Transtibial Versus Anteromedial Portal Anterior Cruciate Ligament Reconstruction Using Soft-Tissue Graft and Expandable Fixation

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Purpose: To compare clinical outcomes between transtibial drilling and anteromedial portal techniques for anterior cruciate ligament (ACL) reconstruction using soft-tissue grafts secured with expandable fixation. **Methods:** Patients undergoing soft-tissue ACL reconstruction using expandable fixation between 2007 and 2011 were reviewed for inclusion in this study. Revision ACL cases were excluded. All surgeries were performed by 1 of 2 sports medicine fellowship−trained surgeons (T.S.D., K.D.M.). A total of 128 patients (67 comprising transtibial cohort and 61 comprising anteromedial portal cohort) had a minimum of 24 months' follow-up (mean, 27 months) and met the inclusion criteria. The patients were divided into 2 groups based on the method used for creation of the femoral tunnel. At final follow-up, outcomes were assessed with KT-1000 (MEDmetric, San Diego, CA) measurements, as well as International Knee Documentation Committee, Lysholm, and Tegner scores. Data were screened for normality and skew before use of parametric statistics and were transformed if necessary. Data were analyzed by 1-way analysis of variance with post hoc paired comparisons using the Bonferroni approximation. **Results:** No differences in demographic characteristics were observed between the 2 groups. There was no significant difference in postoperative KT-1000 measurements between the 2 cohorts (1.571 $\pm$ 0.2275 mm in transtibial cohort [n = 35] and 1.246 $\pm$ 0.09249 mm in anteromedial cohort [n = 61], $P = .1259$). A significant improvement in International Knee Documentation Committee scores was observed in the anteromedial cohort, increasing from 41 $\pm$ 16 to 89 $\pm$ 7.4 (mean $\pm$ SD) ($P < .0001$). Similar changes were observed for the Lysholm score. There was no significant difference between cohorts for any postoperative scores measured ($P > .2$). **Conclusions:** Our data show comparable KT-1000 measurements for both anteromedial and transtibial femoral drilling techniques when using a soft-tissue graft with expandable fixation. **Level of Evidence:** Level IV, therapeutic case series.

Numerous studies support the efficacy of anatomic anterior cruciate ligament (ACL) reconstruction in restoring normal kinematics and postoperative function of the knee.[1-3] The goal of anatomic reconstruction is to place the ACL graft at a more anatomic location on both the tibia and femur. The graft is therefore being placed lower on the medial wall of the lateral femoral condyle, thereby orienting it in a more horizontal position,[4] with the presumption that a more horizontally oriented graft, as opposed to a vertical graft, would optimize rotatory as well as translational stability.[5,6] Some studies suggest that restoration of the native ACL orientation and obliquity leads to improved knee stability and kinematics.[2,3,7-9] Other studies, however, show no difference in knee stability between the 2 techniques.[10,11] A recent systematic review, meta-analysis, and meta-regression by Riboh et al.[10] identified cadaveric, in vivo, and clinical studies comparing transtibial (TT) and independent femoral tunnel drilling techniques. On the basis of this analysis, Riboh et al. concluded that although there are biomechanical studies supporting more anatomic graft placement and

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improved knee stability with independent drilling, there are no significant differences in clinical outcomes between the 2 techniques. Chalmers et al.[11] performed a systematic review to evaluate the level of scientific evidence to support the ability of the anteromedial (AM) portal versus TT femoral tunnel drilling techniques to achieve rotational stability of the knee. They concluded that the TT technique is capable of producing equivalent clinical and biomechanical outcomes to those achieved using the AM portal technique.

