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Review article

Comparison of Clinical Outcomes between Anteromedial and Transtibial Techniques of Single-Bundle Anterior Cruciate Ligament Reconstruction: A Systematic Review and Meta-Analysis

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Abstract
This study compared clinical outcomes obtained after single-bundle anterior cruciate ligament (ACL) reconstruction using the anteromedial (AM) and transtibial (TT) techniques, which comprise the conventional transtibial (cTT) and modified transtibial (mTT) techniques. This study included clinical randomized controlled trials and prospective and retrospective controlled trials with AM and TT techniques from the PubMed and Embase databases and the Cochrane Library. All databases were searched from January 2010 to July 2020. Two independent evaluators verified the quality of the included studies using the Cochrane Collaboration's risk of bias tool and the Newcastle-Ottawa Scale (NOS). Outcome measures analysed included the Lachman test, pivot-shift test, side-to-side difference (SSD), Lysholm score, Tegner activity scale, International Knee Documentation Committee (IKDC) grade and score. Ten randomized controlled trials (RCTs) and 16 prospective and retrospective controlled trials were included with a total of 2202 patients. There were 1180 patients and 1022 patients in the AM and TT groups, respectively. Compared to the cTT group, superior postoperative results were observed in the AM group based on the negative rate of the Lachman test and the pivot-shift test, IKDC grade and score, Lysholm score, Tegner activity scale and SSD ($p < 0.05$). However, there was no significant difference between the AM and mTT groups ($p > 0.05$). Compared to the conventional TT technique, the AM technique exhibited superior clinical outcomes. Nevertheless, the modified TT and AM techniques had comparable results. With neither of the techniques (mTT or AM) producing significantly superior outcomes, surgeons can choose either of them depending on their preferences.

Key words: Anterior cruciate ligament reconstruction, anteromedial, transtibial, modified transtibial, meta-analysis.

Introduction

Anterior cruciate ligament (ACL) tears are among the most common knee injuries, and single-bundle ACL reconstruction has increasingly become the standard method for restoring knee stability and function (Kopf et al., 2010; Duquin et al., 2009). Technology in ACL reconstruction has made great progress over the past few decades (Csintalan et al., 2008). Initially, the conventional transtibial (cTT) technique for drilling the femoral tunnel played an important role in single-bundle ACL reconstruction (Mirzatolooei, 2012), owing to its simplicity in creating tunnels (Robin et al., 2015). However, several studies have shown that the conventional TT technique may lead to ACL reconstruction failure due to the increased obliquity of the femoral tunnel and placement of the graft in a non-anatomic site (Arnold et al., 2001; Heming et al., 2007; Loh et al., 2003; Paessler et al., 2004). Independent drilling techniques, such as the anteromedial (AM) and outside-in (OI) methods, have been advocated for single-bundle ACL reconstruction (Bottoni 2008; Duquin et al., 2009; Chechik et al., 2013; Seo et al., 2013). To restore anatomical insertion of the ACL, AM and OI techniques create an additional incision for a solitary femoral tunnel on the anteromedial and outside-in aspects, which is efficient but challenging. Recently, the modified transtibial (mTT) method has been introduced to the field. Furthermore, some studies have shown that the mTT technique may result in the femoral tunnel being in a similar anatomic position with comparable clinical outcomes to the AM technique (Hussin et al., 2018; Lee et al., 2014; Youm et al., 2014).

Many studies have attempted to compare the cTT and AM techniques for single-bundle ACL reconstruction since 2010. Some of them reported that the AM technique yields superior outcomes. Based on the physical examination and functional outcome measures, two meta-analyses (Chen et al., 2017; Liu et al., 2017) agreed that the AM technique is superior to the cTT technique. However, several recent studies (Cury et al., 2017; Geng and Gai, 2018; Özer et al., 2018) also claimed that the two techniques are not significantly different. However, it is unclear whether the mTT technique yields similar clinical outcomes to those of the AM technique with respect to anatomical reconstruction. Consequently, in this meta-analysis, we reviewed and analysed the latest studies on TT and AM techniques in single-bundle ACL reconstruction to compare postoperative clinical outcomes between the cTT and AM techniques, as well as for mTT and AM techniques.

Methods

Search strategy

PubMed and Embase databases and the Cochrane Library were searched from January 2010 to July 2020. The following terms were searched in the title, abstract, MeSH and keyword fields: (TP OR Transportal OR Transtibial OR TT OR "modified transtibial" OR mTT) AND (AM OR Anteromedial Portal) AND ("Reconstructive Surgical Procedures" OR Arthroscopy OR "Joint instability" OR Reconstructions) AND ("Anterior Cruciate Ligament" OR ACL).

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Inclusion criteria and exclusion criteria

Inclusion criteria were as follows: 1) clinical studies comparing AM and TT (or mTT) techniques in ACL reconstruction; 2) patients who underwent primary arthroscopic single-bundle ACL reconstruction; and 3) complete reports on clinical outcomes, including the Lachman test, pivot-shift test, side-to-side difference (SSD), Lysholm score, Tegner activity score, IKDC grade or score.

Exclusion criteria were as follows: 1) comparisons that were not between AM and TT (or mTT) techniques in ACL reconstruction; 2) animal or cadaveric studies; 3) all patients underwent double-bundle ACL reconstruction; 4) absent reports on clinical outcomes; and 5) studies with a low level of evidence.

Literature selection

Two researchers (RL and TL) independently included and excluded studies based on titles, abstracts and full text. After reading the full text, the two researchers selected the studies that met the inclusion criteria. At the end of the selection, disagreements were resolved after discussion between two researchers.

Data extraction

Two researchers (RL and TL) independently checked all suitable studies using the data extraction sheet, and all disagreements were resolved by discussion. The extracted data included author, publication date, study design, patient demographics (sample size, sex and age), follow-up period, graft type, and clinical outcomes. If there were omitted outcomes, they were estimated using a specific method (Hozo et al., 2005) according to relevant original data.

Quality assessment

The same two researchers independently assessed the risk of bias for RCTs using the Cochrane Collaboration's tool (Higgins et al., 2003). The methodological quality of prospective and retrospective controlled trials was assessed using the Newcastle–Ottawa Assessment Scale (NOS) (Stang, 2010). In the NOS, there are three domains: selection, comparability and outcome. For the selection domain (four items) and outcome domain (three items), every item can be given a maximum of one star. The only item in the comparability domain can be given a maximum of two stars. A study can be awarded nine stars at most. Studies with ≥ 7, 5-6, 3-4, and 0-2 stars were identified as good, fair, poor-fair, and poor quality, respectively. For the Cochrane Collaboration's tool, there are seven domains: random sequence generation, allocation of concealment, performance bias, detection bias, attrition bias, reporting bias and other bias. The risk of bias was assessed as high, low and unclear.

Statistical analysis

The TT group was divided into cTT and mTT subgroups. The two subgroups were compared to the AM group.

