Technical Note

Combined All-Inside Anterior Cruciate Ligament Reconstruction and Tibial Anterior Closing Wedge Tibial Osteotomy Using Staple Fixation: Surgical Technique

Tyler K. Khilnani, M.D., Tyler J. Uppstrom, M.D., Giuseppe Anzillotti, M.D., Morgan Rizy, B.S., Sabrina M. Strickland, M.D., and Andreas H. Gomoll, M.D.

Abstract: Failure of anterior cruciate ligament (ACL) reconstruction may be associated with a number of technical, anatomic, and patient-related factors. In particular, increased posterior tibial slope is associated with a greater risk of failure after both primary and revision ACL reconstruction, likely a result of increased load across the ACL graft. Surgical treatment of increased posterior tibial slope most commonly involves an anterior closing-wedge osteotomy of the proximal tibia, which may be performed in a simultaneous or staged fashion with ACL reconstruction. The authors describe a technique for combined, single-stage, all-inside ACL reconstruction and anterior closing-wedge osteotomy using staple fixation. The proposed technique provides adequate fixation of the osteotomy while minimizing hardware interference with the ACL tunnel placement and maximizing proximal femoral bone stock.

Anterior cruciate ligament (ACL) tears are common among athletes, especially those participating in pivoting sports.[1] Anterior cruciate ligament reconstruction (ACLR) is considered the standard of care for the treatment of ACL tears in young, active patients, and patients frequently achieve high functional outcomes and return-to-sport rates after surgery.[2,3] However, up to 11% of patients undergoing ACLR suffer ACL graft retear, requiring additional revision surgery, with increased morbidity for these patients reported.[4,5] One risk factor for revision ACLR is an increased posterior tibial slope (PTS) >12°, which results in excessive anterior tibial shift, thereby increasing the force across the ACL graft, ultimately resulting in graft attenuation and failure.[6-8] Tibial anterior closing-wedge osteotomy (ACWO) has been described as a versatile surgical technique to address excessive PTS.[9] The aim of this Technical Note is to illustrate our preferred surgical technique for a single-stage combined ACWO and all-inside ACLR.

From the Department of Sports Medicine, Hospital for Special Surgery, New York, New York, U.S.A. (T.K.K., T.J.U., G.A., M.R., S.M.S., A.H.G.); IRCCS Humanitas Research Hospital, Rozzano, Milan, Italy (G.A.); and Department of Biomedical Sciences, Humanitas University, Pieve Emanuele, Milan, Italy (G.A.).

Received May 27, 2024; accepted August 9, 2024.

Address correspondence to Dr. Tyler Khilnani, Department of Sports Medicine, Hospital for Special Surgery, New York, NY 10021. E-mail: KhilnaniT@hss.edu

2212-6287/24856
https://doi.org/10.1016/j.eats.2024.103262

Surgical Technique

Indications

Patients indicated for single-stage combined ACLR + ACWO are those with ACL graft retear with recurrent instability and PTS >12° with lack of tunnel widening (i.e., do not require tunnel bone grafting procedures, Fig 1). ACL graft retear was confirmed with both standard magnetic resonance imaging and clinical examination (Fig 2).

Graft Harvesting and Preparation

A 10-cm vertical incision extending distally from the proximal aspect of the tibial tubercle is created (Video 1). Incorporation of the patient's previous bone−patellar tendon−bone or hamstring harvest scars in addition to maintenance of appropriate width skin bridges are critical to minimize wound complications. Full-thickness subcutaneous flaps are raised medially and laterally. The authors' preferred graft choice in this