Controversy exists over the best surgical technique to use in anatomic ACL reconstruction. The femoral tunnel has traditionally been prepared by a TT technique; however, with the recent popularity of anatomic ACL reconstruction, many authors have advocated independent femoral tunnel drilling through an AM portal.[12-14] Clinical evidence comparing the 2 techniques suggests that preparing the femoral tunnel through the AM portal may offer clinical advantages over TT preparation.[15,16] There are, however, several recent studies comparing soft-tissue ACL reconstruction using either a TT or AM portal technique that have shown comparable results with regard to several outcome measures.[17,18]

As surgical techniques for ACL reconstruction have evolved, so have fixation methods. When a soft-tissue graft is used, aperture fixation may have benefits over suspensory techniques by increasing the stiffness of the graft and reducing the incidence of tunnel widening.[19-21] Furthermore, expandable devices that offer aperture fixation have been shown to closely reproduce the biomechanical properties of the native ACL.[22,23] A recent clinical study has corroborated that excellent clinical results are obtainable using a soft-tissue graft with expandable aperture fixation.[24] No existing study has compared clinical outcomes between the 2 methods of femoral tunnel drilling (AM portal approach *v* TT approach) with the use of a soft-tissue graft and expandable fixation.

The goal of this study was to compare clinical outcomes between TT drilling and AM portal techniques for ACL reconstruction using soft-tissue grafts secured with expandable fixation. We hypothesize that patients in the AM cohort will have better knee stability and overall clinical outcomes than patients in the TT cohort.

Methods

This is a retrospective study evaluating 128 consecutive patients diagnosed with ACL insufficiency who underwent primary ACL reconstruction with soft-tissue autograft or allograft by use of the AperFix Reconstruction System (Cayenne Medical, Scottsdale, AZ) for both femoral- and tibial-sided fixation. Revision cases were excluded from this study. Patients who required surgical procedures to address meniscal lesions were included in the study cohort. Four patients (3 AM and 1 TT) were found to have small chondral defects (<2 cm^2) that were amenable to treatment with microfracture. All of the surgical procedures were performed by 2 sports medicine fellowship–trained surgeons (T.D., K.M.). All patients underwent a chart review to collect patient demographic data; preoperative history including mechanism of injury; and intraoperative data including graft used, size of implant, and associated procedures. In addition, patients were evaluated at final follow-up by their respective surgeons using subjective International Knee Documentation Committee (IKDC), Lysholm, and Tegner Activity Scale scores, as well as side-to-side KT-1000 (MEDmetric, San Diego, CA) differences. This evaluation was not blinded.

Study Design

Institutional review board approval was obtained for this study. All patients who underwent soft-tissue ACL reconstruction by 1 of the 2 senior authors and who had 2 years of clinical follow-up were eligible to participate in the study. The patients were divided into 2 groups based on the surgical technique used. The AM cohort consisted of patients who underwent ACL reconstruction using the AM portal technique. Patients in this group underwent surgery by a single senior author. The TT cohort consisted of patients who underwent ACL reconstruction by the TT approach, and all of these operations were performed by the second senior author. In all cases both femoral fixation and tibial fixation were accomplished with a device that achieves expandable fixation of a soft-tissue graft (AperFix system).

Graft Source

ACL reconstruction was performed using only soft-tissue grafts (e.g., hamstring autograft, hamstring allograft, or tibialis anterior allograft). In those patients in whom hamstring allograft was used for their reconstruction, 2 separate semitendinosus grafts were used. Ultimately, specific graft selection was influenced by patient age, sporting activity, surgeon advice, and patient preference.

AM Portal Surgical Technique

Single-tunnel double-bundle ACL reconstruction was performed in all patients. Most of the patients in both groups underwent ACL reconstruction with hamstring autograft.

A standard hamstring harvest was performed, and the tendons were then taken to the back table, whip-stitched at both ends, and passed through the eyelet of a Femoral AperFix Implant. In all cases a standard diagnostic arthroscopy was performed, and associated meniscus and articular cartilage lesions were addressed appropriately. The ruptured cruciate ligament was excised, leaving only the stump fibers to assess the anatomic footprints. A notchplasty was performed by surgeon preference. Semitendinosus and gracilis harvest was performed in the autograft group using a standard pes anserinus incision and a tendon stripper.

Tunnel Drilling for AM Technique

Tibial Tunnel. With the knee flexed to 90°, a tip-aiming ACL guide was placed through the medial portal at a 55° angle to the long axis of the tibia. The tip of the ACL guide was aimed to enter the ACL footprint at the coronal plane of the inner edge of the anterior horn of the lateral meniscus. The tunnel size was based on the measured diameter of the soft-tissue graft.