This meta-analysis was conducted using Review Manager version 5.3 software (Copenhagen, The Nordic Cochrane Centre, The Cochrane Collaboration, 2014), and all extracted data were input and checked by the reviewers. For dichotomous data, odds ratio (OR) and 95% confidence interval (CI) were calculated. For continuous data, the weighted mean difference (WMD) was calculated with the 95% CI. The Chi-square test and inconsistency (I2) were used to estimate statistical heterogeneity. I2 values of 25, 50, and 75% were considered low, medium, and high heterogeneity, respectively. The fixed-effects model was used when I2 < 50%; otherwise, the random-effects model was applied. The Lachman test, pivot-shift test and IKDC grade were analysed as dichotomous variables, while the SSD, Lysholm score, Tegner activity scale and IKDC score were analysed as continuous variables. Publication bias was assessed by the Begg's test.

Results

Identification of studies

Three hundred sixty-two articles were selected after the initial search. Among these articles, 76 were excluded due to being identified as duplicates using endnote X8, and 255 were removed after review of the titles and abstracts. Five studies were excluded after reviewing the full text, as four studies lacked relevant clinical outcome parameters, and one study was low quality. Finally, 26 articles were included in our meta-analysis. A summary is presented in Figure 1.

Characteristics and quality of studies

The 26 selected articles included ten RCTs, 15 retrospective comparative studies and one prospective comparative study. Among the 26 included articles, 21 compared AM and cTT techniques, and the other five compared AM and mTT techniques. All basic information from the articles is shown in Table 1. These 26 studies included 2202 patients, of whom 1180 (53.6%) underwent the AM technique and 1022 (46.4%) received the TT technique for arthroscopic-assisted ACL reconstruction.

Only one study (Lee et al.,2014) used both single-bundle and double-bundle ACL reconstruction in the AM technique; therefore, the single-bundle data were extracted. One study (Cury et al.,2017) compared the AM, TT and OI techniques, while another study (Sohn et al.,2014) compared the AM, mTT and OI techniques. Likewise, data on the OI technique were excluded in the two studies.

In addition, we assessed the quality of the included studies using the Newcastle-Ottawa Quality Assessment scale (NOS) for nonrandomized trials and the Cochrane Collaboration's risk of bias tool for RCTs. The assessment results are summarized in Table 2 and Figure 2. All nonrandomized trials scoring ≥6 were of good or fair quality, and all RCTs were at low or unclear risk of bias.

Lachman test

Seventeen studies involving 1325 patients compared the cTT and AM techniques. The results suggested that the AM group had a significantly higher rate of postoperative negative Lachman tests than the cTT group (OR = 0.46, 95% CI: 0.35 to 0.60, P < 0.001). The data, analysed in a fixed-effects model, exhibited medium heterogeneity (p = 0.02, $I^2 = 46\%$). There were also 144 patients in two studies that compared the AM and mTT techniques with respect to the postoperative Lachman test. Through analysis using a fixed-effects model, no significant difference was found (OR = 1.31, 95% CI: 0.57 to 3.02, $p = 0.53$), and no heterogeneity was found in either study ($p = 0.69$, $I^2 = 0\%$) (Figure 3).

Pivot-shift test

Nineteen studies with a total of 1632 patients compared the postoperative pivot-shift test between the AM and cTT techniques with medium heterogeneity ($p = 0.02$, $I^2 = 44\%$). The results, analysed by a fixed-effects model, showed that the AM group had a significantly higher rate of postoperative negative pivot-shift test than the cTT group (OR = 0.46, 95% CI: 0.37 to 0.59, $p < 0.001$). Three studies with a total of 184 patients reported the postoperative pivot-shift test between the AM and mTT techniques. Furthermore, there was no significant difference between the AM and mTT groups analysed in a fixed-effects model (OR = 1.00, 95% CI: 0.47 to 2.14, $p = 1.00$). Low heterogeneity was found among the three studies ($p = 0.34$, $I^2 = 7\%$) (Figure 4).

IKDC grade

Twelve studies, contributing a total of 955 patients, reported the postoperative IKDC grade between the AM and cTT techniques with medium heterogeneity ($p = 0.07$, $I^2 = 41\%$). The proportion of patients with IKDC grade A was slightly higher in the AM group than in the cTT group after analysis in a fixed-effects model (OR = 0.73, 95% CI: 0.55 to 0.97, $p = 0.03$). There were 40 patients in one study comparing the postoperative IKDC grades of the AM and mTT techniques. The results were analysed with no significant difference using a fixed-effects model (OR = 0.81, 95% CI: 0.23 to 2.86, $p = 0.75$) (Figure 5).

