CURRENT CONCEPTS REVIEW

Anatomical Individualized ACL Reconstruction

Amir Ata Rahnemai-Azar, MD; Soheil Sabzevari, MD; Sebastián Irarrázaval, MD;
Tom Chao, MD; Freddie H. Fu, MD, DSc (Hon.), DPs (Hon.)

Research performed at Department of Orthopedic Surgery, University of Pittsburgh Medical Center, Pittsburgh, USA

Received: 21 July 2016 *Accepted: 31 August 2016*

Abstract

The anterior cruciate ligament (ACL) is composed of two bundles, which work together to provide both antero-posterior and rotatory stability of the knee. Understanding the anatomy and function of the ACL plays a key role in management of patients with ACL injury. Anatomic ACL reconstruction aims to restore the function of the native ACL. Femoral and tibial tunnels should be placed in their anatomical location accounting for both the native ACL insertion site and bony landmarks. One main component of anatomical individualized ACL reconstruction is customizing the treatment according to each patient's individual characteristics, considering preoperative and intraoperative evaluation of the native ACL and knee bony anatomy. Anatomical individualized reconstruction surgery should also aim to restore the size of the native ACL insertion as well. Using this concept, while single bundle ACL reconstruction can restore the function of the ACL in some patients, double bundle reconstruction is indicated in others to achieve optimal outcome.

Keywords: Anatomic ACL reconstruction surgery, Anterior Cruciate Ligament, Individualized medicine

Introduction

Anterior cruciate ligament injury (ACL) is one of the most common ligamentous lesions of the knee. ACL injury is associated with increased risk of menisci and cartilage degeneration, and future development of osteoarthritis (1, 2). The management of these injuries is generally either non-operative rehabilitation or surgical reconstruction. The decision to perform reconstruction surgery is based on the presence of concomitant injuries, the patient's subjective and objective sense of instability, and the desired level of physical and sports activity. This article will focus on the surgical treatment of these patients with special focus on the concept of anatomical individualized ACL reconstruction.

Anatomy and Function of the ACL

The ACL is the primary structure that moderates anteroposterior and rotatory stability of the knee, especially in lower flexion angles (3). ACL is composed of two bundles, the anteromedial (AM) and posterolateral (PL) bundles, which are named based on their respective insertion location on the tibia. The femoral insertion of the ACL is oval shaped and is usually smaller than the fan shaped tibial insertion site [Figure 1]. There are two prominent osseous ridges on the lateral wall of intercondylar notch that denote the borders of the femoral ACL insertion site: the lateral intercondylar ridge marks the anterior border of the ACL, and the lateral bifurcate ridge runs perpendicular to the lateral intercondylar ridge and separates the femoral attachment of the AM and PL bundles (4).

The AM and PL bundles work together as a unit to provide both anterior stability and rotatory stability of the knee in response to complex loads throughout the entire range of knee motion. More specifically, the PL bundle plays a more prominent role in controlling antero-posterior stability and rotation in lower flexion angles (5). The aim of ACL reconstruction surgeries is to restore the function of the both bundles in order to reestablish the dynamic stability of the knee joint.

Non-operative treatment

There is a group of patients with ACL injury generally referred as "copers" that can asymptomatically return to pre-injury level of activity without reconstruction surgery. It has been demonstrated that these patients have

Corresponding Author: Freddie H. Fu, Department of Orthopaedic Surgery, University of Pittsburgh, Kaufman Building Suite 1011, 3471 Fifth Avenue, Pittsburgh, PA 15213, USA
Email: ffu@upmc.edu