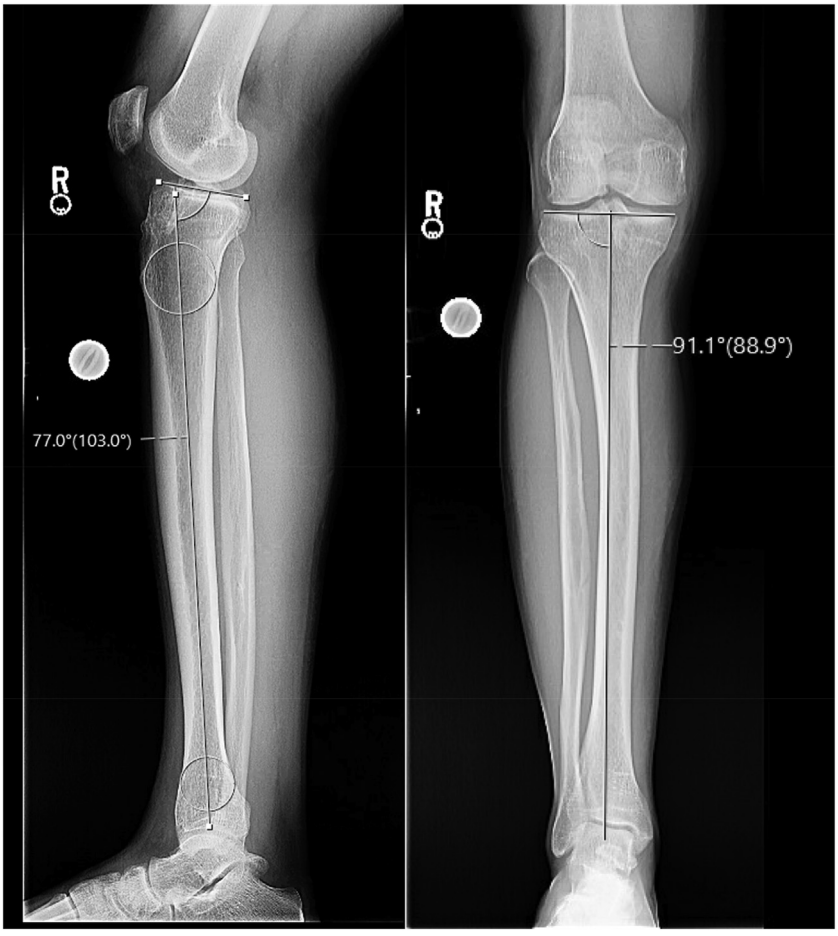

Fig 1. Anterior-posterior and lateral radiographs of the right knee and tibia demonstrating a case example of a 26-year-old man with 2 failed previous anterior cruciate ligament reconstruction reconstructions (first with bone—patellar tendon—bone autograft, followed by revision with hamstring allograft). Posterior tibial slope measures 13° on full-length lateral tibia radiographs (left), with minimal coronal plane malalignment on full length tibia anteroposterior radiographs (right).