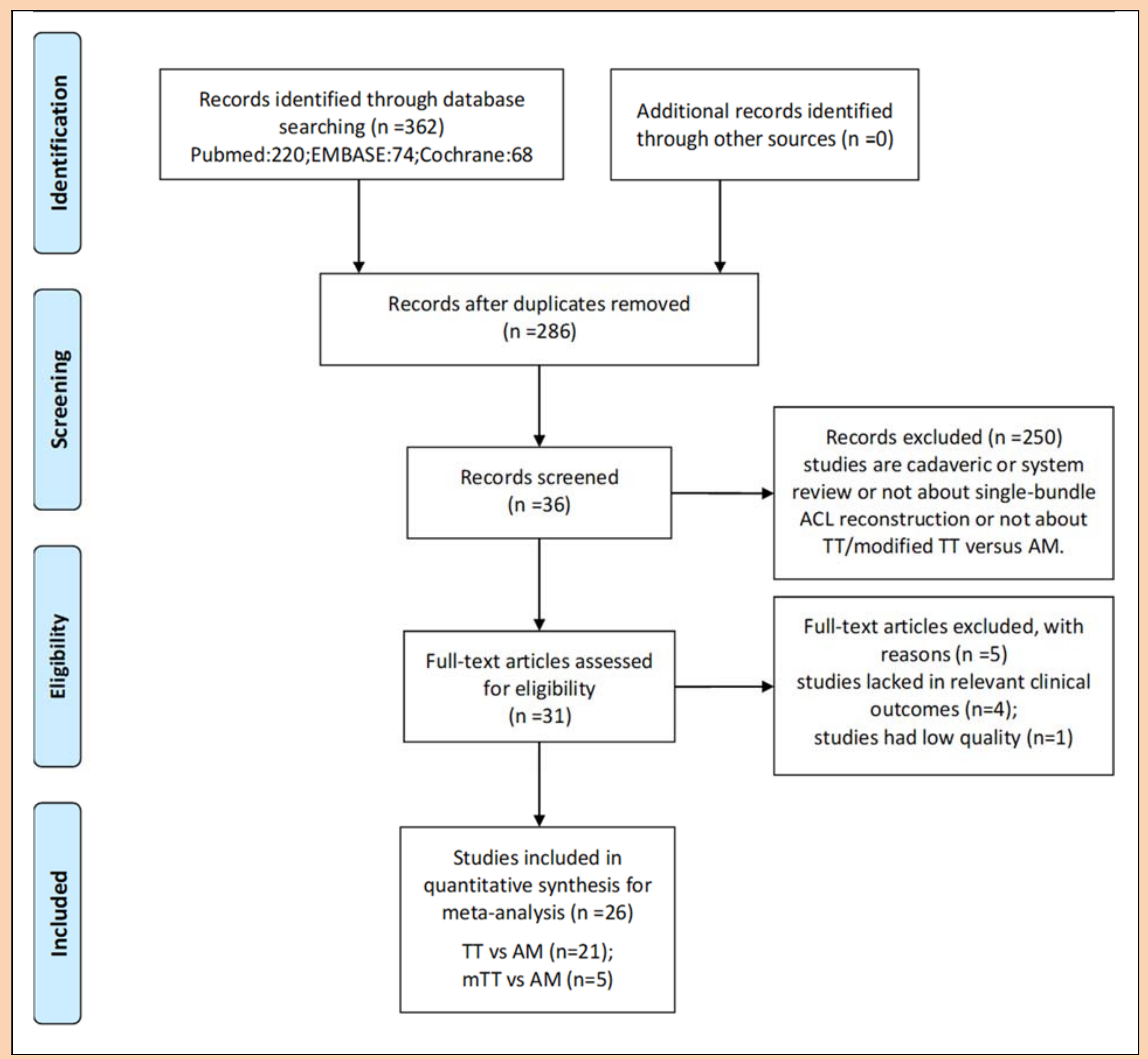

Figure 1. **Flowchart of the article selection process.**

Table 1. **Basic information of included articles.**

Author	Year	Study type	Mean age (years)	Minimum follow-up (months)	Sample size	Graft type	Index of clinical outcomes
Alentorn-Geli	2010		AM:26.4 TT27.5	24	AM:26 TT:21	auto BPTB	LKS; IKDC(G); TAS; LT; PST;
Azboy	2014		AM:27.6 TT:26.5	15	AM:30 TT:34	auto STG	LKS; IKDC(G); TAS; LT; PST;
Bohn	2015	RCT	AM:27.5± .2 TT:24.3±4.9	12	AM:12 TT:11	auto STG	LKS; IKDC(S); IKDC(G); TAS; LT; PST; SSD
Cury	2017		AM:37.1±11.7 TT:31.4±8	24	AM:30 TT:30	auto STG	LKS; IKDC(S); IKDC(G); LT; PST;
de Areu-e-Silva	2014		AM:31.1±10.7 TT: 29.6±8.7	24	AM:41 TT:30	auto Qua	LKS; IKDC(S); LT; PST
Franceschi	2013		AM:29 TT:28	60	AM:42 TT:46	auto STG	LKS; IKDC(G); LT; PST; SSD
Geng	2018	RCT	AM:31.8±11.0 TT:29.6±11.7	12-37	AM:56 TT:48	auto STG	LKS; IKDC(S); TAS; LT; PST; SSD
Guglielmetti	2014	RCT	<40	6	AM:38 TT:35	auto STG	IKDC(G); LT; PST;
Hussein	2012	RCT	AM:32.6 TT:34.2	AM:50.5 TT:52	AM:78 TT:72	auto STG	LKS; IKDC(S); IKDC(G); PST; SSD
Kim	2011		AM:29.8 TT:30.3	12	AM:33 TT:33	allo/auto BPTB	LKS; IKDC(G); LT; PST; SSD
MacDonald	2017	RCT	AM:32.4±8.9 TT:30.7±9.3	24	AM:46 TT:42	auto STG	IKDC(G); PST; SSD
Metso	2020		AM:34 TT:35	24	AM:59 TT:57	auto STG	IKDC(G); LT; PST;
Mirzatolooei	2012	RCT	AM:26.8 TT:26.6	18	AM:80 TT:88	auto STG	LKS; LT; PST; SSD
Noh	2013	RCT	AM:22 TT:24	AM:22 TT:24	AM:31 TT:30	allo Ach	LKS; IKDC(G); LT; PST; SSD
Özer	2018		AM:28.17±5.61 TT:28.07±7.42	12	AM:30 TT:30	auto STG	LKS; IKDC(S); TAS; LT;
Razazadeh	2016		AM:30.0±6.5 TT:30.6±6.5	12	AM:50 TT:44	auto STG	LKS; IKDC(S); TAS; LT; PST;
Sukur	2016		AM:26.8 TT:25.5	24	AM:56 TT:49	auto STG	LKS; IKDC(S); TAS; LT; PST;
Taşdemir	2015		AM:29.04±7.53 TT:29.73±6.33	19	AM:24 TT:15	auto STG	LKS; IKDC(S); LT; PST
Wei	2014		AM:31.5 TT:33.4	12	AM:42 TT:44	Auto STG	LKS; IKDC(S); LT; PST
Zehir	2015		AM:27.2±9.3 TT:28.3±8.8	12	AM:71 TT:58	auto STG	LKS; IKDC(G); TAS; PST; SSD
Zhang	2012	RCT	>28	12	AM:31 TT:34	auto STG	LKS; PST; SSD
Hussin	2018	RCT	16-39	12	AM:30 mTT:30	auto STG	LKS; IKDC(S)
Lee	2014		NR	24	AM:52 mTT:52	auto Qua	LKS; IKDC(S); TAS; LT; PST; SSD
Pande	2017		AM:31.16±7.73 mTT:29.35±7.95	24	AM:43 mTT:49	auto STG	LKS; IKDC(S); TAS;
Sohn	2014		AM:26.9 mTT:29.8	AM:12 mTT:13	AM:20 mTT:20	allo TAT	LKS; IKDC(S); TAS; PST;
Youm	2014	RCT	AM:27.6±9.9 mTT:29.7±11.9	19	AM:20 mTT:20	allo Ach	LKS; IKDC(S); IKDC(G); TAS; LT; PST

AM anteromedial, TT transtibial, mTT modified transtibial, RCT randomized controlled trial, IKDC(S) International Knee Documentation Committee score, IKDC(G) International Knee Documentation Committee grade, LKS Lysholm knee score, TAS Tegner activity score, LT Lachman test, PST Pivot-shift test, SSD side to side difference, NR not reported, auto auto, allo allo, STG semitendinosus and gracilis, Qua quadriceps, Ach Achille, BPTB bone patellar tendon bone, TAT tibialis anterior tendon.

Table 2. The Newcastle-Ottawa Assessment scale for included nonrandomized trials.

