Clinical Sports Medicine Update

Higher Incidence of Radiographic Posttraumatic Osteoarthritis With Transtibial Femoral Tunnel Positioning Compared With Anteromedial Femoral Tunnel Positioning During Anterior Cruciate Ligament Reconstruction

A Systematic Review and Meta-analysis

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Background: Anteromedial (AM) femoral tunnel positioning in anterior cruciate ligament reconstruction (ACLR) has been reported by some authors to yield superior clinical and functional outcomes compared with the transtibial (TT) approach; however, differences in the subsequent rates of posttraumatic osteoarthritis (PTOA) are not clear.

Purpose: To perform a systematic review and meta-analysis of the literature to evaluate the influence of femoral tunnel positioning during primary ACLR on the development of radiographic PTOA.

Study Design: Systematic review and Meta-analysis.

Methods: The Cochrane Database of Systematic Reviews, the Cochrane Central Register of Controlled Trials, PubMed (1980-2019), and MEDLINE (1980-2019) were queried for all studies describing the development of PTOA after TT or AM ACLR. Data pertaining to patient demographics, ACLR technique, and radiographic PTOA were extracted. A meta-analysis utilizing the DerSimonian-Laird method for random effects was used to compare the weighted proportion of PTOA after ACLR between the TT and AM approaches.

Results: There were 16 studies identified for inclusion with a total of 1546 patients. The mean follow-up across all studies was 10.9 years (range, 5.4-17.8 years). The mean follow-up in the AM and TT groups was 10.8 years (range, 5.4-17 years) and 11.4 years (range, 6-17.8 years), respectively. A total of 783 (50.6%) patients underwent TT ACLR. Of these patients, 401 (weighted mean, 49.3%) developed radiographic PTOA. A total of 763 (49.4%) patients underwent AM ACLR. Of these patients, 166 (mean, 21.8%) went on to develop radiographic PTOA. The meta-analysis demonstrated a significantly greater rate of PTOA after ACLR using a TT technique compared with an AM technique overall (49.3% vs 25.4%, respectively; $P < .001$) and when studies were stratified by 5- to 10-year (53.7% vs 14.2%, respectively; $P < .001$) and greater than 10-year (45.6% vs 31.2%, respectively; $P < .0001$) follow-up.

Conclusion: TT ACLR was associated with higher overall rates of radiographic PTOA compared with the AM ACLR approach. The rates of radiographic PTOA after ACLR with a TT approach were also significantly higher than using an AM approach when stratified by length of follow-up (5- to 10-year and >10-year follow-up).

Keywords: anteromedial; transtibial; femoral tunnel; osteoarthritis; ACL; radiographic; anterior cruciate ligament

Femoral tunnel positioning during anterior cruciate ligament (ACL) reconstruction (ACLR) is a factor theorized to affect biomechanical outcomes and knee kinematics, including translational and rotational laxity.[32] The transtibial (TT) method of femoral tunnel positioning has

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historically been utilized in ACLR; however, there are concerns about its capacity to place the femoral tunnel in an anatomic location and restore native stability.[25,53] This nonanatomic positioning may lead to altered kinematics, mainly with a rotational component, potentially predisposing patients to early arthritic degeneration.[37] Persistent instability and disproportionate joint loading have been reported to increase the risk of cartilage wear and meniscal injuries, both of which are associated with an increased risk of osteoarthritis (OA).[30,45] Such concerns have led to the development of anatomic techniques, such as the anteromedial (AM) approach to femoral tunnel positioning.

The AM approach to ream the femoral tunnel allows for femoral drilling independently of tibial tunnel orientation; therefore, a final tunnel position characterized by a more inferior and horizontal orientation is created, which reportedly better approximates the obliquity of the native ACL.[28,40,47] This resultant graft orientation increases rotational stability, prevents joint laxity, and more closely restores native kinematics.[5,49] Several studies have reported that the AM approach results in superior functional outcomes and stability when compared with the TT technique.[3,8,10,17,41,50]

Although the AM technique for femoral tunnel positioning has been proposed to provide better restoration of kinematics and stability in several studies, whether these differences influence the development of radiographically apparent posttraumatic OA (PTOA) when compared with the TT method is not well understood. The purpose of the current study was to perform a systematic review and meta-analysis of the literature to evaluate the influence of femoral tunnel positioning during primary ACLR on the development of radiographic PTOA. It was hypothesized that there would be a higher incidence of radiographic PTOA with the use of TT femoral tunnel positioning compared with the AM approach.