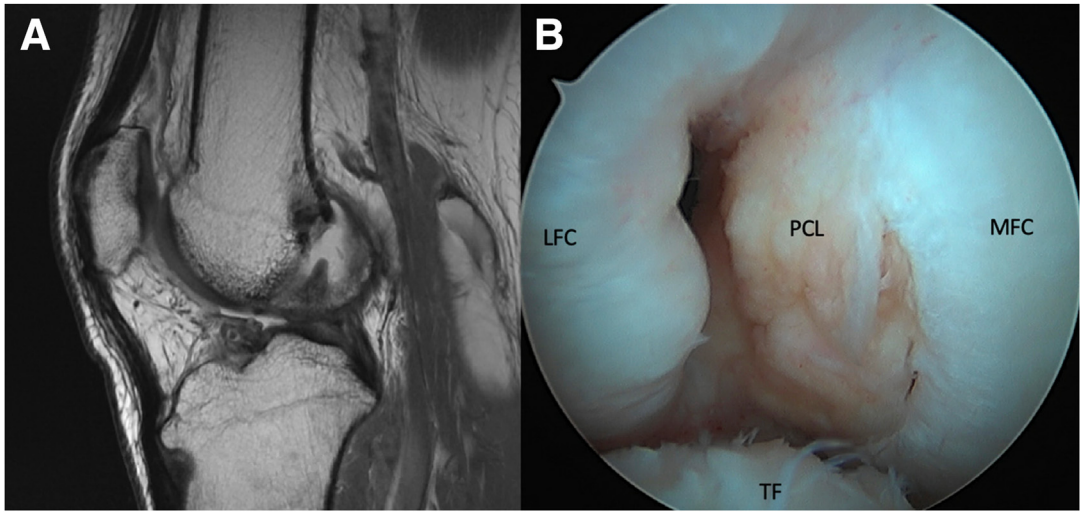

Fig 2. (A) Sagittal proton density magnetic resonance imaging of the right knee demonstrating lack of ACL graft in the femoral intercondylar notch, which was redemonstrated during arthroscopy through the anterolateral port, with no visible ACL fibers and significant overgrowth of the lateral aspect of the intercondylar notch.(ACL, anterior cruciate ligament reconstruction; LFC, lateral femoral condyle; MFC, medial femoral condyle; PCL, posterior cruciate ligament; TF, tibial footprint.)

setting is quadriceps tendon autograft, as it provides a robust all-soft-tissue graft. However, various graft choices may be used depending on the surgeon's preference. The graft is prepared in standard fashion, using 2 Arthrex TightRope buttons and GraftLink technique (Arthrex, Naples, FL). The authors are reluctant to use bone–patellar tendon–bone autograft in this setting, as this the tibial plus may risk compromising fixation of the ACWO.

Diagnostic Arthroscopy and ACL Tunnel Preparation

Standard anterolateral and anteromedial portals are created, and diagnostic arthroscopy is performed. Concomitant meniscal or chondral injuries are addressed as indicated on the basis of diagnostic arthroscopy; these procedures are beyond the scope of this Technical Note. After diagnostic arthroscopy, the medial aspect of the lateral femoral condyle and the tibial footprint are prepared using a combination of arthroscopic shaver and electrocautery. The femoral and tibial tunnels may then be prepared via the operating surgeon's preferred technique and reamer of choice. Of note, a key technical highlight of this combined ACLR + ACWO technique is that creation of the tibial ACL tunnel may occur before or after creation of the ACWO, as the ACWO is infratubercular, thereby leaving ample proximal bone stock for either option. In this setting, the author's preferred technique is using a flip cutter to create the tibial tunnel, in order to maximize proximal tibial bone stock.

Anterior Closing Wedge Osteotomy (ACWO)

The leg is placed over a radiolucent triangle. The fascia of the anterior compartment is incised along the length of the incision and the musculature of the anterior compartment is elevated from the lateral aspect of the tibia. A Hohmann retractor is placed around the posterolateral aspect of the tibia. Next, the remainder of the pes anserinus is identified and reflected posteriorly to expose the superficial medial collateral ligament (sMCL). The sMCL is undermined, but not detached distally, and is elevated. Exposure is then carried around the posteromedial aspect of the tibia and a Hohmann retractor is placed deep to the sMCL. Once the medial and lateral exposures are completed and retractors are in place, 2 short Kirschner (K)-wires are then placed from anterior to posterior across the proximal tibia using fluoroscopic guidance, without penetrating the posterior cortex. The first K-wire is started just distal to the tibial tubercle, aiming for the level of the waist of the fibular head on true lateral fluoroscopic image of the knee. The second K-wire is placed distally and aimed superiorly to converge toward the first wire, with the distance between sets of K-wires measured on the basis of preoperative planning for desired PTS correction (Fig 3).

The osteotomy is then performed using a short oscillating saw (Stryker 8 saw blade; Stryker, Corp, Kalamazoo, MI), with care taken to not perforate the posterior cortex (Fig 4). The wedge is then removed, and any additional bone is removed using a small pituitary rongeur and curettes.