THE ONLINE VERSION OF THIS ARTICLE
ABJS.MUMS.AC.IR

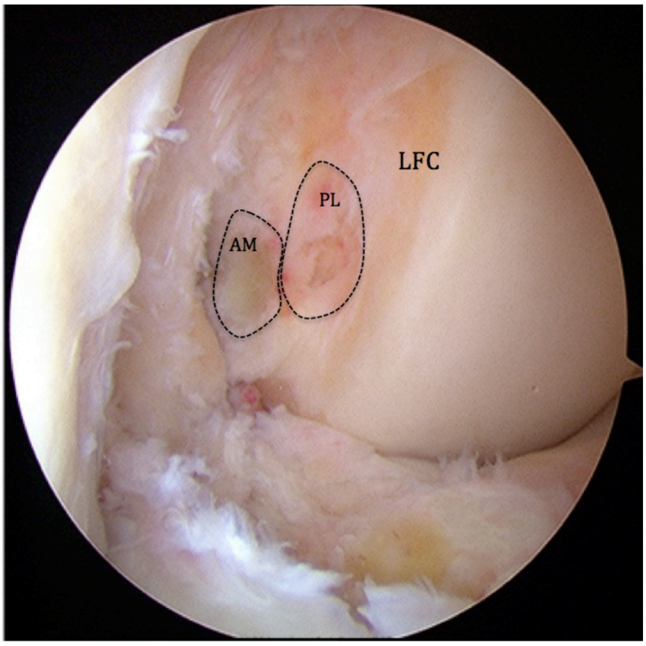

Figure 1. Femoral insertion of the ACL, the "AM" and "PL" denotes the corresponding insertion of posterolateral (PL) and anteromedial (AM) bundle of the ACL. LCF: lateral femoral condyle.

comparable radiographic evidence of osteoarthritis and functional outcome scores to those that have undergone ACL reconstruction surgery (6). One recent randomized clinical trial demonstrated that patients undergoing rehabilitation with delayed optional reconstruction have comparable results to those undergoing early ACL reconstruction surgery (7). Although previous studies have developed criteria to identify "copers" (8, 9), based on current evidence, ACL reconstruction surgery is recommended in management of active young adults with ACL tear to treat symptomatic instability (Strength of Recommendation: Moderate) (10).

Anatomic ACL Reconstruction Concept

Traditional ACL reconstruction surgeries were performed non-anatomically by placing the graft outside of the native insertion of the ACL. The anatomic ACL reconstruction concept asserts that the native ACL must be restored following four fundamental principles: (1) restore the two functional bundles of AM and PL, (2) restore the native insertion sites of the ACL by placing the tunnels in the true anatomic positions by appropriate sized graft, (3) correctly tension each bundle according to knee flexion angle, (4) individualize surgery for each patient considering specific anatomy and needs of each patient.

Augmentation Reconstruction Surgery

If the ACL is partially injured, augmentation reconstruction surgery can be considered by focusing attention on exclusive reconstruction of the injured bundle. Evaluation of joint laxity before surgery and careful probing of the remnants during arthroscopic examination can help to determine the functionality of the remaining fibers. Preserving the intact bundle during augmentation surgery may have benefits over complete reconstruction, such as maintaining proprioceptive fibers, increasing biomechanical strength, and enhancing biological healing potential (11, 12). However studies with long term follow-up are needed to assess the outcomes of these patients (13).

Single Bundle or Double Bundle Reconstruction Surgery

As noted above, one of the main elements of anatomic reconstruction surgery is to restore the native ACL insertion site. Using a single reconstruction technique such as single- or double-bundle ACL reconstruction for all patients regardless of the circumstances is not recommended due to variation of anatomy and injury pattern between individuals. One recent study demonstrated that single bundle reconstruction surgery restores only 70-79% of the native ACL insertion size (14). The need to restore the bulk of the native ACL size is supported by previous reports that showed higher rate of reconstruction failure with smaller grafts (15).

The decision making flowchart in management of ACL injured patients has been previously described in detail (16). Generally, double bundle reconstruction surgery is considered if the patient has a large tibial insertion site size (anteroposterior length >14 mm), large intercondylar notch (length and width >14 mm), absence of concomitant ligament injuries, absence of concomitant arthritic changes (Kellgren Lawrence grade <3), absence of severe bone bruising, and closed physes (16-18). The SB technique is indicated for small tibial insertion sites (<14 mm in length), narrow notches (<12 mm in width), multi-ligamentous injuries, severe bone bruising, severe arthritic changes (grade 3 or higher) and open physes.

Several biomechanical studies report better restoration of knee kinematics with double bundle reconstruction surgery compared to single bundle reconstruction surgery (19-21). In 2012, Hussein et al. performed a prospective randomized clinical trial in ACL injured patients and followed them for a mean period of 51.15 months (22). It was revealed that anatomical double bundle reconstruction surgery results in better restoration of anteroposterior and rotational laxity compared to anatomic single bundle reconstruction. Meta-analysis of clinical studies also support that double bundle reconstruction surgery provides better antero-posterior stability and mid-term outcome scores compared to single bundle reconstruction surgery, however long-term outcome of these patients still need to be determined (23, 24). It should be noted that prospective studies demonstrated no difference among single or double bundle reconstruction techniques in terms of restoration of the anteroposterior and rotational laxity when patients are individually assigned to treatment groups based on the size of the ACL native insertion site and the intercondylar notch width (25). These findings further emphasize the need for individualized treatment of patients.