Femoral Tunnel. With the knee maximally flexed, an over-the-top guide was inserted through the medial portal and placed in the over-the-top position at the 2-o'clock position for left knees and the 10-o'clock position for right knees. A guidewire was then advanced through the guide and into the lateral femoral condyle through the notch to a depth of 30 mm. The diameter of the reamer varied with the size of the graft used in each patient.

Tunnel Drilling for TT Technique

Tibial Tunnel. A standard drill guide was used to pass a guide pin from the AM tibia into the intercondylar notch, typically at a 50° or 55° angle, and aimed along a line carried from the inner border of the anterior horn of the lateral meniscus. The tibial tunnel was then reamed using a barrel reamer.

Femoral Tunnel. Through the tibial tunnel, a guide pin was placed at the 10-o'clock position for right knees and the 2-o'clock position for left knees. A mushroom reamer was used to drill the femoral tunnel, leaving a 1.5-mm back wall. The guide pin was then placed into the femur, and the femoral tunnel was reamed, typically to a depth of 35 to 40 mm. The tendons were placed into the AperFix device. The tendons and implant were inserted through the tibial tunnel and then into the femoral tunnel. The implant was deployed in its standard fashion.

Graft Insertion

In each case, the prepared graft and implant were docked into the femoral tunnel using the same method as that used to drill the tunnel itself (AM or TT). An attempt was made to orient the 2 bundles of the graft into AM and posterolateral limbs on both the femoral and tibial sides of the graft. Once this was accomplished, the knee was cycled repeatedly and tibial fixation accomplished with the knee in slight (10°) flexion.

Outcomes Assessment

KT-1000 measurements, as well as functional outcome measures including the IKDC subjective knee form, Lysholm score, and Tegner Activity Scale, were used to evaluate outcomes before injury and at final follow-up. When filling out the Tegner Activity Scale, the patients were asked to answer questions based on their preinjury level of activity. All of these measures have been validated[25] and published extensively in the literature.

Statistical Analysis

In addition to demographic data, outcome data analyzed included the preoperative and postoperative IKDC, Lysholm, and Tegner scores for the AM portal cohort and postoperative IKDC, Lysholm, and Tegner scores for the TT cohort, which did not include any preoperative data. All outcomes were screened for normality and skew to justify the use of parametric statistics. Skew statistics (g_1 and g_2) and kurtosis statistics less than 1 were considered indicative of a normal distribution. Only the postoperative IKDC and postoperative Lysholm scores from the TT cohort deviated significantly from normal (skewed left), and these were log transformed before data analysis.

Data were analyzed by 1-way analysis of variance with repeated measures of the preoperative and postoperative data for the AM cohort. To compare the postoperative data between the AM and TT cohorts, an unpaired t test was performed. To determine whether outcome scores changed as a function of follow-up time, linear regression was performed with a nonzero y-intercept. Goodness-of-fit statistics with r^2 were used to determine linearity. For all tests, the significance level (α) was set to $P < .05$. Data are presented as mean ± standard deviation of the mean.

Results

Data were accumulated over a 4.8-year period and included a total of 128 patients (67 comprising TT cohort and 61 comprising AM cohort). No differences in demographic characteristics were observed between the cohorts (Table 1). Injuries included isolated ACL ruptures (28% in AM cohort and 22% in TT cohort) and those with associated pathology (e.g., collateral ligament injuries or meniscal tears) (72% in AM cohort and 78% in TT cohort) (Table 2). Magnetic resonance imaging was used to confirm all ACL injuries. The type of graft was hamstring autograft in 87% of patients in the AM cohort and 97% of patients in the TT cohort. In the AM cohort, 7 patients (11%) received hamstring allograft whereas 1 patient (2%) received tibialis anterior allograft. Of the remaining patients in the TT cohort, 1 (1.5%) received hamstring allograft whereas the other patient (1.5%) received tibialis anterior allograft. All grafts were secured by expandable fixation (AperFix) in both the femoral and tibial tunnels.