After the osteotomy, the tourniquet is released to identify any significant bleeding. Once hemostasis is adequately achieved, the radiolucent triangle is removed, and the leg is placed flat on the operative table and the osteotomy is closed with a gentle extension force. A 4.5-mm screw is placed via lag technique from proximal to distal to compress the osteotomy, and

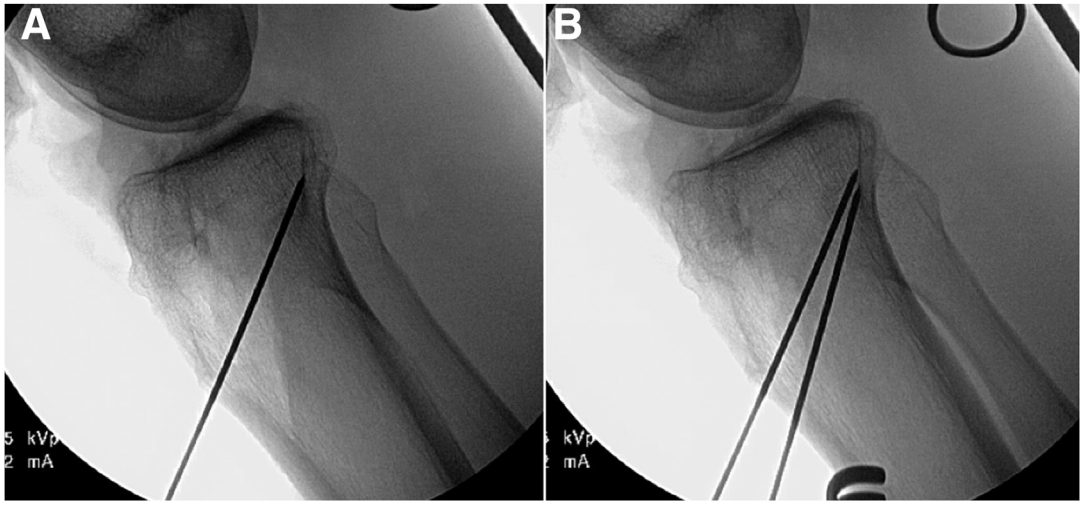

Fig 3. Intraoperative fluoroscopy demonstrating placement of proximal (A) and distal K-wires (B) using the lateral projection of the knee.

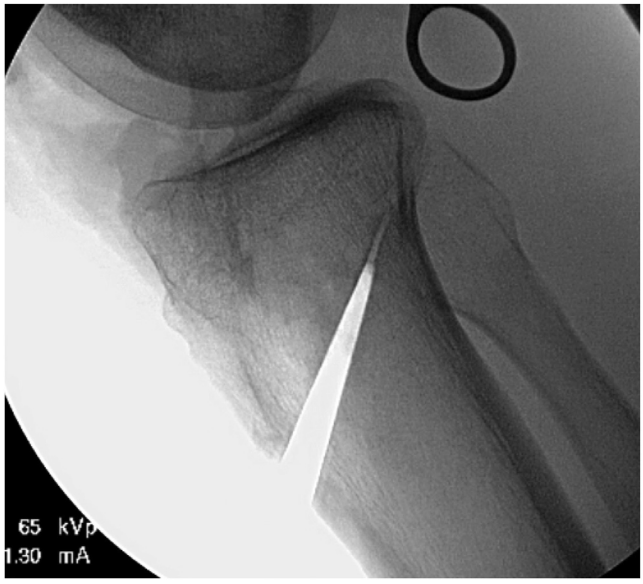

Fig 4. Intraoperative fluoroscopy demonstrating completed anterior closing-wedge osteotomy with intact posterior tibial cortex.

additional fixation is provided by 2 large Richards staples (Smith & Nephew, Inc., Watford, England), one placed medially and laterally (Fig 5 A and B).