Reconstruction Technique

Portals

Three-portal approach is used during reconstruction

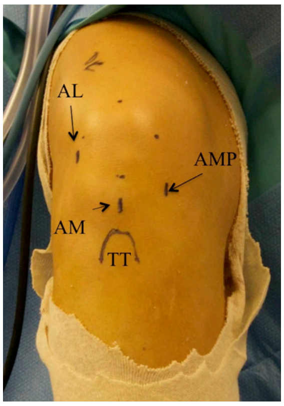

Figure 2. Set up of the right knee in operating position demonstrating the location of the three portals during ACL reconstruction surgery. The exact locations of the portals are finalized during surgery based on individual's anatomy. AMP: accessory medial portal. AM: anteromedial. AL: anterolateral. TT: tibial tuberosity.

surgery: 1) anterolateral (AL) portal, 2) anteromedial (AM) portal and 3) accessory medial portal (AMP) [Figure 2] (26). The AL portal is positioned 1cm lateral to the patellar tendon and at the level of inferior pole of the patella. The AL portal should be high enough to avoid the Hoffa's fat pad. The AM portal is aimed towards the central portion of the notch in the coronal plane and in the lower third of the notch in the proximal to distal direction. Application of a spinal needle under arthroscopic visualization could help in correct placement of AM portal. The AMP should be positioned superior to the medial joint line, approximately two centimeters medial to the medial border of the patellar tendon. Once again, the use of a spinal needle is essential for the placement of the AMP. There should be about 2 mm distance between spinal needle and lateral femoral condyle to avoid any injury during instrumentation. The visualization through AMP removes the need for notchplasty. Indeed, surgeons are advised not to perform notchplasty, as it will remove the important anatomical landmarks needed for tunnel placement. Furthermore, there is possibility of regrowth and overgrowth of the notch after notchplasty, which may result in abnormal forces on the graft, which eventually may cause reconstruction failure.

While AMP provides the best visualization of the native ACL insertion sites, all portals are utilized to obtain a complete view of the ACL origin and insertion sites. During majority of the surgery however, AMP portal is used for instrumentation and allows the AM portal to be used for visualization of the lateral wall of the intercondylar notch and the femoral insertion site.

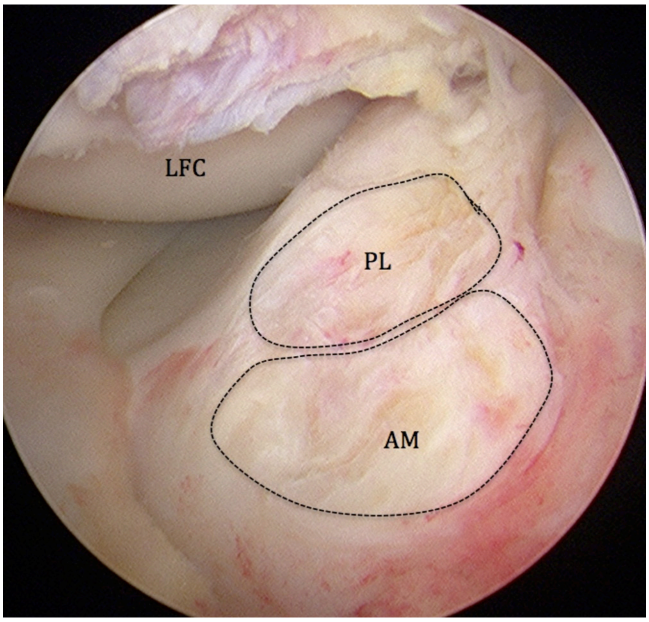

Figure 3. Tibial insertion of the ACL, the "AM" and "PL" denotes the corresponding insertion of posterolateral (PL) and anteromedial (AM) bundle of the ACL. Landmarks of the native ACL play key role in placing the tunnels in anatomic position. LFC: lateral femoral condyle.

Graft Selection

The typical grafts available for ACL reconstruction surgery include patellar tendon autograft, quadriceps tendon autograft, hamstrings tendon autograft and different kinds of allograft (27-29) [Table 1]. Of these options the bone-patellar tendon-bone graft cannot be used for double bundle reconstruction surgery. The graft of choice is individually selected based on age, gender, type and level of activity, desired time of return to sport and the preoperative measurement of native ACL insertion size.