In the AM cohort, KT-1000 measurements ranged from 0 to 3 mm, whereas in the TT group, the

Table 1. Patient Characteristics

Variable	AM Cohort	TT Cohort
No. of patients	61	67
Follow-up (mean [range]) (mo)	26 (17-41)	27 (15-49)
Age (mean [range]) (yr)	29.9 (13-54)	30.3 (16-61)
Gender		
Male	41 (67%)	44 (66%)
Female	20 (33%)	23 (34%)
Side		
Right	31 (51%)	34 (51%)
Left	30 (49%)	33 (49%)
Knee injury		
Isolated ACL injury	17 (28%)	15 (22%)
Associated injuries	44 (72%)	52 (78%)
Graft		
Hamstring autograft	53 (87%)	65 (97%)
Hamstring allograft	7 (11%)	1 (1.5%)
Tibialis anterior allograft	1 (2%)	1 (1.5%)

NOTE. Data are presented as n (%) unless indicated otherwise.

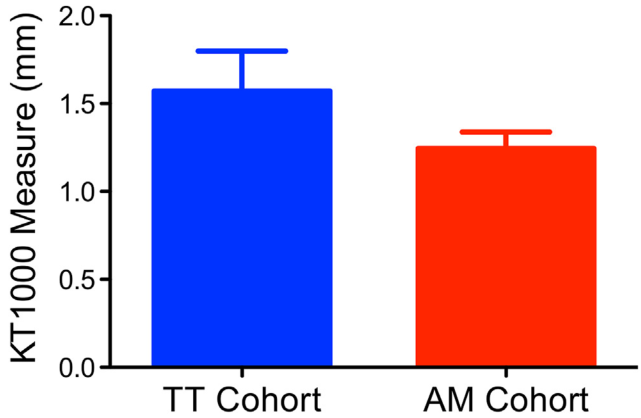

Fig 1. Postoperative KT-1000 measurements were not significantly different in the TT cohort versus the AM cohort ($P = .1259$).

measurements ranged from 0 to 7 mm (Table 2). There was no significant difference in postoperative KT-1000 measurements between the 2 cohorts (1.571 ± 0.2275 mm [mean $\pm$ SEM] in TT cohort [n = 35] and 1.246 ± 0.09249 mm [mean $\pm$ SEM] in AM cohort [n = 61], $P = .1259$) (Fig 1). In the AM cohort, 100% of patients had postoperative KT-1000 measurements and preoperative and postoperative IKDC and Tegner scores whereas 51 patients (84%) had preoperative Lysholm scores. A significant improvement in IKDC scores was observed in the AM cohort, increasing from 41 ± 16 to 89 ± 7.4 (mean $\pm$ SD) ($P < .0001$). Similar changes were observed for the Lysholm score, whereas no significant changes were observed for the Tegner score ($P > .7$). The similarity between preinjury and postoperative Tegner scores indicates that in most cases, patients were able to return to their baseline level of activity. In the TT cohort, 34 patients (51%) had postoperative KT-1000 data, 41 patients (61%) had postoperative IKDC and Lysholm scores, and 42 patients (63%) had preoperative and postoperative Tegner scores. With the data available, we were able to find no significant difference between the cohorts for any postoperative score measured ($P > .2$) (Table 2).

Table 2. Outcome Measures

Variable	AM Cohort	TT Cohort
KT-1000 measurement (mm)	1.2 (0-3)	1.6 (0-7)
IKDC score		
Preoperative	41 (11-69)	NA
Postoperative	89 (69-97)	92 (50-99)
Lysholm score		
Preoperative	50 (13-83)	NA
Postoperative	94 (85-100)	91 (63-100)
Tegner score		
Preoperative	6.5 (3-9)	7.1 (2-9)
Postoperative	6.5 (3-9)	6.8 (2-9)

NOTE. Data are presented as mean (range).
NA, not available.

For the AM cohort, which included complete follow-up data sets and time, there was no significant correlation between either the IKDC score ($P > .1$) (Fig 2A) or the Lysholm score ($P > .3$) (Fig 2B) and follow-up time, and neither was described well by a line ($r^2 = 0.05$ and $r^2 = 0.02$, respectively).