Study	Selection				Comparability of Cases and Control	Outcome			Total
	Case Definition Adequacy	Repres[1] of Case	Selection of Controls	Definition of Controls		Asc [2] of Exposure	Same Method of Asc [2] for Cases and Controls	Nonresponse Rate	
Alentorn-Geli, 2010	★		★	★	★	★	★		6
Azboy, 2014	★	★	★	★	★	★	★	★	8
Cury, 2017	★		★	★	★		★	★	6
de Abreu, 2014		★	★	★	★	★	★	★	7
Franceschi, 2013		★	★	★	★	★	★		6
Kim, 2011	★		★	★	★		★	★	6
Lee, 2014	★		★	★	★	★	★	★	7
Metso, 2020	★		★	★	★	★	★	★	7
Ozer, 2018	★		★	★	★	★	★		6
Pande, 2017		★	★	★	★	★	★	★	7
Razazadeh, 2016	★	★	★	★	★	★	★	★	8
Sohn, 2014	★		★	★	★		★	★	6
Sukur, 2016	★	★	★	★	★	★	★	★	8
Taşdemir, 2015	★		★	★	★	★	★	★	7
Wei, 2014	★		★	★	★	★		★	6
Zehir, 2015	★	★		★	★	★	★	★	7

[1] Repres = Representativenes; [2] Asc = Ascertainment

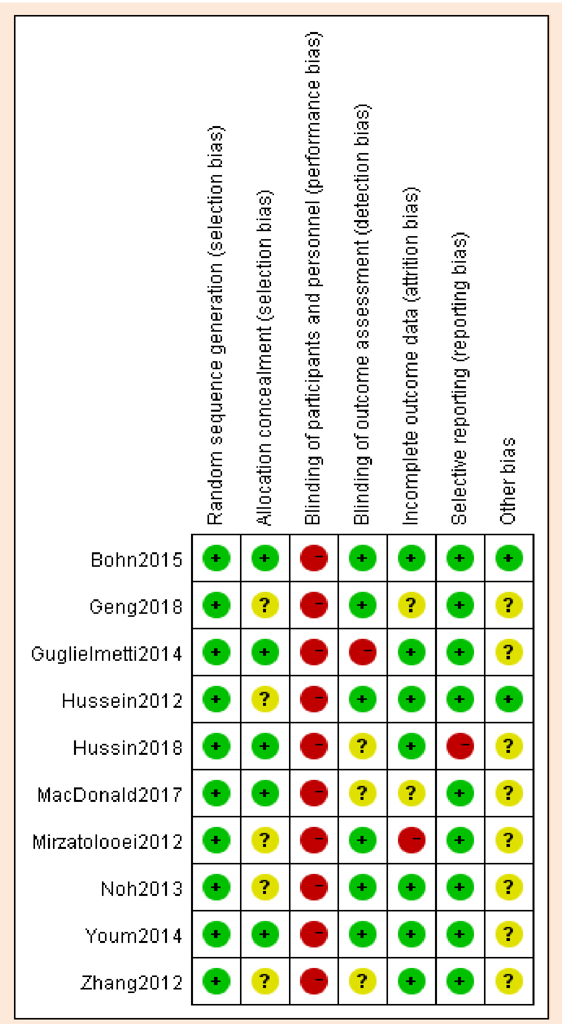

Figure 2. The Cochrane Collaboration's risk of bias tool for RCTs.

IKDC score

Ten studies reported the postoperative IKDC score between the AM and cTT techniques, involving 792 patients. An analysis was performed using a fixed-effects model. The results indicated that there was a significant difference between the AM and cTT groups (WMD = -1.22, 95% CI: -1.92 to -0.52, $p < 0.001$). The AM group exhibited a better postoperative IKDC score without heterogeneity ($p = 0.58$, $I^2 = 0\%$). In addition, 336 patients in five studies compared the AM and mTT techniques in terms of the postoperative IKDC score. Using the fixed-effects model, the results did not show any significant difference between the AM and mTT groups (WMD = -0.19, 95% CI: -0.55 to 0.18, $p = 0.32$). Medium heterogeneity was found among these studies ($p = 0.20$, $I^2 = 34\%$) (Figure 6).

Lysholm score

Sixteen studies with 1353 patients compared the postoperative Lysholm score between the AM and cTT techniques. The data, analysed using a fixed-effects model, exhibited medium heterogeneity ($p = 0.03$, $I^2 = 45\%$). The results suggested that the postoperative Lysholm score in the AM group was significantly higher than in the cTT group (WMD = -0.96, 95% CI: -1.38 to -0.55, $p < 0.001$). The postoperative Lysholm scores of 144 patients in two studies were analysed using a fixed-effects model, with a significant difference observed between the AM and mTT groups (WMD = -0.36, 95% CI: -0.73 to 0.01, $p = 0.06$). The data showed medium heterogeneity ($p = 0.16$, $I^2 = 39\%$) (Figure 7).

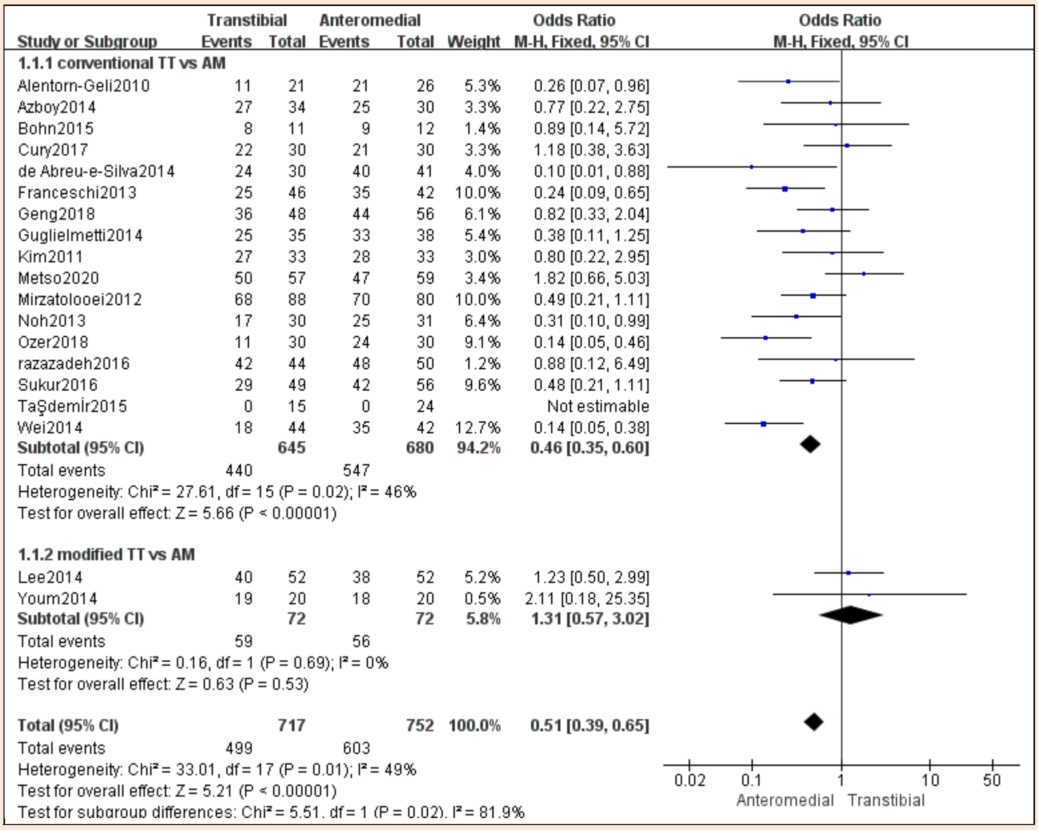

Figure 3. Forest plot of the postoperative negative Lachman test.