METHODS

Study Design

This study was conducted in accordance with the 2009 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. A systematic review of the literature was performed to identify existing evidence regarding the development of PTOA after TT or AM femoral tunnel reaming during ACLR. Searches were performed using the Cochrane Database of Systematic Reviews, the Cochrane Central Register of Controlled Trials, PubMed (1980-2019), and MEDLINE (1980-2019). The queries were performed in January 2020.

Article Inclusion Criteria

The literature search strategy's inclusion criteria were as follows: radiographic evaluation for OA after ACLR, mean follow-up of at least 5 years, and level of evidence of 1 to 3. To meet inclusion criteria, studies had to specifically report or reference the ACLR technique utilized, specifically detailing the method of femoral tunnel positioning and reaming. Studies with a mean follow-up of less than 5 years, cadaveric studies, animal studies, basic science articles, editorial articles, surveys, and non–English language studies were excluded. Double-bundle ACLR and ACLR with concurrent extra-articular procedures were also excluded. In studies comparing multiple reconstruction techniques, only patients who underwent single-bundle ACLR in each study were included in the analysis. If the same patient cohort was analyzed at multiple time points, the analysis performed at the longest follow-up interval was used in our analysis. Studies were also excluded if the number of patients with PTOA could not be discerned from the article's text or figures. Finally, studies were excluded from the AM group if patients underwent outside-in femoral tunnel reaming as opposed to an anatomic AM approach. A flowchart of the study inclusion process is reported in Figure 1.

Data Collection and OA Classification

The level of evidence of the studies was assigned according to the classification specified by Wright et al.[52] Patient demographics, mean follow-up length, mean time from injury to surgery, radiographic OA scores, and total number of patients with OA were extracted and recorded. For continuous variables (eg, age, surgical technique, follow-up length), the mean and range were collected if reported by the included studies. There were 4 different radiographic OA scoring scales used in these studies: Kellgren-Lawrence, Ahlbäck, International Knee Documentation Committee (IKDC), and Osteoarthritis Research Society International (OARSI). As previously described by Cinque et al,[11] an

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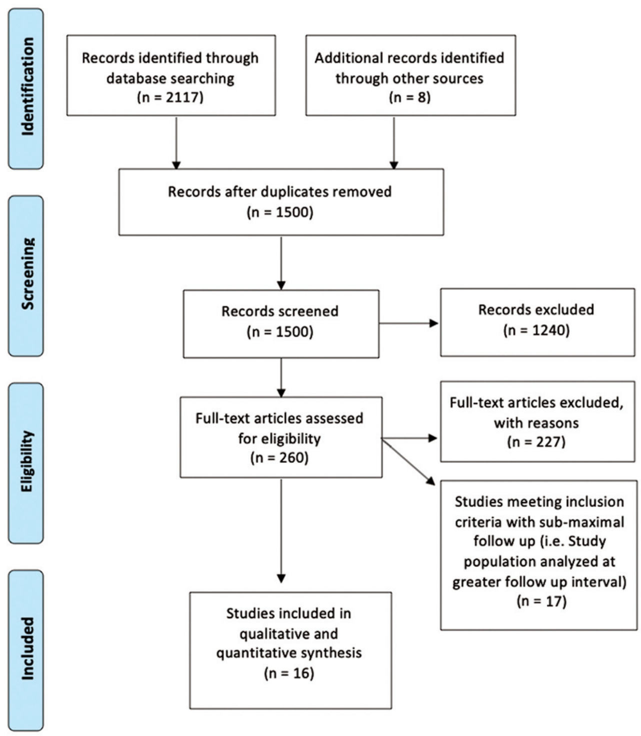

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart of the study selection criteria.

equivalence table of radiographic PTOA was used to determine cut-offs to define the presence or absence of PTOA (Table 1). In studies utilizing multiple grading scales with differing proportions of patients with OA, the scale indicating the higher proportion was utilized.