Thickness of the quadriceps and patellar tendon measured preoperatively on sagittal MRI can guide surgeons in this regard(30). The graft healing time also differs among different types of the grafts; therefore

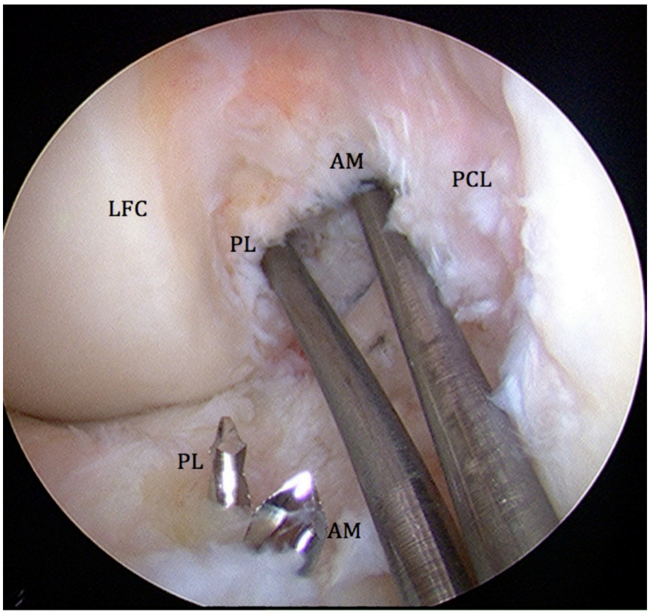

Figure 4. Guide pins during double bundle reconstruction surgery. Guide pins are placed in the position of the anteromedial (AM) and posterolateral (PL) bundle of the ACL. The femoral tunnels are drilled. LFC: lateral femoral condyle, PCL: posterior cruciate ligament.

Table 1. Graft options for Anatomic ACL Reconstruction (27-29)

Graft	Advantages	Disadvantages
Quadriceps tendon	- Large graft Option of a one-sided bone block	- Invasive, large incision - Risk of patellar fracture
Hamstring	- Ease of harvest - Cosmesis - Minimal donor site morbidity	- Soft-tissue healing - Graft size can be unpredictable - Not suitable for certain athletes who rely heavily on their hamstring muscles - Less stiffness than native ACL
Patellar Tendon	- Bone to bone healing - Large graft	- Single bundle only - Residual kneeling pain - Graft-tunnel mismatch - Risk of patellar fracture
Allograft	- No donor site morbidity - Available in various types and sizes - Shortens operative time	- Risk of disease transmission - Healing time - Increased risk of rerupture in irradiated allografts, especially in younger patients(10, 29, 59, 60) - Cost

desired time of return to sport is one of the elements in graft selection (31). Surgeons should consider that several studies reported higher failure rate in ACL reconstruction performed by allograft compared to autograft, especially in younger and highly active patients (10, 32). Although still controversial, a recent meta analysis has linked higher failure of allografts to processing procedures such as irradiation (33).

Finally, the type and size of the graft is determined during reconstruction surgery considering the measurements of the native ACL insertions and the bony morphology of the patient's knee.

Tunnel Placement

Technical errors including non-anatomical tunnel placement and inadequate fixation technique are among the main reasons of graft failure after reconstruction surgery (34). Improper placement of the tunnel can affect the amount of the forces that the graft will experience after reconstruction surgery(35). During reconstruction surgery the remnants of the native ACL and bony ridges of the lateral intercondylar notch (lateral intercondylar ridge and lateral bifurcate ridge) are important landmarks in identifying the tunnel positions [Figure 3](36, 37).

If double bundle reconstruction is indicated, the femoral and tibial tunnels are created on the respective insertion site of the AM and PL bundles [Figure 4]. The drilling tunnels starts with femoral tunnel of the PL bundle through AMP. Then the tibial AM and PL tunnel are drilled with the tibial guide set at 55º and 45°, respectively. The distance between AM and PL bundle tunnels on the tibial extra articular cortex should be at least 2 cm to allow for a bony bridge. Finally the femoral tunnel of the AM bundle is drilled through the AMP.

If single bundle reconstruction is planned, the femoral tunnel is drilled at the center of the femoral insertion site, midway between the AM and PL bundles. Likewise the tibial tunnel is drilled at the center of the tibial insertion site, midway between the center of the AM and PL insertion sites, with the tibial guide set at 55°.

Graft Fixation

Soft tissue grafts are typically fixed by application of suspensory devices in the femoral side. Although suspensory device have higher load to failure and stiffness compared to interference screws, the clinical outcome for both devices have been reported to be comparable (38, 39). Biomechanical studies however, have reported different mechanical properties among suspensory devices (40). Femoral site fixation of grafts with bone plugs is commonly accomplished with metal or bioabsorbable interference screws. Metal interference screws have been suggested as the standard fixation method with bone-patellar tendon-bone autograft (41). Fixation of the tibial site of the graft is typically performed by application of interference screws (most commonly bioabsorbable screws) due to ease of insertion and minimal slippage of the graft.