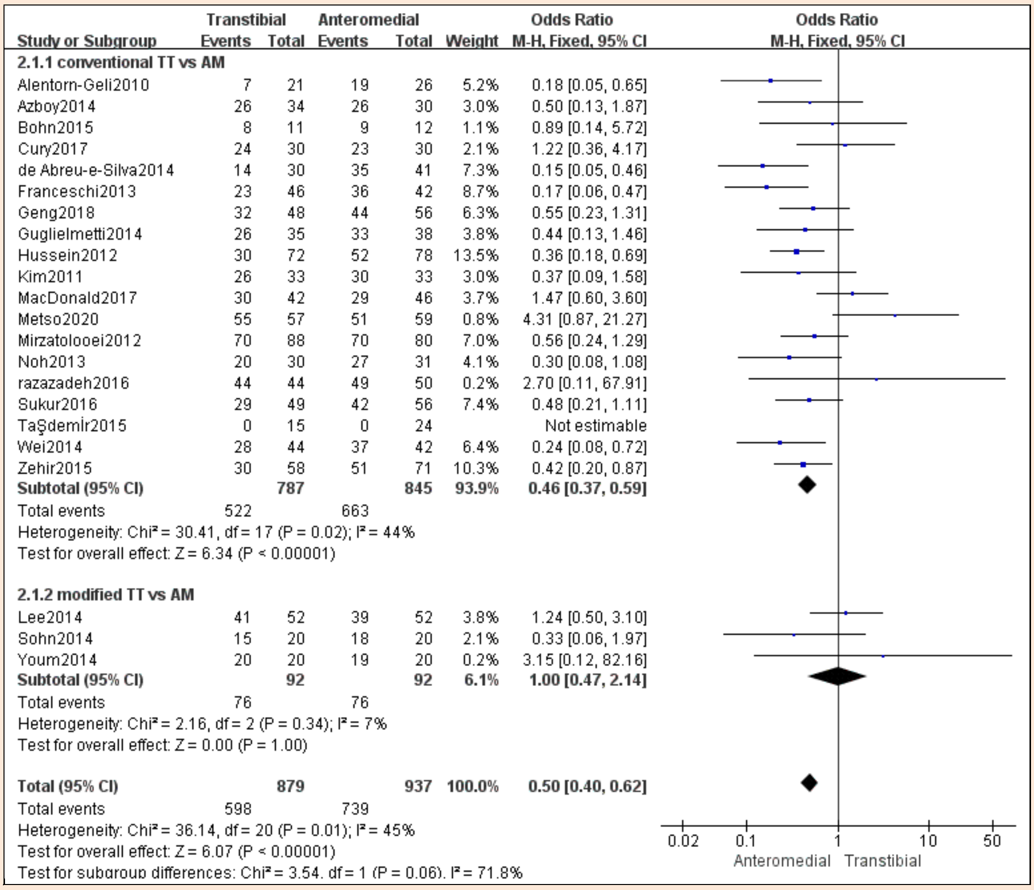

Figure 4. Forest plot of the postoperative negative pivot-shift test.