Heterogeneity and Bias Assessment

Each nonrandomized study was also reviewed using the criteria of the Methodological Index for Non-Randomized Studies (MINORS)[19] instrument to assess the quality of comparative outcome studies (maximum score, 24). Each randomized study was evaluated with the Jadad scale (maximum score, 5).[20]

Statistical Analysis

For studies that reported the rates of PTOA at multiple time points, only the longest follow-up time point was used for the analysis. Absolute and weighted proportions of PTOA after ACLR for each approach were calculated.

A meta-analysis was conducted to compare the weighted proportion of PTOA after ACLR between the TT and AM approaches. The difference in the rates of PTOA between the 2 surgical techniques was expressed as the odds ratio with 95% confidence interval (CI). To perform the meta-analysis, a binary random-effects model using the DerSimonian-Laird method was chosen. Heterogeneity among studies was assessed using the I^2 statistic and reported with 95% CIs. All statistical analyses and subsequent figures were produced via OpenMetaAnalyst using the metafor R console package.[48]

RESULTS

Study Selection

After the application of inclusion and exclusion criteria, 16 studies were identified for the final analysis. Overall, 10 (62.5%) studies utilized a TT approach, while the remaining 6 (37.5%) utilized an AM approach.

Of the included studies, there were 3 (18.8%) level 1 studies, 11 (68.8%) level 2 studies, and 2 (12.5%) level 3 studies. Among the 16 included studies, 7 studies compared bone–patellar tendon–bone autografts with hamstring autografts, 4 compared operative versus nonoperative treatment, 2 compared single- versus double-bundle reconstruction, and 3 studies fell into the “other” category. Studies were classified into the “other” category if the study topic was unique and none of the other included studies compared the same intervention(s).

The median publication year for the TT ACLR studies was 1999 (range, 2005-2016). The median publication year for the AM ACLR studies was 2007 (range, 2011-2018).

Demographics

A total of 1546 patients were included in this review. The mean age at the time of surgery was 28.5 years (range, 24-39 years). The mean follow-up across all studies was 10.9 years (range, 5.4-17.8 years). The mean follow-up in the AM and TT groups was 10.8 years (range, 5.4-17 years) and 11.4 years (range, 6-17.8 years), respectively. This difference in the follow-up interval was not significantly different (P = .37). The mean time from injury to surgery ranged from 5.4 to 58.8 months in studies reporting this information. The overall proportion of PTOA across the 16 included studies ranged between 8.3% and 90.3%. Detailed data are available in Table 2.

Bias Assessment

Of the 8 level 1 and 2 studies that were randomized, the mean Jadad score was 2.6 of 5. Only 2 studies did not lose any points and scored all 5 points. Of the remaining 8 nonrandomized studies assessed using the MINORS criteria, the mean MINORS score was 21.1 of 24. Again, 2 studies did not lose any points and scored all 24 points (Table 3).

Influence of Surgical Approach on PTOA Incidence

A total of 783 (50.6%) patients underwent TT ACLR. Of these patients, 401 (weighted mean, 49.3%) went on to develop radiographic PTOA. A total of 763 (49.4%) patients underwent AM ACLR. Of these patients, 324 (weighted mean, 25.4%) went on to develop radiographic PTOA.