In the TT cohort, 3 patients (4%) required revision ACL reconstruction and an infection developed in 1 patient (1%), which necessitated surgical irrigation and debridement. Eight patients (12%) in the TT cohort returned to the operating room for different reasons, including medial meniscus retear (2), removal of tibial screw (1), osteochondral allograft transplantation (OATS) procedure (1), partial medial meniscectomy (PMM) (1), PMM and chondroplasty (1). In the AM cohort, no patients required revision ACL reconstruction and there were no infections. Four patients (7%) returned to the operating room: 2 for ACL reconstruction of the contralateral knee, 1 (2%) for removal of the tibial screw, and 1 (2%) for revision PMM.

Discussion

To our knowledge, this is the first study to compare the 2 most common methods of femoral tunnel preparation (TT and AM portal) when using a soft-tissue graft and expandable fixation. Our results show comparable anteroposterior stability using either method of femoral tunnel preparation.

Numerous studies have shown the biomechanical advantages of anatomic femoral tunnel positioning.[3,7,8,26,27] Debate remains, however, over the best technique to accurately place the ACL graft at an anatomic location on both the tibia and femur. Using a modification of the conventional TT approach and drilling the femoral tunnel independently through the standard AM portal are 2 commonly described techniques.

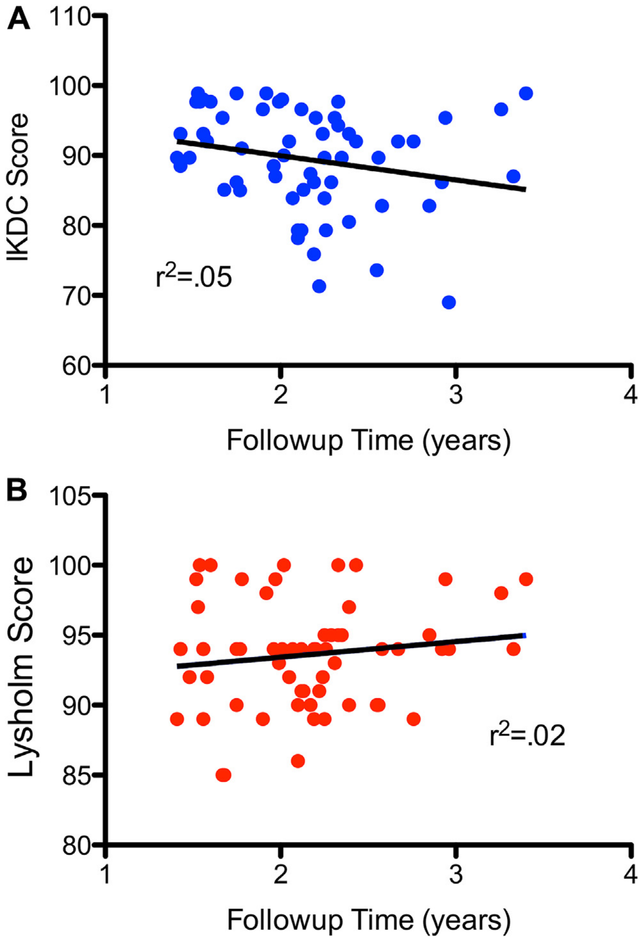

Fig 2. Correlation between (A) IKDC score and (B) Lysholm score and follow-up time in AM cohort. There was no significant correlation between either the IKDC score or the Lysholm score and follow-up time.

Modifications of the TT technique have been proposed in an attempt to improve the angle of the femoral tunnel and to better restore the femoral ACL footprint.[28,29] Authors have recommended shifting the angle of the tibial tunnel to 65° to 70° in the coronal plane to achieve appropriate femoral tunnel obliquity.[28,29] Despite these modifications, concerns still exist about the ability to restore the native femoral ACL insertion through a TT approach. Dargel et al.[30] found that use of the TT technique tends to position the femoral tunnel toward the roof of the notch and anterior to the ACL footprint, whereas other authors concluded that use of this technique often results in a mismatch in graft position from the posterolateral tibial footprint to the AM femoral footprint.[1,8] With these concerns in mind, many authors have advocated independent femoral tunnel drilling through the standard AM arthroscopic portal.[12,13]

