yes or no) a logit link with a binomial distribution was specified and for the continuous outcomes (distances and length) an identity link with a normal distribution was used. The effect of ALL tunnel angulation is investigated in this model by introducing ALL tunnel angulation as an explanatory variables in the model. A 5% level of significance is used and statistical analysis are performed in SAS for windows version 9.4. A power calculation for a one-sided test for paired proportions with a significance level of 5% has a power of 78% to detect a difference in femoral tunnel convergence rate with a sample size of 15 cadaver knees between tunnels drilled at 30° coronal/ 30° axial angulation and 0° coronal/ 20 axial angulation.

RESULTS

Tunnel convergence occurred in 20 of 30 cases (67%). Convergence occurred significantly more frequent (P=0.0072) when tunnels were drilled at 0° coronal and 20 axial angulation (87% conflicts) compared to 30° coronal and 30° axial angulation (47% conflicts), with an odds ratio of 7.4.

In the non-converging tunnels, the mean minimal distance between tunnels was 3.1 mm (95% CI [2.1; 4.1]), ranging from 1 to 6 mm. From that distance, the mean length of the ALL and ACL tunnels was respectively 17.5 mm (95% CI 14.4; 20.5]) and 23 mm (95% CI [20; 26]). When tunnel conflict occurred, the mean length of the ALL tunnel was 15.9 mm (95% CI [13.6; 18.1]) and 19 mm (95% CI [17.3; 20.8])] for the ACL tunnel. (Table 1)

All specimens were divided in 2 groups (large femurs / small femurs) according to the average LFC width of 29.8mm (95% CI [26.4; 29.8]). Large femurs were defined as those with above average LFC width, and small femurs as those with LFC width below average. There were 9 small femurs with a tunnel convergence rate of 77.7%. From the 6 large femurs, 50% of reaming combinations showed tunnel conflicts. There was no significant difference between both groups (n.s.) and an odds that was 3.5 times higher for the small femur group, relative to the large femur group.

The intra cluster correlation between the two independent observers was always higher than 0.95. The mean orientation of the ACL tunnel was 48.1° ± 9.5° in the sagittal plane and 39.6° ± 8.4° in the coronal plane. Using the quadrant method described by Forsythe [10] with a 2 x 2 grid, the aperture of all ACL tunnels were located in the same proximal upper quadrant.

DISCUSSION

The primary finding of this work is that there is a high risk of tunnel convergence in combined ACL and ALL reconstructions. The risk of creating a tunnel conflict can be significantly reduced by drilling the ALL tunnel in a more proximal and anterior direction, supporting our initial hypothesis.

Despite the growing interest in ALL reconstructions and the high convergence rate in combined ACL and PLC reconstructions [11,13,28,34], to our knowledge, no studies were performed on the risk assessment for combined ACL and ALL reconstructions. When tunnels converge in multiple knee ligament reconstructions, it may lead to graft damage or excessively short tunnels. [13] During the last decades more attention has been drawn onto anatomical placement of the ACL femoral tunnel because of its biomechanical advantage for rotational stability. [24,29,33] In this study the femoral tunnel was drilled through a low anteromedial portal in the center of the ACL footprint. With this technique it was found to allow easier and more anatomical placement of the ACL tunnel compared to the transtibial technique. [12] As a consequence, the direction of the tunnel is more horizontal and in closer proximity with the ALL origin. There is some discussion about the exact femoral insertion, but experts reached a consensus that the ALL origin is just proximal and posterior to the lateral epicondyle [14,37], and thus this was used as the entry point of the ALL tunnel. Because of this close relation with the origin of the fibular collateral ligament (FCL), our tunnel directions were based on studies which examined tunnel conflicts in combined ACL-FCL reconstructions. Gelber et al. [13] and Moatshe et al. [28] found that 30° axial angulation and 0° coronal angulation was the most safe combination for FCL tunnel drilling. Gali et al. [11] concluded 20° axial and 20° coronal angulation as the least risky combination for tunnel convergence. Tunnel angulations greater than 40° in the axial plane were avoided because this can result in elliptical tunnels and thinned cortices. [34] In the same way, 0° directions in the axial plane were excluded because of the risk of penetrating the posterior cortex or intercondylar notch. [11]