TABLE 1
Equivalence of Radiographic OA Scoring Scales[a]

Classification	Kellgren-Lawrence	Ahlbäck	IKDC	OARSI
Normal	Grade 0	Grade 0	A (no or doubtful changes in knee joint)	JSN 1
Minimal OA	Grade 1		B (small osteophytes, slight sclerosis, flattening of femoral condyles)	JSN 2
Moderate to severe OA	Grade 2	Grade 1	C (JSN <50%)	JSN >2
	Grade 3	Grade 2		
	Grade 4	Grade 3	D (JSN of 50%-100%)	
		Grade 4		
		Grade 5		

[a]Table adapted from the following: Claes S, Hermie L, Verdonk R, Bellemans J, Verdonk P. Is osteoarthritis an inevitable consequence of anterior cruciate ligament reconstruction? A meta-analysis. *Knee Surg Sports Traumatol Arthrosc*. 2013;21(9):1967-1976. IKDC, International Knee Documentation Committee; JSN, joint space narrowing; OA, osteoarthritis; OARSI, Osteoarthritis Research Society International.

TABLE 2
Bibliometric and Demographic Data of Included Studies[a]

First Author (Year)	LOE	Approach	Comparison	OA Scoring Scale (Definition)	No. of Patients	Mean Age, y[c]	Mean Follow-up, y	Mean Time to Surgery, mo	OA Percentage
Fithian[15] (2005)	2	TT	OP vs non-OP	IKDC (NR)	83	39.0 (34.3 for early surgery)	6.6	NR	90.3
Matsumoto[29] (2006)	1	TT	BTB vs hamstring	IKDC (B-D)	72	24.0	7.0	10.2	8.3
Keays[23] (2007)	2	TT	BTB vs hamstring	JSN[b]	56	27.0	6	35.1	48.2
Kessler[24] (2008)	2	TT	OP vs non-OP	KL (1-3)	60	30.7 at injury	11.1	NR	45
Meuffels[31] (2009)	3	TT	OP vs non-OP	KL (≥2)	25	37.6	10	<6.0	48
Sajovic[39] (2011)	2	AM	BTB vs hamstring	IKDC (C-D)	48	26 at surgery (37 at follow-up)	17	24.0	27.1
Song[42] (2013)	2	AM	SB vs DB	KL (≥2)	60	33.1 (35.5 for SB)	5.7	7.9	10
Janssen[21] (2013)	2	TT	Other	KL (3) + Ahlbäck (1)	86	31.2 at surgery	10	58.8	73.3
Barenius[4] (2014)	1	TT	BTB vs hamstring	KL (≥2)	135	26.3 at surgery (40.4 at follow-up)	14.1	15.1	59.2
Webster[51] (2016)	2	TT	BTB vs hamstring	KL (≥2)	38	26.3 at surgery (41.6 at follow-up)	15.3	NR	28.9
Bjornsson[7] (2016)	2	TT	BTB vs hamstring	KL (≥2)	61 (BTB only)	28.2	16	NR	49.2
Karikis[22] (2016)	1	AM	SB vs DB	KL (≥2)	38	29.0 (28 for SB)	5.4	23.5 (23 for SB)	21.1
Risberg[38] (2016)	2	TT	Other	KL (≥2)	167	27.4 at surgery (45.2 at follow-up)	17.8	26.4	41.9
Tsoukas[44] (2016)	2	AM	OP vs non-OP	IKDC (C-D)	17	31	10.1	NR	23.5
Chen[9] (2017)	2	AM	Other	KL (≥2)	59	28.6	10.3	NR	55.9
Lecoq[27] (2018)	3	AM	BTB vs hamstring	IKDC (C-D)	541	29.4	11.9	20.3	18.9

[a]AM, anteromedial; BTB, bone–patellar tendon–bone; DB, double bundle; IKDC, International Knee Documentation Committee; JSN, joint space narrowing; KL, Kellgren-Lawrence; LOE, level of evidence; non-OP, nonoperative; NR, not reported; OA, osteoarthritis; OP, operative; SB, single bundle; TT, transtibial.
[b]Defined as mild (presence of osteophytes, minimal JSN [<50%]), moderate (presence of osteophytes, definite JSN [~50%]), or severe (marked osteophytes, marked JSN, minimal joint space remaining, subchondral bone changes including geodes).
[c]Age at the time of radiographic follow-up.