Bedi et al.[14] showed the biomechanical superiority of ACL reconstruction using the AM portal technique versus the conventional TT approach. They found that the AM portal reconstruction resulted in Lachman examination findings equivalent to the uninjured knee whereas the Lachman examination findings after TT reconstruction could not be differentiated from the ACL-deficient condition. The AM portal reconstruction produced significantly more translational restraint during manual and instrumented pivot-shift examination when compared with both the native ACL and TT ACL reconstruction.[14]

Lubowitz[31] has described many advantages to independent femoral tunnel drilling using the AM portal, but he also has emphasized the challenges associated with this technique. Other studies have reported the importance of knee hyperflexion while drilling the femoral tunnel through the AM portal to avoid posterior wall blowout or creation of a short femoral tunnel.[32,33]

Recent studies comparing clinical outcomes of TT versus AM portal ACL reconstruction have not found significant clinical differences.[17,18] Koutras et al.[17] compared short-term functional clinical outcomes using both reconstruction methods and found that the only difference was better lateral movement functional test results at 3 and 6 months using the AM technique. This study, however, involved 12 different surgeons, each with varying techniques for fixation. Kim et al.[18] compared TT and AM femoral tunnel drilling and found differences in pivot-shift test results favoring the AM group. There were, however, no measurable clinical differences when comparing both groups.

This study compares the 2 most common methods of femoral tunnel preparation while standardizing tibial fixation for soft-tissue ACL reconstruction. The fixation device used in this study (AperFix) is unique in its circumferential compression of the soft-tissue graft against the surrounding bone tunnel. When placed at the tunnel aperture, this device can provide what we refer to as “expandable fixation” and differs from the standard interference screw by avoiding insertional torque, which can damage and/or change the graft's position within the tunnel, and by providing circumferential graft compression rather than the unilateral compression of an interference screw. A recent study by Uribe et al.[24] using the same expandable fixation device used in this study reported excellent clinical outcomes. Expandable aperture fixation has also been validated by Uzumcugil et al.,[34] who found comparable outcomes of ACL reconstruction with the TransFix fixation method (Arthrex, Naples, FL) to those achieved using the AperFix system. They concluded that the AperFix system had a satisfactory performance comparable with that of cross-pin fixation. Gadikota et al.[22] evaluated the mechanical stability of the AperFix system using fresh-frozen human cadaveric knee specimens. They performed single-tunnel double-bundle and single-bundle ACL reconstruction and subsequently investigated the response of the knee joint to an anterior tibial load (130 N), a simulated quadriceps load (400 N), and combined torques at various degrees of knee flexion using a robotic testing device. They showed that the AperFix system reliably held the grafts in place during testing. Our outcomes support the work by Uribe et al. showing that aperture fixation using an expandable device can lead to acceptable short-term outcomes. In addition, our results indicate that satisfactory results can be achieved through either a TT or AM approach as shown by the absence of a statistically significant difference in KT-1000 measurements between the 2 cohorts.

Limitations

This study has several limitations. This is a retrospective study and thus is subject to multiple limitations inherent in this type of study design. The ACL reconstructions using the AM portal were performed by 1 surgeon (T.S.D.) whereas all TT cases were performed by a different surgeon (K.D.M.); this may introduce performance bias. Distinct differences in technique for preparation of the tibial and femoral tunnels between the 2 surgeons may affect the resulting stability, motion, and overall outcome. In most patients hamstring autograft was used for ACL reconstruction; however, a small subset of patients received allograft. Although the combination of the data from these 2 groups may have influenced the overall results, a recent study comparing autograft with allograft hamstring reconstruction for ACL deficiency found no statistically significant differences in subjective or objective data at a mean follow-up of 7.8 years.[35] There were no preoperative IKDC or Lysholm scores available in the TT cohort. Thus it was not possible to determine the overall level of improvement or compare the degree of improvement between the 2 cohorts; however, the overall outcomes were quite similar. The outcome score data set was not complete for all patients, which may influence the significance of the results obtained.

Conclusions

Our data show comparable outcomes in terms of overall anteroposterior stability as evidenced by similar KT-1000 measurements in the 2 cohorts.