Femoral graft fixation for ALL reconstruction varies but is usually achieved by an interference screw or bone anchor, with a femoral socket diameter ranging from 4.5mm to 6mm and tunnel length of at least 20mm [5,15,16,35,37]. The ALL reconstruction technique consists of a 1 cm wide iliotibial band strip that is passed underneath the most proximal part of the FCL and is fixed in a femoral socket of 25mm length using a 4.8mm fully threaded knotless anchor (SwiveLock PEEK, Arthrex). In this study a guide pin was overreamed by a 4.5mm drill until the medial femoral cortex was reached. In that way the length of the ALL tunnel could be measured from the lateral femoral entry point until the point where both tunnels were at the shortest distance from each other. Our results showed that the mean ALL tunnel length was 15.9 mm when convergence occurred. No significant difference between the different drilling combinations was noticed. (table 1) However, most authors recommend tunnel length of 20mm or 25mm for safe graft to bone tunnel healing [1,12,13,23], so using shorter tunnels in order to avoid tunnel convergence could potentially compromise graft tunnel healing. Because of the high rate of tunnel convergence and short ALL tunnel length, the authors recommend to first look arthroscopically through the ACL tunnel to see if the guide pin appears. (figure 3) If so, the guide pin can be re-drilled under arthroscopic view.

Different surgical techniques for combined ALL and ACL reconstructions are described [5,9,15,31,35,36,41,48] and the high rate of tunnel convergence seen in our paper is not relative to all of them. Specifically, outside-in femoral ACL reconstruction techniques allow a precise placement of the femoral tunnel and this can be adapted in function of the ALL tunnel position, reducing the risk of tunnel conflicts. [15,36] Furthermore, Sonnery-Cottet et al published the largest outcome study of ALL reconstructions using a single femoral tunnel for both ALL and ACL reconstructions, and hereby the risk of tunnel convergence was avoided. [41]

The odds to have a tunnel conflict was 3.5 times higher in knees with a small LFC relative to knees with a large LFC. The non-significant difference is probably due to the relative low sample size, although the number of cadaveric specimens in our study was higher than other papers that have used human knees to assess the risk of tunnel convergence. [11,13,34]

This study has a number of limitations. A limited number of drilling combinations were tested, whereas in theory one could consider several other combinations of angulation. In addition, the ACL was drilled through an anteromedial portal in 125° of flexion using an offset guide, whereas several variations in anatomic ACL reconstructions exist. Another limitation is that only an 8 mm ACL tunnel diameter was used, based upon the most frequently used single-bundle ACL graft diameter. [27] Finally, no clinical outcome reports are available for the combined ACL and ALL reconstruction technique used in this study.

CONCLUSION

Tunnel convergence in combined ACL and ALL reconstructions was studied using an inside-out anteromedial portal technique for ACL tunnel drilling. A high risk of tunnel convergence was observed and this could be reduced by aiming the ALL tunnel in a more proximal and anterior direction, however tunnel conflicts were still seen in almost 50%. The clinical relevance is that surgeons should be aware of this, since tunnel convergence could jeopardize the ACL reconstruction and fixation. Outside-in or transtibial femoral ACL drilling techniques have not been evaluated.

FIGURE CAPTIONS

Figure 1: The ALL tunnel was drilled at (a) 0° coronal and 20° axial angulation and (b) 30° coronal and 30° axial angulation. *= anatomical axis ; **= transepicondylar axis

Figure 2: Computed tomography scan of tunnel convergence in the coronal, axial and sagittal plane. a = ACL tunnel; b= 30° coronal and 30° axial ALL tunnel; c= 0° coronal and 20° axial ALL tunnel; d = transepicondylar axis. If tunnel convergence was observed, the tunnel length was measured from the cortex to the point of contact with the other tunnel (green line). The red line represents the shortest distance between the ACL and ALL tunnel if no convergence was seen. From the point where this line touches the respective tunnel, the length to the entry point was determined.

Figure 3: Arthroscopic view of a tunnel conflict between the ACL tunnel and the ALL tunnel guide pin drilled at 0° coronal 20° axial angulation.

ADDITIONAL FILES

Additional file 1: Table 1: Tunnel length and minimal distance between ALL and ACL tunnels.