To determine if there was a significant difference in the proportion of PTOA between the TT and AM ACLR approaches, weighted mean proportions were computed and compared. The weighted mean proportion of PTOA across the 16 studies was 40.6% (95% CI, 26.7%-54.5%). There was a significant degree of heterogeneity across the included studies (I^2 = 97.60; P < .001). When comparing the 2 techniques, the meta-analysis demonstrated a significantly greater proportion of PTOA in the TT group (mean, 49.3% [range, 8.3%-90.4%]) compared with the AM group (mean, 25.4% [range, 10%-55.9%]) (Z = –12.02; P < .001). A forest plot for the comparison of surgical techniques is reported in Figure 2.

Comparison of PTOA Rates by Midterm and Long-term Follow-up

To more precisely describe the influence of the surgical approach on PTOA, the included studies were divided into 2 groups: those with a 5- to 10-year follow-up (7 studies) and those with an 11- to 25-year follow-up (9 studies).

The 5- to 10-year follow-up group was composed of 420 patients with a mean follow-up of 7.2 years (range, 5.4-10 years). The weighted mean proportion of PTOA in this time frame was 42.7%. TT ACLR (53.7%) resulted in a significantly greater incidence of PTOA compared with the AM

TABLE 3
Methodological Quality Assessment of Included Studies[a]

First Author (Year)	Quality Scale	Score
Fithian[15] (2005)	Jadad	3/5 (study not blinded)
Matsumoto[29] (2006)	Jadad	1/5 (randomization not described, study not blinded)
Keays[23] (2007)	MINORS	24/24 (no points lost)
Kessler[24] (2008)	MINORS	17/24 (no a priori power analysis, baseline demographics not compared, nonconsecutive patients, follow-up not described)
Meuffels[31] (2009)	MINORS	21/24 (no a priori power analysis, loss to follow-up >5%)
Sajovic[39] (2011)	Jadad	3/5 (study not blinded)
Song[42] (2013)	Jadad	1/5 (randomization not described, study not blinded)
Janssen[21] (2013)	MINORS	20/24 (aim stated but nonspecific, no a priori power analysis, loss to follow-up >5%)
Barenius[4] (2014)	Jadad	0/5 (randomization not appropriate, not blinded, reasons for withdrawal not mentioned)
Webster[51] (2016)	Jadad	3/5 (study not blinded)
Bjornsson[7] (2016)	Jadad	5/5 (no points lost)
Karikis[22] (2016)	Jadad	5/5 (no points lost)
Risberg[38] (2016)	MINORS	20/24 (no a priori power analysis, loss to follow-up >5%, inadequate description of study endpoint assessment)
Tsoukas[44] (2016)	MINORS	22/24 (no a priori power analysis)
Chen[9] (2017)	MINORS	21/24 (no a priori power analysis, loss to follow-up >5%)
Lecoq[27] (2018)	MINORS	24/24 (no points lost)

[a]MINORS, Methodological Index for Non-Randomized Studies.