There is still no standard protocol regarding pretensioning or preconditioning of the graft, nor does consensus exist regarding the amount of tension during the graft fixation (42, 43). The knee flexion angle for graft fixation is determined with respect to the tension pattern of the native ACL. However there is no consensus in the current literature regarding knee flexion angle for fixation of the graft. For single bundle reconstruction, the graft is generally fixed at 0-20º of knee flexion (44).

Extra-articular reconstruction surgery

Recent reports regarding presence of a distinct ligamentous structure in the anterolateral capsule area or anterolateral ligament (ALL), have fueled surgeons to perform extra-articular reconstruction surgeries in addition to intra-articular ACL reconstruction. However, the anatomical characteristics and biomechanical function of this structure have been debated (45-48). Two recent meta-analysis that compared isolated ACL reconstruction with combined extra-articular tenodesis (EAT) and ACL reconstruction reported decreased laxity for combined EAT patients; however, no difference was found in functional outcomes or return to play (49, 50). It has been demonstrated that a potential risk with EAT involves over-constraining knee range of motion in respect to internal rotation (51-53). Indeed, several studies revealed that ACL reconstruction over-constrain the internal rotation of the knee during in vivo activities (54). These findings further criticize the logic of enhancing an additional restraint to the lateral side of the knee. Therefore the decision to perform additional extra articular reconstruction surgeries should be carefully made until greater consensus is achieved with future research.

Future directions

Development of clinically applicable devices to quantify rotatory laxity has the potential to improve the management of patients with ACL injury (55, 56). Employing these technologies, a cohort of ACL injured patients demonstrated wide range of kinematics during rotatory laxity testing (57). These findings support previous findings from more classic articles regarding the presence of a specific "envelope of motion" in each patient (58). Quantification of rotatory laxity in ACL injured patients could help in assigning patients to different treatment groups as well as screening the healing during post-operative rehabilitation. Future studies need to be performed to improve treatment protocols based on quantitative rotatory laxity measurements.

Amir Ata Rahnemai-Azar MD
Soheil Sabzevari MD
Sebastián Irarrázaval MD
Tom Chao MD
Freddie H. Fu MD, DSc (Hon.), DPs (Hon.)
Department of Orthopaedic Surgery, University of Pittsburgh Medical Center, Pittsburgh, USA

References

1. Ajuied A, Wong F, Smith C, Norris M, Earnshaw P, Back D, et al. Anterior cruciate ligament injury and radiologic progression of knee osteoarthritis: a systematic review and meta-analysis. The American journal of sports medicine. 2014;42(9):2242-52.
2. Atarod M, Frank CB, Shrive NG. Increased meniscal loading after anterior cruciate ligament transection in vivo: a longitudinal study in sheep. Knee. 2015;22(1):11-7.
3. Lipke JM, Janecki CJ, Nelson CL, McLeod P, Thompson C, Thompson J, et al. The role of incompetence of the anterior cruciate and lateral ligaments in anterolateral and anteromedial instability. A biomechanical study of cadaver knees. J Bone Joint Surg Am. 1981;63(6):954-60.
4. Fu FH, Jordan SS. The lateral intercondylar ridge--a key to anatomic anterior cruciate ligament reconstruction. J Bone Joint Surg Am. 2007;89(10):2103-4.
5. Zantop T, Herbort M, Raschke MJ, Fu FH, Petersen W. The role of the anteromedial and posterolateral bundles of the anterior cruciate ligament in anterior tibial translation and internal rotation. The American journal of sports medicine. 2007;35(2):223-7.
6. Chalmers PN, Mall NA, Moric M, Sherman SL, Paletta GP, Cole BJ, et al. Does ACL reconstruction alter natural history?: A systematic literature review of long-term outcomes. J Bone Joint Surg Am. 2014;96(4):292-300.
7. Frobell RB, Roos EM, Roos HP, Ranstam J, Lohmander LS. A randomized trial of treatment for acute anterior cruciate ligament tears. The New England journal of medicine. 2010;363(4):331-42.
8. Fitzgerald GK, Axe MJ, Snyder-Mackler L. Proposed practice guidelines for nonoperative anterior cruciate ligament rehabilitation of physically active individuals. J Orthop Sports Phys Ther. 2000;30(4):194-203.
9. Fitzgerald GK, Axe MJ, Snyder-Mackler L. A decision-making scheme for returning patients to high-level activity with nonoperative treatment after anterior cruciate ligament rupture. Knee Surg Sports Traumatol Arthrosc. 2000;8(2):76-82.
10. Shea KG, Carey JL, Richmond J, Sandmeier R, Pitts RT, Polousky JD, et al. The American Academy of Orthopaedic Surgeons evidence-based guideline on management of anterior cruciate ligament injuries. J Bone Joint Surg Am. 2015;97(8):672-4.
11. Adachi N, Ochi M, Uchio Y, Sumen Y. Anterior cruciate ligament augmentation under arthroscopy. A minimum 2-year follow-up in 40 patients. Arch Orthop Trauma Surg. 2000;120(3-4):128-33.
12. Ochi M, Adachi N, Uchio Y, Deie M, Kumahashi N, Ishikawa M, et al. A minimum 2-year follow-up after selective anteromedial or posterolateral bundle anterior cruciate ligament reconstruction. Arthroscopy. 2009;25(2):117-22.
13. Hu J, Qu J, Xu D, Zhang T, Zhou J, Lu H. Clinical outcomes of remnant preserving augmentation in anterior cruciate ligament reconstruction: a systematic review. Knee Surg Sports Traumatol Arthrosc. 2014;22(9):1976-85.
14. Middleton KK, Muller B, Araujo PH, Fujimaki Y, Rabuck SJ, Irrgang JJ, et al. Is the native ACL insertion site "completely restored" using an individualized approach to single-bundle ACL-R? Knee Surg Sports Traumatol Arthrosc. 2015;23(8):2145-50.
15. Magnussen RA, Lawrence JT, West RL, Toth AP, Taylor DC, Garrett WE. Graft size and patient age are predictors of early revision after anterior cruciate ligament reconstruction with hamstring autograft. Arthroscopy. 2012;28(4):526-31.
16. van Eck CF, Lesniak BP, Schreiber VM, Fu FH. Anatomic single-and double-bundle anterior cruciate ligament