References

1. Brophy RH, Voos JE, Shannon FJ, et al. Changes in the length of virtual anterior cruciate ligament fibers during stability testing: A comparison of conventional single-bundle reconstruction and native anterior cruciate ligament. *Am J Sports Med* 2008;36:2196-2203.
2. Cha PS, Brucker PU, West RV, et al. Arthroscopic double-bundle anterior cruciate ligament reconstruction: An anatomic approach. *Arthroscopy* 2005;21:1275.
3. Yamamoto Y, Hsu WH, Woo SL, Van Scyoc AH, Takakura Y, Debski RE. Knee stability and graft function after anterior cruciate ligament reconstruction: A comparison of a lateral and an anatomical femoral tunnel placement. *Am J Sports Med* 2004;32:1825-1832.
4. Miller CD, Gerdeman AC, Hart JM, et al. A comparison of 2 drilling techniques on the femoral tunnel for anterior cruciate ligament reconstruction. *Arthroscopy* 2011;27:372-379.
5. Steiner ME, Battaglia TC, Heming JF, et al. Independent drilling outperforms conventional transtibial drilling in anterior cruciate ligament reconstruction. *Am J Sports Med* 2009;37:1912-1919.
6. Seon JK, Park SJ, Lee KB, et al. In vivo stability and clinical comparison of anterior cruciate ligament reconstruction using low or high femoral tunnel positions. *Am J Sports Med* 2011;39:127-133.
7. Lee MC, Seong SC, Lee S, et al. Vertical femoral tunnel placement results in rotational knee laxity after anterior cruciate ligament reconstruction. *Arthroscopy* 2007;23:771-778.
8. Pearle AD, Shannon FJ, Granchi C, Wickiewicz TL, Warren RF. Comparison of 3-dimensional obliquity and anisometric characteristics of anterior cruciate ligament graft positions using surgical navigation. *Am J Sports Med* 2008;36:1534-1541.
9. Yasuda K, Kondo E, Ichiyama H, et al. Anatomic reconstruction of the anteromedial and posterolateral bundles of the anterior cruciate ligament using hamstring tendon grafts. *Arthroscopy* 2004;20:1015-1025.
10. Riboh JC, Hasselblad V, Godin JA, et al. Transtibial versus Independent drilling techniques for anterior cruciate ligament reconstruction: A systematic review, meta-analysis, and meta-regression. *Am J Sports Med* 2013;41:2693-2702.
11. Chalmers PN, Mall NA, Cole BJ, Verma NN, Bush-Joseph CA, Bach BR Jr. Anteromedial versus transtibial drilling in anterior cruciate ligament reconstruction: A systematic review. *Arthroscopy* 2013;7:1235-1242.
12. Harner CD, Honkamp NJ, Ranawat AS. Anteromedial portal technique for creating the anterior cruciate ligament femoral tunnel. *Arthroscopy* 2008;24:113-115.
13. Bottoni CR. Anterior cruciate ligament femoral tunnel creation by use of anteromedial portal. *Arthroscopy* 2008;24:1319.
14. Bedi A, Musahl V, Steuber V, et al. Transtibial versus anteromedial portal reaming in anterior cruciate ligament reconstruction: An anatomic and biomechanical evaluation of surgical technique. *Arthroscopy* 2011;27:380-390.
15. Alentorn-Geli E, Samitier G, Alvarez P, Steinbacher G, Cugat R. Anteromedial portal versus transtibial drilling techniques in ACL reconstruction: A blinded cross-sectional study at two- to five-year follow-up. *Int Orthop* 2010;34:747-754.
16. Wang H, Fleischli JE, Zheng NN. Transtibial versus anteromedial portal technique in single-bundle anterior cruciate ligament reconstruction: Outcomes of knee joint kinematics during walking. *Am J Sports Med* 2013;41:1847-1856.
17. Koutras G, Papadopoulos P, Terzidis IP, Gigis I, Pappas E. Short-term functional and clinical outcomes after ACL reconstruction with hamstring autograft: Transtibial versus anteromedial portal technique. *Knee Surg Sports Traumatol Arthrosc* 2013;21:1904-1909.