REFERENCES

1. Basdekis G, Abisafi C, Christel P (2008) Influence of knee flexion angle on femoral tunnel characteristics when drilled through the anteromedial portal during anterior cruciate ligament reconstruction. Arthroscopy 24:459-464.
2. Bedi A, Musahl V, Steuber V, Kendoff D, Choi D, Allen AA, Pearle AD, Altchek DW (2011) Transtibial versus anteromedial portal reaming in anterior cruciate ligament reconstruction: an anatomic and biomechanical evaluation of surgical technique. Arthroscopy 27:380-390.
3. Bedi A, Raphael B, Maderazo A, Pavlov H, Williams RJ, 3rd (2010) Transtibial versus anteromedial portal drilling for anterior cruciate ligament reconstruction: a cadaveric study of femoral tunnel length and obliquity. Arthroscopy 26:342-350.
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. Chahla J, Menge TJ, Mitchell JJ, Dean CS, LaPrade RF (2016) Anterolateral Ligament Reconstruction Technique: An Anatomic-Based Approach. Arthrosc Tech 5:e453-457.
6. 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.
7. Daggett M, Ockuly AC, Cullen M, Busch K, Lutz C, Imbert P, Sonnery-Cottet B (2016) Femoral Origin of the Anterolateral Ligament: An Anatomic Analysis. Arthroscopy 32:835-841.
8. Engebretsen L, Lew WD, Lewis JL, Hunter RE (1990) The effect of an iliotibial tenodesis on intraarticular graft forces and knee joint motion. Am J Sports Med 18:169-176.
9. Ferreira Mde C, Zidan FF, Miduati FB, Fortuna CC, Mizutani BM, Abdalla RJ (2016) Reconstruction of anterior cruciate ligament and anterolateral ligament using interlinked hamstrings - technical note. Rev Bras Ortop 51:466-470.
10. Forsythe B, Kopf S, Wong AK, Martins CA, Anderst W, Tashman S, Fu FH (2010) The location of femoral and tibial tunnels in anatomic double-bundle anterior cruciate ligament reconstruction analyzed by three-dimensional computed tomography models. J Bone Joint Surg Am 92:1418-1426.
11. Gali JC, Bernardes Ade P, dos Santos LC, Ferreira TC, Almagro MA, da Silva PA (2016) Tunnel collision during simultaneous anterior cruciate ligament and posterolateral corner reconstruction. Knee Surg Sports Traumatol Arthrosc 24:195-200.
12. Gelber PE, Erquicia J, Abat F, Torres R, Pelfort X, Rodriguez-Baeza A, Alomar X, Monllau JC (2011) Effectiveness of a footprint guide to establish an anatomic femoral tunnel in anterior cruciate ligament reconstruction: computed tomography evaluation in a cadaveric model. Arthroscopy 27:817-824.
13. Gelber PE, Erquicia JI, Sosa G, Ferrer G, Abat F, Rodriguez-Baeza A, Segura-Cros C, Monllau JC (2013) Femoral tunnel drilling angles for the posterolateral corner in multiligamentary knee reconstructions: computed tomography evaluation in a cadaveric model. Arthroscopy 29:257-265.
14. Getgood A, Brown C, Lording T, Amis A, Claes S, Geeslin A, Musahl V (2018) The anterolateral complex of the knee: results from the International ALC Consensus Group Meeting. Knee Surg Sports Traumatol Arthrosc 10.1007/s00167-018-5072-6.
15. Helito CP, Bonadio MB, Gobbi RG, da Mota EARF, Pecora JR, Camanho GL, Demange MK (2015) Combined Intra- and Extra-articular Reconstruction of the Anterior Cruciate Ligament: The Reconstruction of the Knee Anterolateral Ligament. Arthrosc Tech 4:e239-244.
16. Herbst E, Arilla FV, Guenther D, Yacuzzi C, Rahnemai-Azar AA, Fu FH, Debski RE, Musahl V (2017) Lateral Extra-articular Tenodesis Has No Effect in Knees With Isolated Anterior Cruciate Ligament Injury. Arthroscopy 10.1016/j.arthro.2017.08.258.
17. Jonsson H, Riklund-Ahlstrom K, Lind J (2004) Positive pivot shift after ACL reconstruction predicts later osteoarthrosis: 63 patients followed 5-9 years after surgery. Acta Orthop Scand 75:594-599.
18. Karikis I, Desai N, Sernert N, Rostgard-Christensen L, Kartus J (2016) Comparison of Anatomic Double- and Single-Bundle Techniques for Anterior Cruciate Ligament Reconstruction Using

Hamstring Tendon Autografts: A Prospective Randomized Study With 5-Year Clinical and Radiographic Follow-up. Am J Sports Med 44:1225-1236.

19. Katakura M, Koga H, Nakamura K, Sekiya I, Muneta T (2016) Effects of different femoral tunnel positions on tension changes in anterolateral ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 10.1007/s00167-016-4178-y.