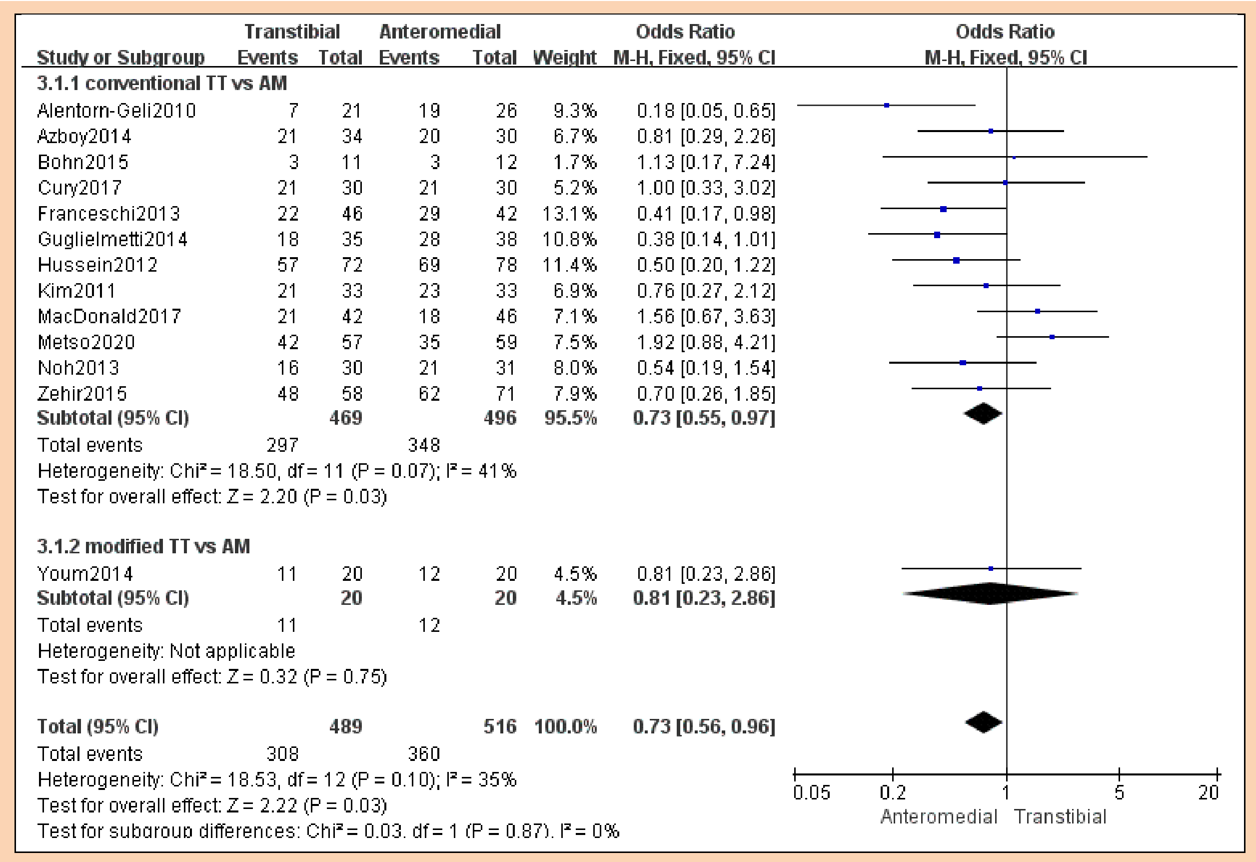

Figure 5. **Forest plot of the postoperative IKDC grade.**

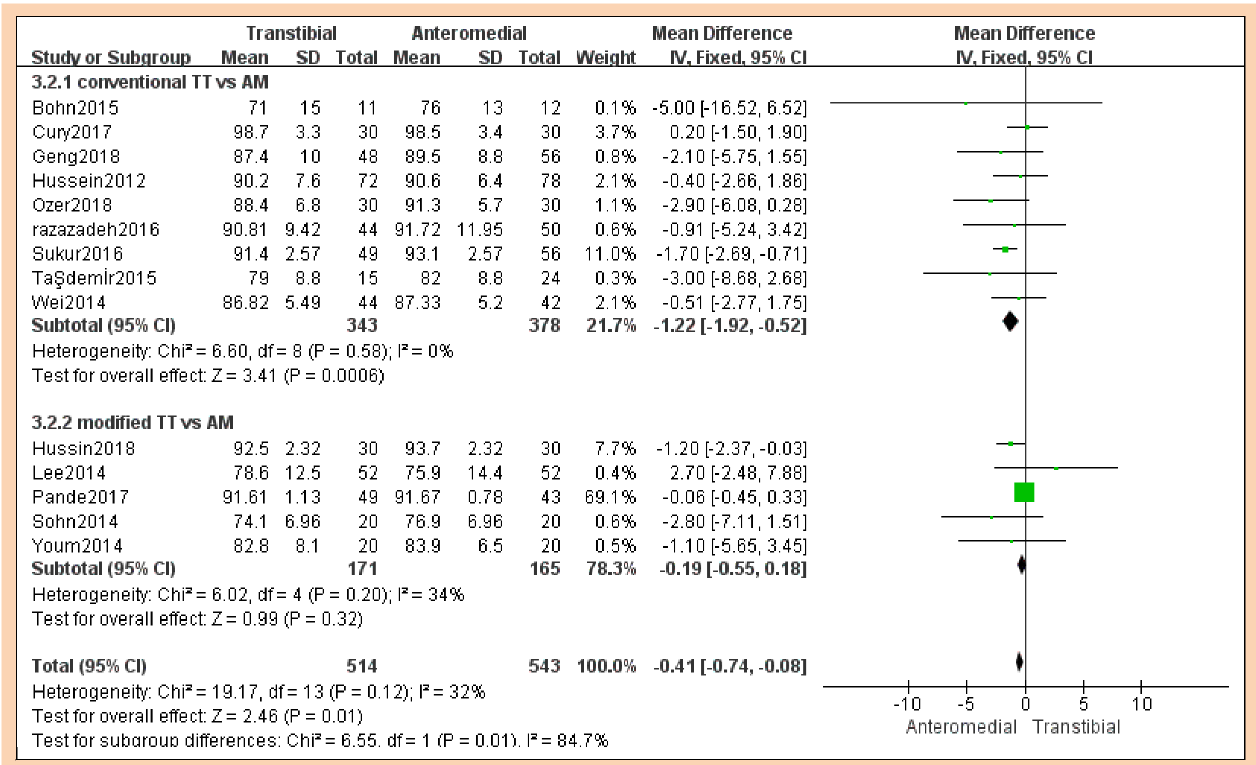

Figure 6. **Forest plot of the postoperative IKDC score.**

Tegner activity scale

Eight studies involving 626 patients reported the postoperative Tegner activity scale in the AM and cTT techniques. Analysis using a fixed-effects model indicated that there was a significant difference between the AM and cTT groups (WMD = -0.30, 95% CI: -0.49 to -0.12, p = 0.001), and the data showed no heterogeneity (p = 0.57, I^2 = 0%). Postoperative Lysholm scores of 276 patients in four studies were analysed using a fixed-effects model, with no significant difference observed between the AM and mTT groups (WMD = -0.03, 95% CI: -0.27 to 0.22, p = 0.83). The data showed no heterogeneity (p = 0.83, I^2 = 0%) (Figure 8).

Side-to-side difference

Nine studies reported postoperative SSD between the AM and cTT techniques, involving a total of 876 patients. Medium heterogeneity was identified among the studies (p = 0.19, I^2 = 29%). The results indicated that the postoperative SSD in the cTT group was significantly higher than in the AM group (WMD = 0.33, 95% CI: 0.19 to 0.47, p < 0.001). In addition, in the postoperative SSD between the AM and mTT techniques, a study with 92 patients indicated no significant differences between the two groups (WMD = 0.00, 95% CI: -0.57 to 0.57, p = 1.00). The results were analysed using a fixed-effects model. The KT-1000 knee arthrometer was applied to all 10 studies (Figure 9).

Sensitivity analysis

In this meta-analysis, we also performed a series of sensitivity analyses to evaluate the pooled results' stability. The sensitivity analysis was performed by classifying studies as RCTs or nonrandomized trials based on their comparison between cTT and AM techniques. When RCTs were included, there were significant changes in the Lachman test (OR = 0.52, 95% CI: 0.32 to 0.83, p = 0.006), the pivotshift test (OR = 0.54, 95% CI: 0.38 to 0.77, p < 0.0006), the Lysholm score (WMD = -0.74, 95% CI: -1.22 to -0.27, p = 0.002) and the SSD (WMD = 0.34, 95% CI: 0.19 to 0.50, p < 0.001). Compared to the mTT and AM techniques, there were sufficient data only on the IKDC score and the Lysholm score. Consequently, the sensitivity analysis between the mTT and AM subgroups was performed in two terms, as mentioned above. We also classified the included studies by graft type. When the two studies with allografts were included, the data showed that the AM group was superior to the mTT group in the Lysholm score (WMD = -1.98, 95% CI: -3.71 to -0.25, p = 0.02), but no changes were found in the IKDC score. There was no significant change when the three studies with autografts were included.

Publication bias

To ensure accuracy, the Lachman test and the IKDC score were chosen as indicators in the cTT and mTT subgroups. Publication bias was not observed in either the cTT (p = 0.93) or the mTT subgroups (p = 1.00) using Begg's test.