ACL Graft Passage and Fixation

After completion of the ACWO, the ACL graft is passed through the anteromedial portal. First, the femoral button of the adjustable TightRope is flipped and fluoroscopy is used to confirm the femoral button is appropriately positioned on the lateral cortex before the graft is pulled into the femoral tunnel. Then, the distal end of the graft is passed through the tibial tunnel and tensioned accordingly. Both TightRopes are tensioned to create even suture lengths, ensuring there is be equal graft length in each tunnel. Arthroscopic visualization is used to confirm there is no evidence of graft impingement in full extension. At this point, the knee is examined to ensure appropriate stability. The wound is then irrigated and closed in layered fashion.

Postoperative Protocol

Patients are restricted to toe-touch weight bearing in a hinged knee brace locked in extension for ambulation the first 4 weeks postoperatively. At 4 weeks, patients may begin progressive weight-bearing as tolerated, with the goal of full weight-bearing without crutches by 6 weeks postoperatively. No open-chain exercises are allowed until 6 weeks postoperatively. Once full weight-bearing is achieved and radiographs demonstrate appropriate healing, a formal strengthening program is conducted over the next 3 to 9 months. Return to activities typically occurs between 9 and 12 months postoperatively (Fig 6).

Discussion

ACLR is considered the standard of care for the surgical intervention of ACL tears, although risk of retear is significant.[1] There are a number of technique-associated and patient-specific factors that increase the likelihood of ACL re-rupture, including increased PTS. Previous biomechanical studies have demonstrated ACWO may reduce anterior tibial translation[10-13] and the force experienced by the native ACL and ACL grafts.[14] In addition, multiple retrospective clinical studies have demonstrated significant improvements in PTS after ACWO, with correction of preoperative PTS of 13° to 18.5° to postoperative PTS of 4.4° to 9.2°.[10,15-18] In this setting, pivot shift grade, side-to-side anterior tibial translation and patient-reported outcome measures were also significantly improved postoperatively,

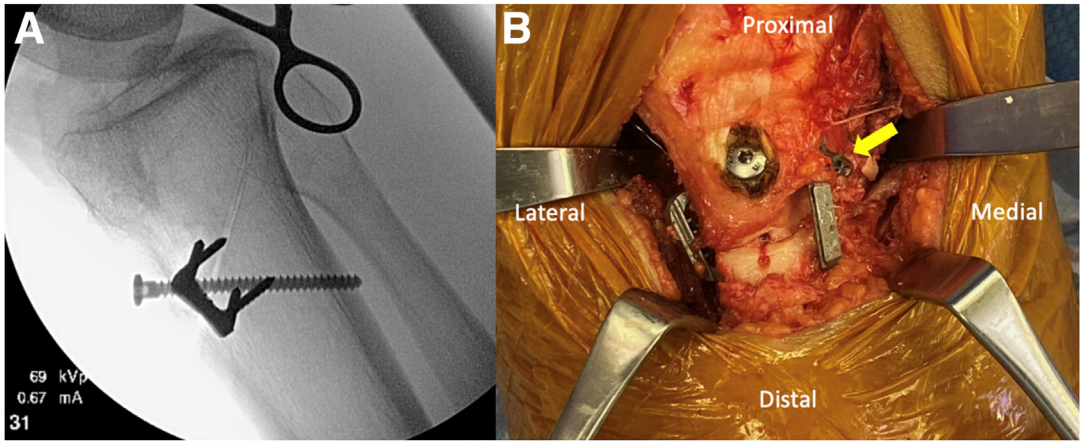

Fig 5. Reduction of the ACWO is visualized using intraoperative fluoroscopy demonstrating reduction and fixation of the ACWO (A), with interoperative photograph demonstrating the position of the 4.5-mm lag screw, medial staple and lateral staple with patient supine (B). Also noted is the tibial revision anterior cruciate ligament reconstruction button on the medial tibia (yellow arrow), which is not impeded by the medial ACWO staple. (ACWO, anterior closing-wedge osteotomy.)