18. Kim MK, Lee BC, Park JH. Anatomic single bundle anterior cruciate ligament reconstruction by the two anteromedial portal method: The comparison of transportal and transtibial techniques. *Knee Surg Relat Res* 2011;23:213-219.
19. Brown CH Jr, Wilson DR, Hecker AT, Ferragamo M. Graft-bone motion and tensile properties of hamstring and patellar tendon anterior cruciate ligament femoral graft fixation under cyclic loading. *Arthroscopy* 2004;20:922-935.
20. Benfield D, Otto DD, Bagnall KM, Raso VJ, Moussa W, Amirfazil A. Stiffness characteristics of hamstring tendon graft fixation methods at the femoral site. *Int Orthop* 2005;29:35-38.
21. Fauno P, Kaalund S. Tunnel widening after hamstring anterior cruciate ligament reconstruction is influenced by the type of graft fixation used: A prospective randomized study. *Arthroscopy* 2005;21:1337-1341.
22. Gadikota HR, Seon JK, Kozanek M, et al. Biomechanical comparison of single-tunnel-double-bundle and single-bundle anterior cruciate ligament reconstructions. *Am J Sports Med* 2009;37:962-969.
23. Gadikota HR, Wu JL, Seon JK, Sutton K, Gill TJ, Li G. Single-tunnel double-bundle anterior cruciate ligament reconstruction with anatomical placement of hamstring tendon graft: Can it restore normal knee kinematics? *Am J Sports Med* 2010;38:713-720.
24. Uribe JW, Arango D, Frank J, Kiebzak GM. Two-year outcome with the AperFix system for ACL reconstruction. *Orthopedics* 2013;36:e159-e164.
25. Smith MV, Klein SE, Clohisy JC, Baca GR, Brophy RH, Wright RW. Lower extremity-specific measures of disability and outcomes in orthopaedic surgery. *J Bone Joint Surg Am* 2012;94:468-477.
26. Pearle AD, Solomon DJ, Wanich T, et al. Reliability of navigated knee stability examination: A cadaveric evaluation. *Am J Sports Med* 2007;35:1315-1320.
27. Buchner M, Schmeer T, Schmitt H. Anterior cruciate ligament reconstruction with quadrupled semitendinosus tendon—Minimum 6-year clinical and radiological follow-up. *Knee* 2007;14:321-327.
28. Howell SM, Gittins ME, Gottlieb JE, Traina SM, Zoellner TM. The relationship between the angle of the tibial tunnel in the coronal plane and loss of flexion and anterior laxity after anterior cruciate ligament reconstruction. *Am J Sports Med* 2001;29:567-574.
29. Chhabra A, Diduch DR, Blessey PB, Miller MD. Recreating an acceptable angle of the tibial tunnel in the coronal plane in anterior cruciate ligament reconstruction using external landmarks. *Arthroscopy* 2004;20:328-330.
30. Dargel J, Schmidt-Wiethoff R, Fischer S, Mader K, Koebke J, Schneider T. Femoral bone tunnel placement using the transtibial or the anteromedial portal in ACL reconstruction: A radiographic evaluation. *Knee Surg Sports Traumatol Arthrosc* 2009;17:220-227.
31. Lubowitz JH. Anteromedial portal technique for the anterior cruciate ligament femoral socket: Pitfalls and solutions. *Arthroscopy* 2009;25:95-101.
32. Basdekis G, Abisafi C, Christel P. Influence of knee flexion angle on femoral tunnel characteristics when drilled through the anteromedial portal during anterior cruciate ligament reconstruction. *Arthroscopy* 2008;24:459-464.
33. Jabara MRF, Clancy WG Jr. Anatomic arthroscopic anterior cruciate ligament reconstruction using bone-patellar tendon bone autograft. *Tech Orthop* 2005;20:405-413.
34. Uzumcugil O, Dogan A, Dalyaman E, et al. AperFix versus TransFix in reconstruction of anterior cruciate ligament. *J Knee Surg* 2010;23:29-35.
35. Sun K, Zhang J, Wang Y, et al. Arthroscopic reconstruction of the anterior cruciate ligament with hamstring tendon autograft and fresh-frozen allograft: A prospective, randomized controlled study. *Am J Sports Med* 2011;39:1430-1438.