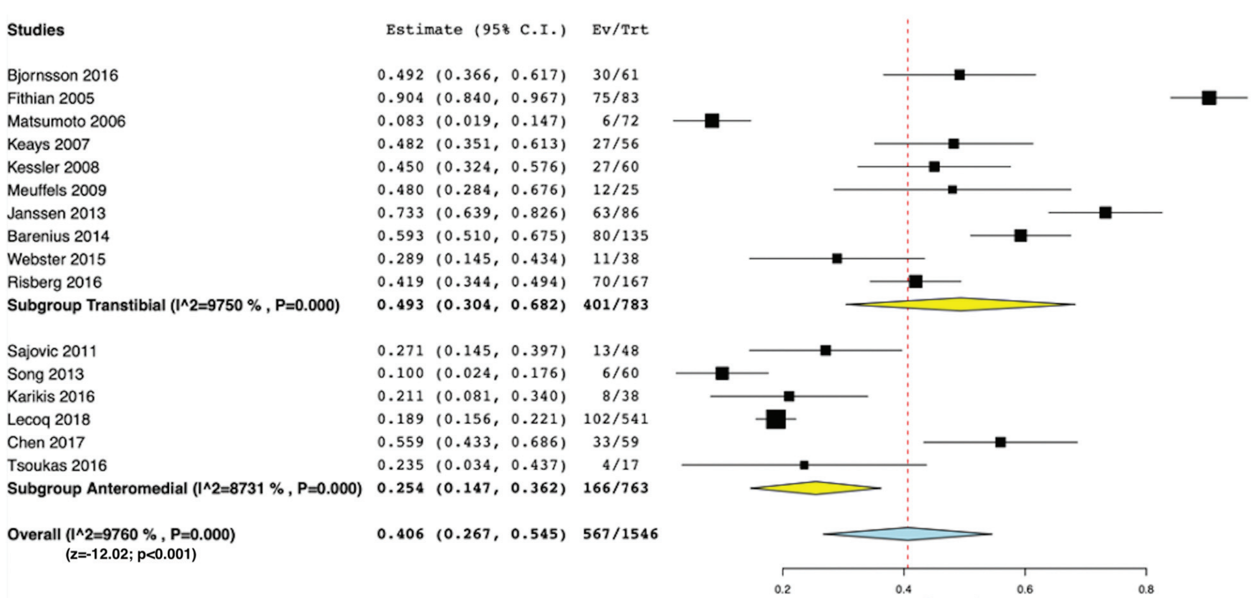

Figure 2. Forest plot comparing the proportion of radiographic posttraumatic osteoarthritis between the anteromedial and transtibial anterior cruciate ligament reconstruction approaches. The diamonds represent the mean and standard deviation for each surgical technique and overall for all included studies.

approach (14.2%) at 5- to 10-year follow-up (Z = 7.39; P < .001). A forest plot of this analysis is depicted in Figure 3.

The 11- to 25-year follow-up group was composed of 1126 patients with a mean follow-up of 13.7 years (range, 10.1-17.8 years). The overall weighted mean proportion of PTOA in this group was 39.1%. TT ACLR again resulted in a significantly greater rate of PTOA (45.6%) compared with the AM approach (31.2%) at long-term follow-up (Z = 8.58; P < .0001). A forest plot of this analysis is reported in Figure 4.

DISCUSSION

The most important finding from the current study was that the rates of radiographic PTOA after TT ACLR were

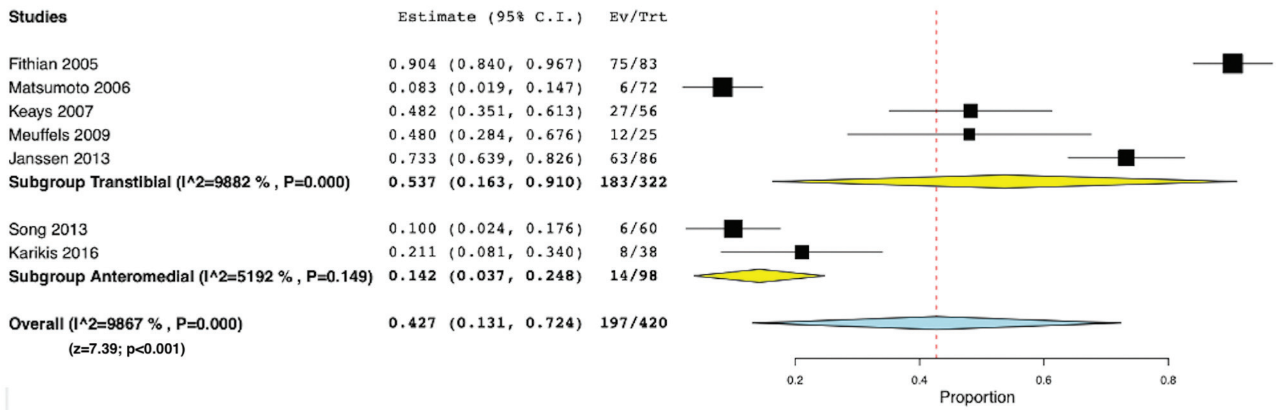

Figure 3. Forest plot comparing the proportion of radiographic posttraumatic osteoarthritis between the anteromedial and transtibial approaches at 5- to 10-year follow-up. The diamonds represent the mean and standard deviation for each surgical technique and overall for all included studies.