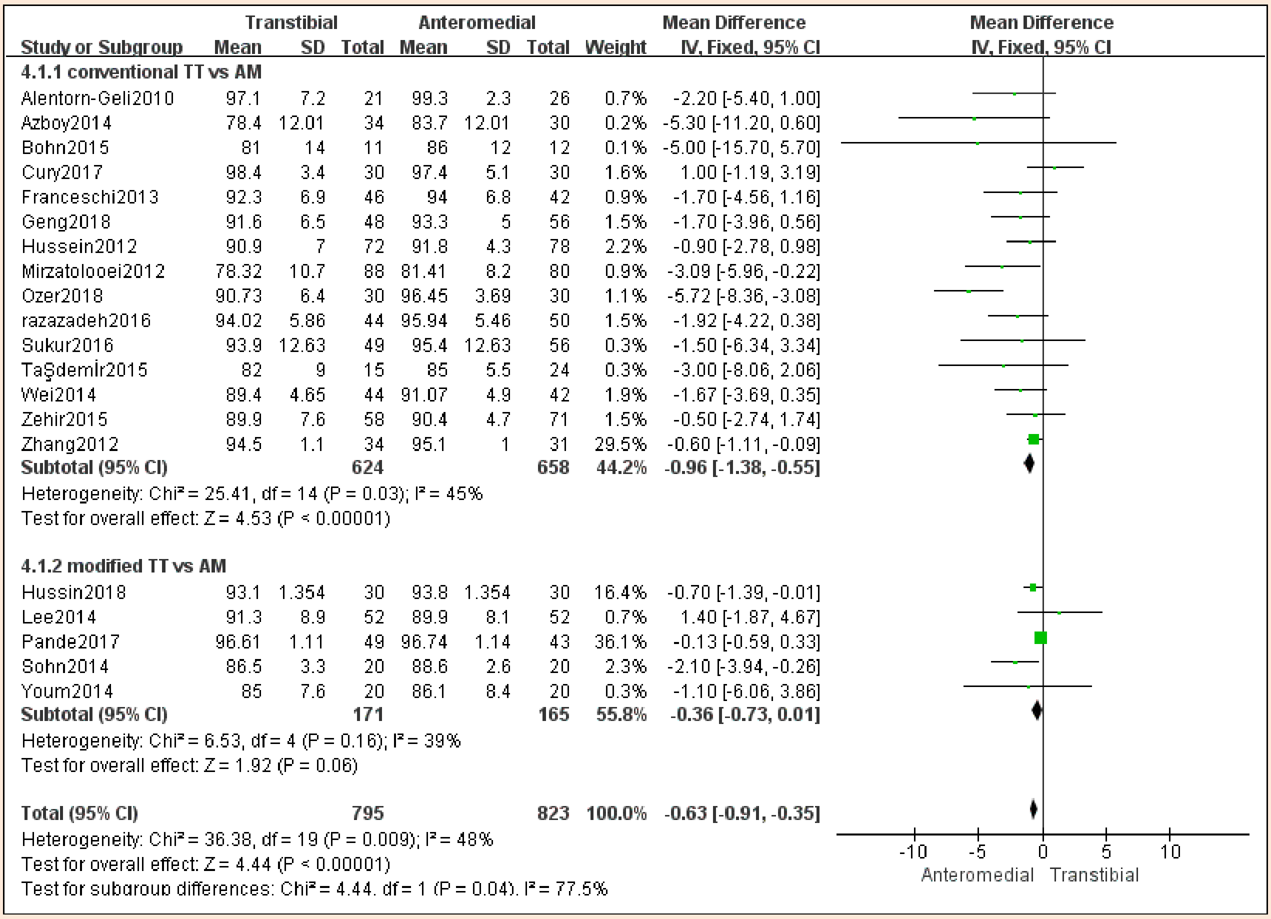

Figure 7. Forest plot of the postoperative Lysholm score.

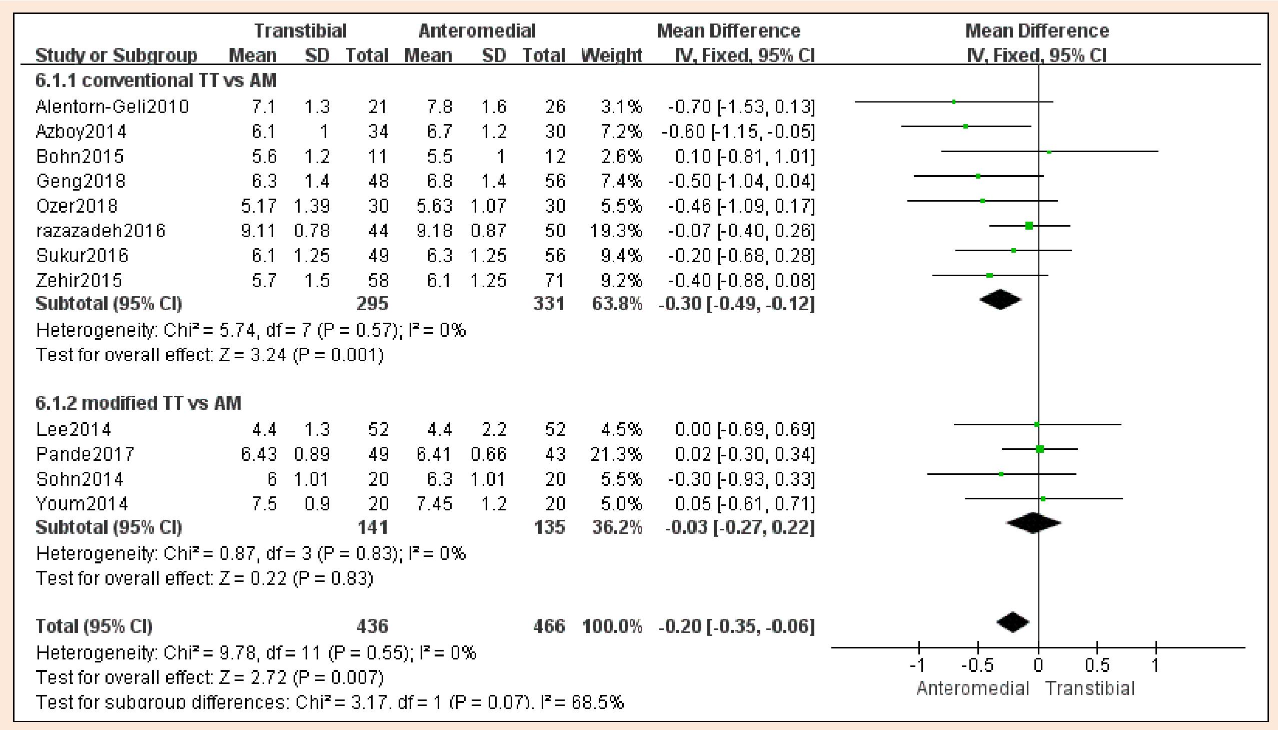

Figure 8. Forest plot of the postoperative Tegner activity scale.

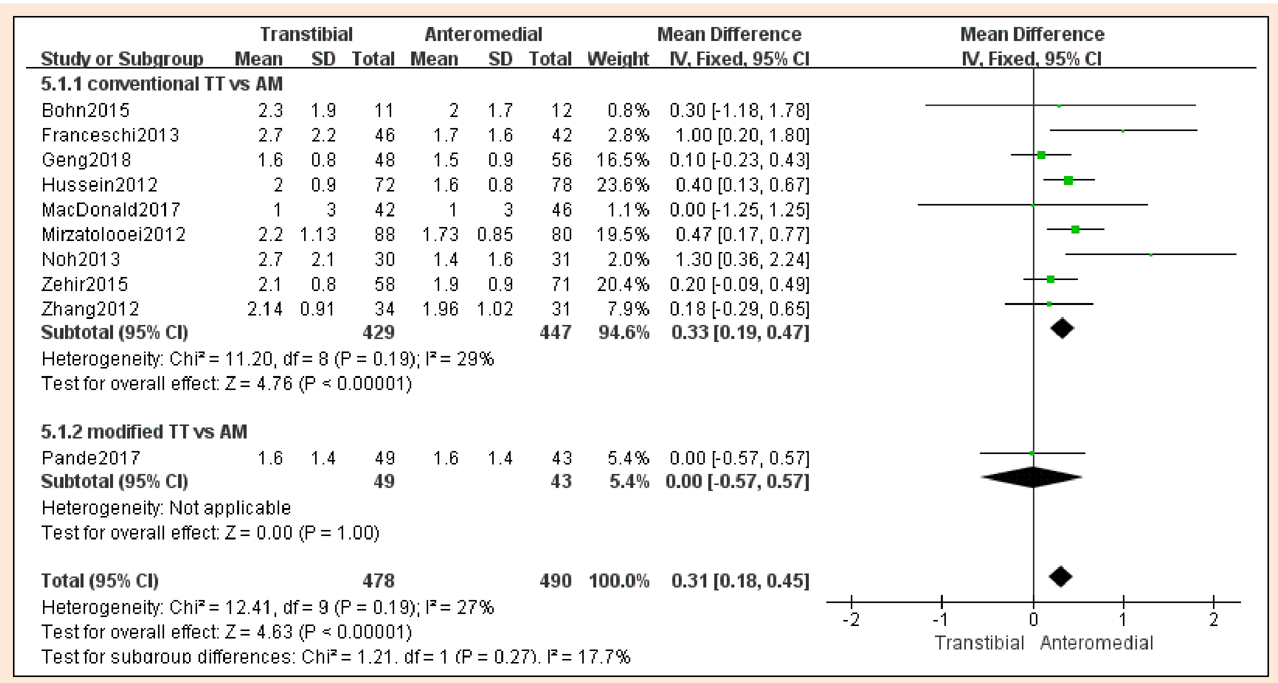

Figure 9. Forest plot of the postoperative side-to-side difference.