20. Kernkamp WA, van de Velde SK, Bakker EW, van Arkel ER (2015) Anterolateral Extra-articular Soft Tissue Reconstruction in Anterolateral Rotatory Instability of the Knee. Arthrosc Tech 4:e863-867.

21. Kittl C, El-Daou H, Athwal KK, Gupte CM, Weiler A, Williams A, Amis AA (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.

22. Kraeutler MJ, Welton KL, Chahla J, LaPrade RF, McCarty EC (2017) Current Concepts of the Anterolateral Ligament of the Knee: Anatomy, Biomechanics, and Reconstruction. Am J Sports Med 10.1177/0363546517701920:363546517701920.

23. LaPrade RF, Johansen S, Wentorf FA, Engebretsen L, Esterberg JL, Tso A (2004) An analysis of an anatomical posterolateral knee reconstruction: an in vitro biomechanical study and development of a surgical technique. Am J Sports Med 32:1405-1414.

24. Loh JC, Fukuda Y, Tsuda E, Steadman RJ, Fu FH, Woo SL (2003) Knee stability and graft function following anterior cruciate ligament reconstruction: Comparison between 11 o'clock and 10 o'clock femoral tunnel placement. 2002 Richard O'Connor Award paper. Arthroscopy 19:297-304.

25. Maletis GB, Inacio MC, Funahashi TT (2013) Analysis of 16,192 anterior cruciate ligament reconstructions from a community-based registry. Am J Sports Med 41:2090-2098.

26. Mall NA, Chalmers PN, Moric M, Tanaka MJ, Cole BJ, Bach BR, Jr., Paletta GA, Jr. (2014) Incidence and trends of anterior cruciate ligament reconstruction in the United States. Am J Sports Med 42:2363-2370.

27. Middleton KK, Hamilton T, Irrgang JJ, Karlsson J, Harner CD, Fu FH (2014) Anatomic anterior cruciate ligament (ACL) reconstruction: a global perspective. Part 1. Knee Surg Sports Traumatol Arthrosc 22:1467-1482.

28. Moatshe G, Brady AW, Slette EL, Chahla J, Turnbull TL, Engebretsen L, LaPrade RF (2017) Multiple Ligament Reconstruction Femoral Tunnels: Intertunnel Relationships and Guidelines to Avoid Convergence. Am J Sports Med 45:563-569.

29. Musahl V, Plakseychuk A, VanScyoc A, Sasaki T, Debski RE, McMahon PJ, Fu FH (2005) Varying femoral tunnels between the anatomical footprint and isometric positions: effect on kinematics of the anterior cruciate ligament-reconstructed knee. Am J Sports Med 33:712-718.

30. Nitri M, Rasmussen MT, Williams BT, Moulton SG, Cruz RS, Dornan GJ, Goldsmith MT, LaPrade RF (2016) An In Vitro Robotic Assessment of the Anterolateral Ligament, Part 2: Anterolateral Ligament Reconstruction Combined With Anterior Cruciate Ligament Reconstruction. Am J Sports Med 44:593-601.

31. Saithna A, Thaunat M, Delaloye JR, Ouanezar H, Fayard JM, Sonnery-Cottet B (2018) Combined ACL and Anterolateral Ligament Reconstruction. JBJS Essent Surg Tech 8:e2.

32. Schon JM, Moatshe G, Brady AW, Serra Cruz R, Chahla J, Dornan GJ, Turnbull TL, Engebretsen L, LaPrade RF (2016) Anatomic Anterolateral Ligament Reconstruction of the Knee Leads to Overconstraint at Any Fixation Angle. Am J Sports Med 44(10):2546-2556.

33. Scopp JM, Jasper LE, Belkoff SM, Moorman CT, 3rd (2004) The effect of oblique femoral tunnel placement on rotational constraint of the knee reconstructed using patellar tendon autografts. Arthroscopy 20:294-299.

34. Shuler MS, Jasper LE, Rauh PB, Mulligan ME, Moorman CT, 3rd (2006) Tunnel convergence in combined anterior cruciate ligament and posterolateral corner reconstruction. Arthroscopy 22:193-198.