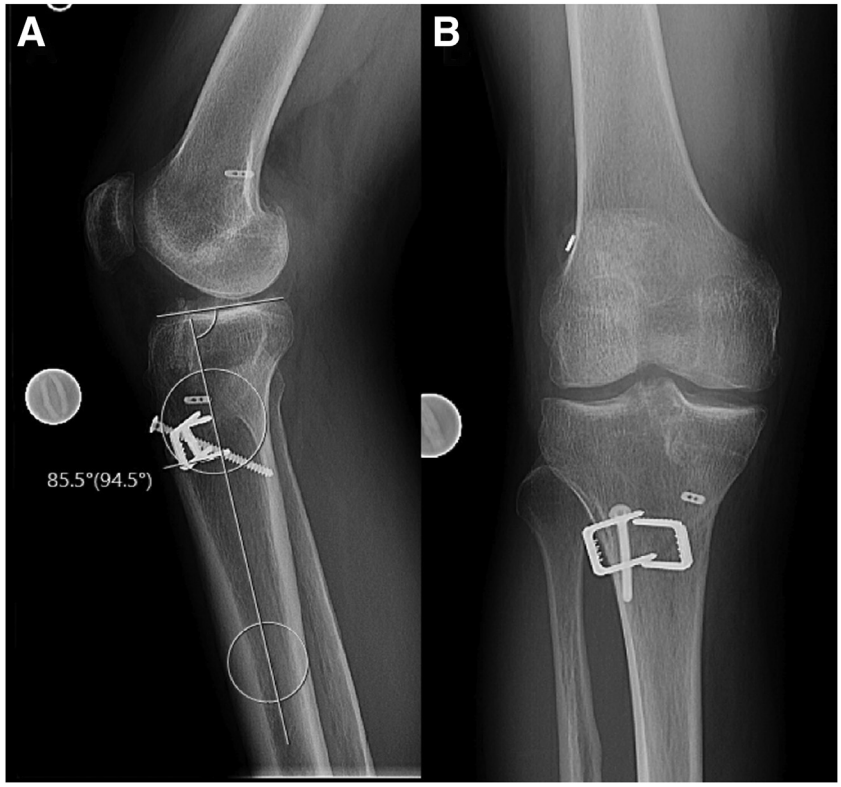

Fig 6. Three-month postoperative lateral (A) and anteroposterior (B) radiographs of the right knee demonstrating healed anterior closing-wedge osteotomy with correction of posterior tibial slope from 13° to 4.5°.

suggesting that the biomechanical results may be translatable to clinical practice.[10,15-17]

Currently, there is no agreement on the optimal surgical technique, including one- versus two-stage ACWO + ACLR, management of the tibial tubercle, osteotomy fixation strategy, and optimal amount of PTS correction.[10,15] Although there may be instances in which ACWO + ACLR should be performed in a two-stage fashion (i.e., tunnel widening requiring bone grafting), the authors prefer a one-stage technique, when possible, as this reduces the morbidity of multiple surgeries and has been associated with improved return-to-sport rates.[15-17] We present a one-stage ACWO + all-inside ACLR technique that offers several advantages (Table 1). First, the use of staple fixation (as opposed to a medial-sided plate) allows for optimization of ACLR tibial tunnel placement and prevents interference of ACWO fixation hardware and ACLR tunnel placement. Second, the use of suspensory fixation in the all-inside ACLR technique preserves proximal tibial bone stock and may decrease the risk of tunnel convergence with the ACWO, reducing risk of iatrogenic fracture.