reconstruction flowchart. Arthroscopy: The Journal of Arthroscopic & Related Surgery. 2010;26(2):258-68.
17. Shen W, Forsythe B, Ingham SM, Honkamp NJ, Fu FH. Application of the anatomic double-bundle reconstruction concept to revision and augmentation anterior cruciate ligament surgeries. J Bone Joint Surg Am. 2008;90(Supplement 4):20-34.
18. Kopf S, Pombo MW, Szczodry M, Irrgang JJ, Fu FH. Size variability of the human anterior cruciate ligament insertion sites. The American journal of sports medicine. 2011;39(1):108-13.
19. Zelle BA, Vidal AF, Brucker PU, Fu FH. Double-bundle reconstruction of the anterior cruciate ligament: anatomic and biomechanical rationale. J Am Acad Orthop Surg. 2007;15(2):87-96.
20. Yagi M, Wong EK, Kanamori A, Debski RE, Fu FH, Woo SL. Biomechanical analysis of an anatomic anterior cruciate ligament reconstruction. The American journal of sports medicine. 2002;30(5):660-6.
21. Morimoto Y, Ferretti M, Ekdahl M, Smolinski P, Fu FH. Tibiofemoral joint contact area and pressure after single- and double-bundle anterior cruciate ligament reconstruction. Arthroscopy. 2009;25(1):62-9.
22. Hussein M, van Eck CF, Cretnik A, Dinevski D, Fu FH. Prospective randomized clinical evaluation of conventional single-bundle, anatomic single-bundle, and anatomic double-bundle anterior cruciate ligament reconstruction 281 cases with 3-to 5-year follow-up. The American journal of sports medicine. 2012;40(3):512-20.
23. Desai N, Bjornsson H, Musahl V, Bhandari M, Petzold M, Fu FH, et al. Anatomic single- versus double-bundle ACL reconstruction: a meta-analysis. Knee Surg Sports Traumatol Arthrosc. 2014;22(5):1009-23.
24. Chen G, Wang S. Comparison of single-bundle versus double-bundle anterior cruciate ligament reconstruction after a minimum of 3-year follow-up: a meta-analysis of randomized controlled trials. Int J Clin Exp Med. 2015;8(9):14604-14.
25. Hussein M, van Eck CF, Cretnik A, Dinevski D, Fu FH. Individualized Anterior Cruciate Ligament Surgery A Prospective Study Comparing Anatomic Single-and Double-Bundle Reconstruction. The American journal of sports medicine. 2012;40(8):1781-8.
26. Cohen SB, Fu FH. Three-portal technique for anterior cruciate ligament reconstruction: use of a central medial portal. Arthroscopy. 2007;23(3):325 e1-5.
27. Steiner ME, Hecker AT, Brown CH, Hayes WC. Anterior cruciate ligament graft fixation comparison of hamstring and patellar tendon grafts. The American journal of sports medicine. 1994;22(2):240-7.
28. Beynnon BD, Johnson RJ, Fleming BC, Kannus P, Kaplan M, Samani J, et al. Anterior cruciate ligament replacement: comparison of bone-patellar tendon-bone grafts with two-strand hamstring grafts. J Bone Joint Surg Am. 2002;84(9):1503-13.
29. Adam F, Pape D, Schiel K, Steimer O, Kohn D, Rupp S. Biomechanical properties of patellar and Hamstring graft tibial fixation techniques in anterior cruciate ligament reconstruction experimental study with roentgen stereometric analysis. The American journal of sports medicine. 2004;32(1):71-8.