35. Smith JO, Yasen SK, Lord B, Wilson AJ (2015) Combined anterolateral ligament and anatomic anterior cruciate ligament reconstruction of the knee. Knee Surg Sports Traumatol Arthrosc 23:3151-3156.
36. Sonnery-Cottet B, Barbosa NC, Tuteja S, Daggett M, Kajetanek C, Thaunat M (2016) Minimally Invasive Anterolateral Ligament Reconstruction in the Setting of Anterior Cruciate Ligament Injury. Arthrosc Tech 5:e211-215.
37. Sonnery-Cottet B, Daggett M, Fayard JM, Ferretti A, Helito CP, Lind M, Monaco E, de Padua VB, Thaunat M, Wilson A, Zaffagnini S, Zijl J, Claes S (2017) Anterolateral Ligament Expert Group consensus paper on the management of internal rotation and instability of the anterior cruciate ligament - deficient knee. J Orthop Traumatol 10.1007/s10195-017-0449-8.
38. Sonnery-Cottet B, Lutz C, Daggett M, Dalmay F, Freychet B, Niglis L, Imbert P (2016) The Involvement of the Anterolateral Ligament in Rotational Control of the Knee. Am J Sports Med 44:1209-1214.
39. Sonnery-Cottet B, Saithna A, Blakeney WG, Ouanezar H, Borade A, Daggett M, Thaunat M, Fayard JM, Delaloye JR (2018) Anterolateral Ligament Reconstruction Protects the Repaired Medial Meniscus: A Comparative Study of 383 Anterior Cruciate Ligament Reconstructions From the SANTI Study Group With a Minimum Follow-up of 2 Years. Am J Sports Med 46:1819-1826.
40. Sonnery-Cottet B, Saithna A, Cavalier M, Kajetanek C, Temponi EF, Daggett M, Helito CP, Thaunat M (2017) Anterolateral Ligament Reconstruction Is Associated With Significantly Reduced ACL Graft Rupture Rates at a Minimum Follow-up of 2 Years: A Prospective Comparative Study of 502 Patients From the SANTI Study Group. Am J Sports Med 45:1547-1557.
41. 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.
42. Spencer L, Burkhart TA, Tran MN, Rezansoff AJ, Deo S, Caterine S, Getgood AM (2015) Biomechanical analysis of simulated clinical testing and reconstruction of the anterolateral ligament of the knee. Am J Sports Med 43:2189-2197.
43. Suomalainen P, Jarvela T, Paakkala A, Kannus P, Jarvinen M (2012) Double-bundle versus single-bundle anterior cruciate ligament reconstruction: a prospective randomized study with 5-year results. Am J Sports Med 40:1511-1518.
44. 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.
45. Thompson SM, Salmon LJ, Waller A, Linklater J, Roe JP, Pinczewski LA (2016) Twenty-Year Outcome of a Longitudinal Prospective Evaluation of Isolated Endoscopic Anterior Cruciate Ligament Reconstruction With Patellar Tendon or Hamstring Autograft. Am J Sports Med 44:3083-3094.
46. Tibor L, Chan PH, Funahashi TT, Wyatt R, Maletis GB, Inacio MC (2016) Surgical Technique Trends in Primary ACL Reconstruction from 2007 to 2014. J Bone Joint Surg Am 98:1079-1089.
47. Vundelinckx B, Herman B, Getgood A, Litchfield R (2017) Surgical Indications and Technique for Anterior Cruciate Ligament Reconstruction Combined with Lateral Extra-articular Tenodesis or Anterolateral Ligament Reconstruction. Clin Sports Med 36:135-153.
48. Wagih AM, Elguindy AM (2016) Percutaneous Reconstruction of the Anterolateral Ligament of the Knee With a Polyester Tape. Arthrosc Tech 5:e691-e697.

Table 1. Tunnel length and minimal distance between ALL and ACL tunnels.

	Convergence		Non-convergence		
	ALL Tunnel Length	ACL Tunnel Length	Minimal Distance	ALL Tunnel Length	ACL Tunnel Length
0° coronal / 20° axial	15.94 (13.67-18.20)	16.70 (15.49-17.93)	1.34 (0.23-2.44)	19.73 (18.49-20.98)	17.14 (13.64-20.63)
30° coronal / 30° axial	15.58 (13.17-17.99)	22.97 (20.57-25.39)	3.34 (2.23-4.45)	16.80 (12.71-20.88)	23.79 (20.13-27.44)
P value	n.s.	<0.001	<0.001	n.s.	<0.001

Notes. All data are expressed in millimeters as mean (95% CI). In non-convergence tunnels, tunnel length is measured from the entry point to the point where the tunnel is at the shortest distance to the other tunnel.