Several surgical techniques have been described for management of the tibial tubercle in the setting of ACWO, including supratubercular, retrotubercular, and

Table 1. Advantages and Disadvantages of Our Combined ACWO + All-Inside ACLR Technique

Advantages	Disadvantages
Improved PTS to normal range reduces force experienced by the graft, reducing risk of graft rupture	Risk of iatrogenic tibia fracture is possibly increased when performing concurrent ACWO and tibial tunnel placement
Use of staple fixation avoids medial-sided tibial plate that may interfere with ACLR tibial tunnel	Longer operative times
Use of suspensory fixation preserves tibial and femoral bone stock	Steep learning curve
Infratubercular ACWO optimizes proximal bone stock, maintains patellar height, and avoids detachment of patellar tendon/tibial tubercle	
Single-stage procedure reduces morbidity and cost of multiple surgeries	
May be used with most ACLR graft types	

ACLR, anterior cruciate ligament reconstruction; ACWO, anterior closing-wedge osteotomy; PTS, posterior tibial slope.

infratubercular ACWO.[10,16-21] The authors prefer the described infratubercular ACWO approach, as this technique (1) avoids detachment of the patellar tendon/tibial tubercle (in contrast to a retrotubercular approach); (2) provides more proximal bone stock, thereby minimizing risk of fracture and allowing for ACLR tibial tunnel placement in the proximal fragment without crossing the osteotomy site; and (3) preserves patellar height and the distance from the tibial plateau to the tibial tubercle (in contrast to a supratubercular approach), which may be relevant for future total knee arthroplasty.

The described surgical technique does have several limitations, including increased operative times, risk of iatrogenic tibial fracture, convergence of tibial tunnel and ACWO, and a steep learning curve for the surgeon. However, this technique provides a versatile, practical approach for a difficult clinical problem, combining ACWO with staple fixation and all-inside ACLR to address increased posterior tibial slope in the setting of failed ACLR.