30. Araujo P, van Eck CF, Torabi M, Fu FH. How to optimize the use of MRI in anatomic ACL reconstruction. Knee Surgery, Sports Traumatology, Arthroscopy. 2013;21(7):1495-501.
31. Ma Y, Murawski CD, Rahnemai-Azar AA, Maldjian C, Lynch AD, Fu FH. Graft maturity of the reconstructed anterior cruciate ligament 6 months postoperatively: a magnetic resonance imaging evaluation of quadriceps tendon with bone block and hamstring tendon autografts. Knee Surg Sports Traumatol Arthrosc. 2015;23(3):661-8.
32. Kaeding CC, Aros B, Pedroza A, Pifel E, Amendola A, Andrish JT, et al. Allograft versus autograft anterior cruciate ligament reconstruction predictors of failure from a MOON prospective longitudinal cohort. Sports Health: A Multidisciplinary Approach. 2011;3(1):73-81.
33. Zeng C, Gao SG, Li H, Yang T, Luo W, Li YS, et al. Autograft Versus Allograft in Anterior Cruciate Ligament Reconstruction: A Meta-analysis of Randomized Controlled Trials and Systematic Review of Overlapping Systematic Reviews. Arthroscopy. 2016;32(1):153-63 e18.
34. Chen JL, Allen CR, Stephens TE, Haas AK, Huston LJ, Wright RW, et al. Differences in mechanisms of failure, intraoperative findings, and surgical characteristics between single- and multiple-revision ACL reconstructions: a MARS cohort study. The American journal of sports medicine. 2013;41(7):1571-8.
35. Araujo PH, Asai S, Pinto M, Protta T, Middleton K, Linde-Rosen M, et al. ACL graft position affects in situ graft force following ACL reconstruction. J Bone Joint Surg Am. 2015;97(21):1767-73.
36. Ferretti M, Ekdahl M, Shen W, Fu FH. Osseous landmarks of the femoral attachment of the anterior cruciate ligament: an anatomic study. Arthroscopy: The Journal of Arthroscopic & Related Surgery. 2007;23(11):1218-25.
37. Ferretti M, Doca D, Ingham SM, Cohen M, Fu FH. Bony and soft tissue landmarks of the ACL tibial insertion site: an anatomical study. Knee Surgery, Sports Traumatology, Arthroscopy. 2012;20(1):62-8.
38. Colvin A, Sharma C, Parides M, Glashow J. What is the best femoral fixation of hamstring autografts in anterior cruciate ligament reconstruction?: a meta-analysis. Clinical Orthopaedics and Related Research®. 2011;469(4):1075-81.
39. Ibrahim SAR, Ghafar SA, Marwan Y, Mahgoub AM, Al Misfer A, Farouk H, et al. Intratunnel Versus Extratunnel Autologous Hamstring Double-Bundle Graft for Anterior Cruciate Ligament Reconstruction A Comparison of 2 Femoral Fixation Procedures. The American journal of sports medicine. 2015;43(1):161-8.
40. Johnson JS, Smith SD, LaPrade CM, Turnbull TL, LaPrade RF, Wijdicks CA. A biomechanical comparison of femoral cortical suspension devices for soft tissue anterior cruciate ligament reconstruction under high loads. The American journal of sports medicine. 2015;43(1):154-60.
41. Matsumoto A, Yoshiya S, Muratsu H, Matsui N, Yagi M, Kuroda R, et al. Mechanical evaluation of a soft tissue