Discussion

In our meta-analysis, one of the most important findings is that, compared to the cTT technique, the AM technique is superior in clinical outcome parameters for single-bundle ACL reconstruction, including the negative rate of Lachman test and Pivot-shift test, the proportion with IKDC grade A, the IKDC score, the Lysholm score, Tegner activity scale and SSD. However, no significant difference was found in the abovementioned terms between the AM and mTT techniques in single-bundle ACL reconstruction.

The reason that these differences exist has not been elucidated. This may be because of the biomechanics, especially the position of the femoral tunnel. As with traditional isometric and non-anatomic reconstruction, the cTT technique places the femoral tunnel more superiorly and anteriorly or rather vertically than the native femoral ACL site (Arnold et al., 2001; Dargel et al., 2009; Paessler et al., 2004). As an anatomical reconstruction, the AM technique does more horizontally, where the centre of the femoral tunnel drilled is nearer to the native ACL footprint (Strauss et al., 2011; Osti et al., 2015; Jennings et al., 2017; Venosa et al., 2017). Anatomical ACL reconstruction involves placement of the femoral tunnel at the centre of the original femoral footprint (Xu et al., 2016). Furthermore, the femoral tunnel being in a more anatomical position benefits the knee's anterior-posterior and rotational stability (Lee et al., 2014; Tasdemir et al., 2015; Kilinc et al., 2016) because of translational and tensioning patterns similar to the native ACL (Zhang et al., 2012; Zavras et al., 2005). In our meta-analysis, this finding is supported by the lower SSD and the greater percentage of the negative rate of the postoperative Lachman test and pivot-shift test in the AM group. The cTT exhibits weak anti-rotation force (Franceschi et al., 2013; Inderhaug et al., 2013) and fails to prevent knee osteoarthritis (Ro et al., 2018), which may directly affect the long-term efficacy of ACL reconstruction. The cTT technique may result in feelings or motions of instability when patients perform daily activities after undergoing ACL reconstruction, which is likely to decrease postoperative functional outcomes (Ro et al., 2018). This seems to result in a worse postoperative Lysholm score, IKDC score, Tegner activity scale and a lower proportion of IKDC grade A in the cTT group.

Although the AM technique has been advocated for anatomic single-bundle ACL reconstruction, there are still some drawbacks. For instance, the AM technique leads to a limited arthroscopic view and a shorter femoral tunnel (Lubowitz, 2009; Bedi et al., 2010). Additionally, it is possible to cause posterior wall blowout and damage the posterior articular cartilage (Nakamura et al., 2009; Koutras et al., 2013; Rahr-Wagner et al., 2013). Thus, several surgeons have suggested several simple technical modification of the conventional TT technique, which may overcome the limitations of the AM technique. Youm et al. (2014) created the femoral tunnel by positioning the tibia in internal rotation and varus alignment. Lee et al. (2014) attempted this technique when an anterior drawer force, a varus force and an external rotation force were applied to the tibia. Other surgeons claimed that the external rotation of the femoral guide or a far medial entry into the tibia could achieve an extra few degrees of obliquity in the femoral tunnel (Sohn et al., 2014; Hussin et al., 2018; Pande et al., 2017; Golish et al., 2007). Some studies have shown that the mTT technique has better clinical outcomes and stability (Salinas et al., 2017), while some have indicated that both techniques have similar clinical outcomes (Pande et al., 2017; Youm et al., 2014; Hussin et al., 2018). Our meta-analysis supports the idea that the mTT and AM techniques have comparable clinical outcomes. Given this, surgeons can choose the one with which they are more familiar.

The mTT technique was optimized based on the cTT technique to achieve anatomical reconstruction. Anatomically placing tibial and femoral tunnels has obtained a consensus in the literature for providing the preferred results (Alentorn-Geli et al., 2010; Kopf et al., 2010; Arnold et al., 2001). Comparison between the AM and mTT techniques is of greater clinical significance. Furthermore, there are deficient data comparing the cTT and mTT techniques. Consequently, we did not compare the cTT and mTT techniques.

Furthermore, Chen et al. (2015) concluded that they did not observe a significant difference in functional outcomes, but in stability, after comparing the AM and cTT techniques. This study only included three RCTs and one study in double-bundle ACL reconstruction, with a total of 10 included studies, which lacked the Tegner activity scale and SSD. Liu et al. (2017) reported that the AM technique was superior to the cTT technique based on both physical examination and scoring system results. Similarly, this study analysed only nine studies from 2010 to 2014, involving six retrospective comparative studies, lacking randomization and blinding. Chen et al. (2017) reported that the AM technique performed better in terms of postoperative stability and functional outcomes compared to the cTT technique in single-bundle ACL reconstruction. However, only five studies were included, incurring limitations of small sample size and relevant data. In contrast, there were 10 RCTs in the 26 included studies in our meta-analysis, with a rich set of data. Second, only studies comparing single-bundle ACL reconstruction were included. Finally, we added analysis of an mTT subgroup compared to the AM group to explore whether the AM or mTT techniques presented better clinical outcomes.

There are some limitations in our meta-analysis. First, retrospective studies lacked randomization and blinding, although we had already excluded low-quality studies. Second, the graft types, follow-up period and surgical performance were varied, possibly affecting the heterogeneity. Although we cannot neglect the influence of the graft type on the results, we only included the soft tissue graft instead of artificial ligaments, which reduced the heterogeneity to the greatest extent. The third limitation refers to the time to return to sports and rate of re-rupture, which were also recorded, but there were insufficient data from the included studies to be pooled for meta-analysis, and the data were measured using different methods. Finally, considering the small sample size, the comparison between the AM and mTT techniques needs more data to support credible long-term conclusions.

Conclusion

Compared to the conventional TT technique, the AM technique exhibited superior clinical outcomes. Nevertheless, the modified TT and AM techniques presented comparable results. With neither of the techniques (mTT and AM) producing significantly superior outcomes, surgeons can choose either of them, depending on their preferences.

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Key points

- This meta-analysis was conducted based on the latest studies about the cTT, mTT and AM techniques.
- Compared to the cTT technique, the AM technique showed superior clinical outcomes.
- The mTT and AM techniques had comparable clinical outcomes.
- Surgeons can choose the one between the mTT and AM techniques, depending on their preferences.

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