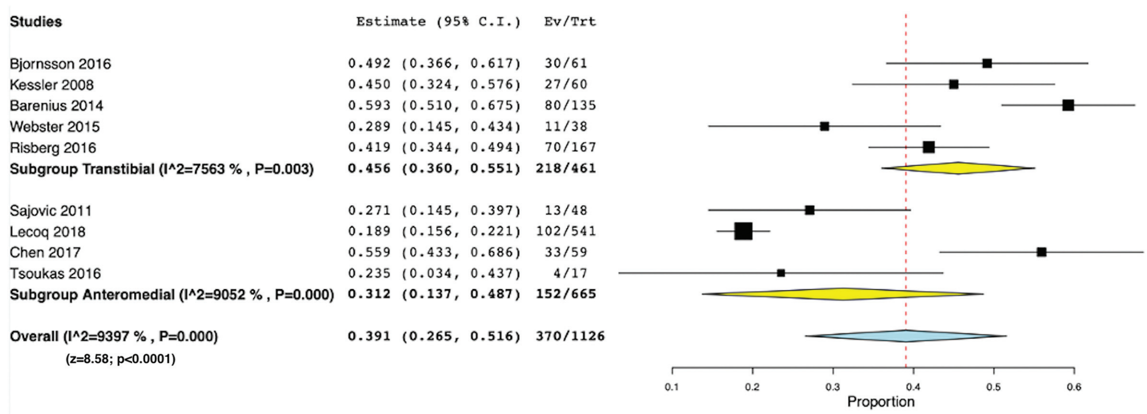

Figure 4. Forest plot comparing the proportion of radiographic posttraumatic osteoarthritis between the anteromedial and transtibial approaches at 11- to 25-year follow-up. The diamonds represent the mean and standard deviation for each surgical technique. The blue diamond represents the overall mean and standard deviation for all included studies.

significantly higher overall compared with the AM technique. Furthermore, subgroup analysis demonstrated that TT ACLR resulted in significantly higher rates of radiographic PTOA when follow-up ranges were restricted to both 5 to 10 years and greater than 10 years; however, it should be noted that there were significantly more patients included in the 11- to 25-year follow-up group compared with the 5- to 10-year group. Taken together, these findings suggest that anatomic placement of the ACL femoral tunnel may reduce the risk of PTOA development compared with a TT femoral tunnel position. Moreover, this reduction in PTOA using an anatomic approach can be expected at both midterm and long-term follow-up time points.

The current study found that the weighted proportion of radiographic PTOA among the 16 studies was 40.6% at a mean of 10.9 years and ranged widely across studies. Despite ACLR conferring reproducible and clinically meaningful improvements in pain and function,[33,34,46] these results suggest that a significant number of patients may go on to develop PTOA at midterm to long-term follow-up. Furthermore, the findings of this study suggest that the development of PTOA started relatively early, within the first decade after surgery, because 42.7% of the patients developed PTOA at 5- to 10-year follow-up. This is particularly interesting because the mean age at surgery among the studies was 28.5 years, suggesting that PTOA affects a relatively younger population than a general idiopathic OA population. The longest follow-up study[38] (TT approach) that reported radiological outcomes at a mean 17.8 years postoperatively showed that 41.9% of patients ultimately developed radiographic OA.[14] As many studies have reported asymmetry in knee kinematics and biomechanics after ACLR such as vertical forces,[43] gait patterns,[13] quadriceps strength and hop testing,[12] translation, and stability,[2] it is likely that the rate of eventual arthritic development is slightly increased secondary to such changes. However, future studies are warranted to determine direct causative effects and what factors influence early versus late development.