interference screw with a small diameter: significance of graft/bone tunnel cross-sectional area ratio. Knee Surgery, Sports Traumatology, Arthroscopy. 2006;14(4):330-4.
42. Jisa KA, Williams BT, Jaglowski JR, Turnbull TL, LaPrade RF, Wijdicks CA. Lack of consensus regarding pretensioning and preconditioning protocols for soft tissue graft reconstruction of the anterior cruciate ligament. Knee Surgery, Sports Traumatology, Arthroscopy. 2015:1-8.
43. Arneja S, McConkey MO, Mulpuri K, Chin P, Gilbart MK, Regan WD, et al. Graft tensioning in anterior cruciate ligament reconstruction: a systematic review of randomized controlled trials. Arthroscopy: The Journal of Arthroscopic & Related Surgery. 2009;25(2):200-7.
44. Austin JC, Phornphutkul C, Wojtys EM. Loss of knee extension after anterior cruciate ligament reconstruction: effects of knee position and graft tensioning. J Bone Joint Surg Am. 2007;89(7):1565-74.
45. Spencer L, Burkhart TA, Tran MN, Rezansoff AJ, Deo S, Caterine S, et al. Biomechanical analysis of simulated clinical testing and reconstruction of the anterolateral ligament of the knee. The American journal of sports medicine. 2015;43(9):2189-97.
46. Kittl C, El-Daou H, Athwal KK, Gupte CM, Weiler A, Williams A, et al. The role of the anterolateral structures and the ACL in controlling laxity of the intact and ACL-deficient knee. The American journal of sports medicine. 2016;44(2):345-54.
47. Dombrowski ME, Costello JM, Ohashi B, Murawski CD, Rothrauff BB, Arilla FV, et al. Macroscopic anatomical, histological and magnetic resonance imaging correlation of the lateral capsule of the knee. Knee Surgery, Sports Traumatology, Arthroscopy. 2015:1-7.
48. Rasmussen MT, Nitri M, Williams BT, Moulton SG, Cruz RS, Dornan GJ, et al. 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. The American journal of sports medicine. 2016;44(3):585-92.
49. Rezende FC, de Moraes VY, Martimbianco AL, Luzo MV, da Silveira Franciozi CE, Belloti JC. Does Combined Intra- and Extraarticular ACL Reconstruction Improve Function and Stability? A Meta-analysis. Clin Orthop Relat Res. 2015;473(8):2609-18.
50. Hewison CE, Tran MN, Kaniki N, Remtulla A, Bryant D, Getgood AM. Lateral Extra-articular Tenodesis Reduces Rotational Laxity When Combined With Anterior Cruciate Ligament Reconstruction: A Systematic Review of the Literature. Arthroscopy. 2015;31(10):2022-34.
51. Arilla F, Guenther D, Yacuzzi C, Rahnemai-Azar A, Fu F, Debski R, et al. Effects Of Anterolateral Capsular Injury And Extra-Articular Tenodesis On Knee Kinematics During Physical Examination. American Orthopaedic Society for Sports Medicine; 2015; Orlando, FL, USA: Orthopaedic Journal of Sports Medicine; 2015. p. 2325967115S00032.
52. Rahnemai-Azar AA, Miller RM, Guenther D, Fu FH, Lesniak BP, Musahl V, et al. Structural properties of the anterolateral capsule and iliotibial band of the knee. The American journal of sports medicine. 2016;44(4):892-7.
53. Branch T, Lavoie F, Guier C, Branch E, Lording T, Stinton S, et al. Single-bundle ACL reconstruction with and without extra-articular reconstruction: evaluation with robotic lower leg rotation testing and patient satisfaction scores. Knee Surg Sports Traumatol Arthrosc. 2015;23(10):2882-91.
54. Tashman S. Letter to the Editor: Does Combined Intra-and Extraarticular ACL Reconstruction Improve Function and Stability? A Meta-analysis. Clinical Orthopaedics and Related Research®. 2016;474(5):1339-40.
55. Muller B, Hofbauer M, Rahnemai-Azar AA, Wolf M, Araki D, Hoshino Y, et al. Development of computer tablet software for clinical quantification of lateral knee compartment translation during the pivot shift test. Computer methods in biomechanics and biomedical engineering. 2016;19(2):217-28.
56. Hoshino Y, Araujo P, Ahlden M, Samuelsson K, Muller B, Hofbauer M, et al. Quantitative evaluation of the pivot shift by image analysis using the iPad. Knee Surg Sports Traumatol Arthrosc. 2013;21(4):975-80.
57. Rahnemai-Azar AA, Naendrup JH, Soni A, Olsen A, Zlotnicki J, Musahl V. Knee instability scores for ACL reconstruction. Curr Rev Musculoskelet Med. 2016;9(2):170-7.
58. Bull AM, Earnshaw PH, Smith A, Katchburian MV, Hassan AN, Amis AA. Intraoperative measurement of knee kinematics in reconstruction of the anterior cruciate ligament. The Journal of bone and joint surgery British volume. 2002;84(7):1075-81.