Disclosures

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: A.H.G. reports consulting or advisory and speaking and lecture fees from Vericel; speaking and lecture fees from Linvatec and Pacira Pharmaceuticals; consulting or advisory and equity or stocks from Smith & Nephew; and consulting or advisory from Organogenesis and Bioventus. S.M.S. reports consulting or advisory, equity or stocks, speaking and lecture fees, and travel reimbursement from Smith & Nephew; and consulting or advisory and speaking and lecture fees from Vericel and Miach Orthopaedics. All other authors (T.K.K., T.J.U., G.A., M.R.) declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Buller LT, Best MJ, Baraga MG, Kaplan LD. Trends in anterior cruciate ligament reconstruction in the United States. *Orthop J Sports Med* 2015;3:1-8.
2. Maletis GB, Inacio MCS, Funahashi TT. Analysis of 16,192 anterior cruciate ligament reconstructions from a community-based registry. *Am J Sports Med* 2013;41:2090-2098.
3. Mouarbes D, Menetrey J, Marot V, Courtot L, Berard E, Cavaignac E. Anterior cruciate ligament reconstruction: A systematic review and meta-analysis of outcomes for quadriceps tendon autograft versus bone–patellar tendon–bone and hamstring-tendon autografts. *Am J Sports Med* 2019;47:3531-3540.
4. Gans I, Retzky JS, Jones LC, Tanaka MJ. Epidemiology of recurrent anterior cruciate ligament injuries in national collegiate athletic association sports: The Injury Surveillance Program, 2004-2014. *Orthop J Sports Med* 2018;6:1-7.
5. Vadhera AS, Knapik DM, Gursoy S, et al. Current concepts in anterior tibial closing wedge osteotomies for anterior cruciate ligament deficient knees. *Curr Rev Musculoskelet Med* 2021;14:485-492.
6. Bayer S, Meredith SJ, Wilson KW, et al. Knee morphological risk factors for anterior cruciate ligament injury: A systematic review. *J Bone Joint Surg Am* 2020;102:703-718.
7. Liu Z, Jiang J, Yi Q, et al. An increased posterior tibial slope is associated with a higher risk of graft failure following ACL reconstruction: A systematic review. *Knee Surg Sports Traumatol Arthrosc* 2022;30:2377-2387.
8. Ni Q, Song G, Zhang Z, et al. Steep posterior tibial slope and excessive anterior tibial translation are predictive risk factors of primary anterior cruciate ligament reconstruction failure: A case-control study with prospectively collected data. *Am J Sports Med* 2020;48:2954-2961.
9. Hees T, Petersen W. Anterior closing-wedge osteotomy for posterior slope correction. *Arthrosc Tech* 2018;7:e1079-e1087.
10. Dejour D, Saffarini M, Demey G, Baverel L. Tibial slope correction combined with second revision ACL produces good knee stability and prevents graft rupture. *Knee Surg Sports Traumatol Arthrosc* 2015;23:2846-2852.
11. Imhoff FB, Mehl J, Comer BJ, et al. Slope-reducing tibial osteotomy decreases ACL-graft forces and anterior tibial translation under axial load. *Knee Surg Sports Traumatol Arthrosc* 2019;27:3381-3389.
12. Imhoff FB, Comer B, Obopilwe E, Beitzel K, Arciero RA, Mehl JT. Effect of slope and varus correction high tibial osteotomy in the ACL-deficient and ACL-reconstructed knee on kinematics and ACL GRAFT FORce: A biomechanical analysis. *Am J Sports Med* 2021;49:410-416.
13. Shelburne KB, Kim H-J, Sterett WI, Pandy MG. Effect of posterior tibial slope on knee biomechanics during functional activity. *J Orthop Res* 2011;29:223-231.
14. Yamaguchi KT, Cheung EC, Markolf KL, et al. Effects of anterior closing wedge tibial osteotomy on anterior cruciate ligament force and knee kinematics. *Am J Sports Med* 2018;46:370-377.
15. Sonnery-Cottet B, Mogos S, Thaunat M, et al. Proximal tibial anterior closing wedge osteotomy in repeat revision of anterior cruciate ligament reconstruction. *Am J Sports Med* 2014;42:1873-1880.
16. Akoto R, Alm L, Drenck TC, Frings J, Krause M, Frosch K-H. Slope-correction osteotomy with lateral extra-articular tenodesis and revision anterior cruciate ligament reconstruction is highly effective in treating high-grade anterior knee laxity. *Am J Sports Med* 2020;48:3478-3485.
17. Song G, Ni Q, Zheng T, Zhang Z, Feng H, Zhang H. Slope-reducing tibial osteotomy combined with primary anterior cruciate ligament reconstruction produces improved knee stability in patients with steep posterior tibial slope, excessive anterior tibial subluxation in extension, and chronic meniscal posterior horn tears. *Am J Sports Med* 2020;48:3486-3494.
18. Weiler A, Gwinner C, Wagner M, Ferner F, Strobel MJ, Dickschas J. Significant slope reduction in ACL deficiency can be achieved both by anterior closing-wedge and

medial open-wedge high tibial osteotomies: Early experiences in 76 cases. *Knee Surg Sports Traumatol Arthrosc* 2022;30:1967-1975.

19. Alaia MJ, Kaplan DJ, Mannino BJ, Strauss EJ. Tibial Sagittal slope in anterior cruciate ligament injury and treatment. *J Am Acad Orthop Surg* 2021;29:e1045-e1056.
20. Cruz CCA, Harris CMC, Wake CJL, Lause CGE, Mannino BJ, Bottoni CR. Tibial tubercle—sparing anterior closing wedge osteotomy with cross-screw fixation to correct pathologic posterior tibial slope. *Arthrosc Tech* 2021;10:e897-e902.
21. Floyd ER, Carlson GB, Monson J, LaPrade RF. Tibial tubercle preserving anterior closing wedge proximal tibial osteotomy and ACL tunnel bone grafting for increased posterior tibial slope in failed ACL reconstructions. *Arthrosc Tech* 2021;10:e2221-e2228.