When controlling for the varying durations of follow-up among studies, the TT approach resulted in significantly higher rates of PTOA compared with the AM approach at both 5- to 10-year (53.7% vs 14.2%, respectively) and 11- to 25-year (45.6% vs 31.2%, respectively) follow-up. The placement of more anatomically aligned femoral tunnels achieved with an AM approach during primary ACLR has been reported to better restore knee stability and function.[5,50] Previous studies have indicated that there are optimal femoral tunnel positions along the wall of the lateral femoral condyle that better approximate the native ACL attachment.[16] The Bernard and Hertel radiographic quadrant classification concludes that the anatomic femoral ACL insertion is located at the posterior border of the lateral femoral condyle at approximately a quarter of the whole sagittal diameter of the condyle and from the roof of the notch at approximately a quarter of the notch height.[6] Pietrini et al[36] expanded on identifying radiographic landmarks for tunnel positioning by defining specific quantitative landmarks for double-bundle ACLR.[18,54] The authors also reported that the femoral attachments of both ACL bundles were horizontally aligned at 115° of knee flexion, while the posterolateral tibial attachment was located in the center of the tibia. The inability to anatomically restore the native ACL insertion on both the femur and tibia likely influences the development of radiographic PTOA. Interestingly, Ahn et al[1] studied 117 patients who underwent ACLR and reported that a sagittal tibial tunnel position was associated with an 18% increased odds of developing OA, which corresponded to the more central location of a TT graft relative to an AM graft. By reconstructing the native position of the ACL and better replicating intercondylar tunnel dimensions with the AM approach, femoral tunnel parameters such as graft fixation length, femoral tunnel axis, and femoral tunnel entry angle are optimized when compared with the TT technique.[35]

It is plausible that the less anatomic femoral tunnel position utilized during graft placement with the TT approach by creating a more central point of rotation leads to abnormal knee kinematics through less resistance to rotation and increased anterior translation.[26] This, in turn, may result in subsequent cartilage degeneration due to harsh intra-articular force vectors,[26] which increases the risk of developing OA. Additionally, utilizing the TT technique may result in a less anatomic, more posteriorly placed tibial tunnel position, which may further contribute to abnormal kinematics. With improved understanding of the anatomy and biomechanics of the ACL, the TT approach has also been modified to achieve a more anatomic femoral tunnel placement; however, the long-term outcomes and prevalence of PTOA with the modified TT approach are still lacking.

We acknowledge the limitations of the present investigation. Foremost, the strength of the conclusions that can be made is dependent on the quality of the studies eligible for inclusion. In addition, we were limited by significantly fewer studies reporting follow-up time points between 5 and 10 years compared with 11 and 25 years, and the percentages of radiographic OA should be interpreted accordingly. Furthermore, the evolution of surgical techniques over time such as increases in the utilization of the AM approach was likely accompanied by additional advances in the comprehensive treatment of ACL injuries from improved diagnoses, newer surgical equipment and implants, increasing rates of meniscal repair over meniscectomy, and improved rehabilitation protocols. Meniscectomy has been demonstrated to influence the rate of PTOA. Historically, meniscectomy was performed more frequently during the range of publication dates of the TT ACLR studies compared with the AM ACLR studies; this may have influenced the observed rates of PTOA. A more in-depth analysis on the effects of meniscal abnormalities and treatment was not performed because of significant underreporting and heterogeneity across the included studies.

However, we want to emphasize the efforts made in this systematic review to include the best evidence possible, including a comprehensive systematic query of the available literature and excluding studies with greater than level 3 evidence. Additionally, given the large number of patients included across studies and the robust meta-analysis that was performed, we are confident in the conclusions put forth. Another consideration exists in the definition of radiographic OA, which was heterogeneous among studies, as some authors classified OA as any degree of degenerative change, while others considered it only to be severe OA.

CONCLUSION

TT ACLR was associated with higher overall rates of radiographic PTOA compared with the AM ACLR approach. The rates of radiographic PTOA after ACLR with a TT approach were also significantly higher than using an AM approach when stratified by length of follow-up (5- to 10-year and >10-year follow-up).

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