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REVIEW

Transtibial versus anteromedial transportal femoral tunnel in single-bundle anterior cruciate ligament reconstruction: a systematic review and meta-analysis of prospective randomized controlled trials

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Abstract
The purpose of this study was to systematically review and meta-analyze randomized controlled trials (RCTs) reporting the comparative clinical and functional outcomes, postoperative complications, and radiological outcomes of single-bundle anterior cruciate ligament reconstruction (ACLR) performed using the transtibial (TT) approach or anteromedial (AM) technique. A systematic review of the literature was performed according to Cochrane and PRISMA guidelines. RCTs comparing TT and AM techniques were considered only. The quality of the studies was defined using the GRADE system, and the risk of bias was assessed with the RoB 2 tool. The primary endpoint was to systematically review and meta-analyze the clinical outcomes, residual laxity and failure rate of both AM and TT techniques. In the current meta-analysis 13 RCTs involving 989 patients who underwent arthroscopic single-bundle ACLR (486 TT and 503 AM) were included. Patients undergoing AM technique resulted in higher objective-IKDC ($p<0.001$) and Lysholm scores ($p=0.002$), despite a lower incidence of pathological anterior tibial translation ($p<0.001$) and positive pivot-shift test ($p<0.001$). No differences were detected in IKDC subjective score ($p=0.26$), Tegner activity scale ($p=0.18$) and graft failure ($p=0.07$). ACL reconstruction through AM portal technique provides better clinical outcomes and lower incidence of residual rotational and anteroposterior laxity in comparison with the TT technique. No statistically significant difference in subjective outcomes and graft failure was reported.

Keywords Transtibial · Anteromedial · Transportal · Arthroscopy · Knee

Introduction

Anterior cruciate ligament (ACL) rupture is one of the most common knee injuries affecting more than 200,000 patients every year [1, 2]. Arthroscopic ACL reconstruction is recommended to restore knee stability in young patients, particularly those hoping to return to pivoting sports, and more than 120,000 procedures are performed every year in United States [3, 4].

National web-based registries revealed that the most commonly used technique to perform ACL reconstruction is the single-bundle [5–7]. However, different strategies for ACL femoral tunnel drilling have been described, including the arthroscopic transtibial (TT) technique, anteromedial (AM) portal technique, outside-in, and retrograde drilling [8].

The discrepancy between the tunnel position and the native ACL insertion site with the TT technique has been criticized by some authors as potentially leading to a "non-anatomical" ACL reconstruction and positioning of the graft in a more vertical orientation [9].

The popularity of tibial-independent femoral tunnel techniques has increased over the years to improve the accuracy of femoral tunnel placement achieving a more anatomic ACL position [10].

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Despite the growing interest in the AM portal drilling technique, some studies reported an increased risk of revision compared to the traditional TT technique [11, 12].

Many clinical trials have evaluated the drilling of femoral tunnels through the AM and TT portals during ACL reconstruction, but there is no high-quality and updated, evidence-based agreement on which approach results in the best outcomes and the literature is often inconclusive [13–15].

The purpose of this study is to systematically review and meta-analyze randomized controlled trials reporting the comparative clinical and functional outcomes, postoperative complications, and radiological outcomes of single-bundle anterior cruciate ligament reconstruction (ACLR) performed using the TT approach or AM technique.

Materials and methods

Criteria for considering studies for this review

Prospective randomized studies reporting comparative outcomes of arthroscopic ACL reconstruction performed with TT and AM transportal femoral drilling were considered eligible for inclusion.

Participants were patients with a diagnosis of ACL rupture with an indication of ACL reconstruction.

Non-randomized trials, cohort studies, retrospective studies, case reports, technical notes, editorial commentaries, ex vivo, biomechanical, pre-clinical, and clinical studies without adequate quantitative or qualitative data were excluded.

The primary endpoint of this research was to systematically review and meta-analyze the clinical outcome in patients who were randomized for the TT approach or AM technique in ACL reconstruction.

The primary outcome measure was considered the IKDC objective score.

Secondary endpoints were to assess and compare the objective anterior laxity, the pivot-shift test, the subjective IKDC score, the Lysholm score, the Tegner scale, the failure rate and the femoral tunnel length.

Search methods for identification of studies

A systematic review of the literature has been performed, following the Cochrane Handbook of Systematic Reviews of Interventions [16] and Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) [17] for study selection (Fig. 1).

A systematic search from January 1st, 1990, to January 1st, 2023, was performed in the following databases: the Cochrane Central Register of Controlled Trials (CENTRAL), MEDLINE/PubMed, Embase, Scopus, the Science Citation Index Expanded from Web of Science, ScienceDirect, CINAHL, and LILACS. The research was conducted using the following keywords alone and in all the various combinations: "ACL" AND "anterior cruciate ligament" AND "reconstruction" AND "transtibial" OR "conventional" AND "anteromedial" OR "transportal."

The selection process was based on the participants, intervention, control, outcome, and study design (PICOS).

Two reviewers (AMM, PG) independently screened each title and abstract collected from the primary electronic search. In case of a relevant title and abstract, the full-text version was obtained.

All references of each study were screened to find any additional relevant paper potentially missed with the first review process. The two reviewers independently followed the same checklist to screen all studies and evaluate the eligibility criteria. Disagreements were resolved by consensus agreement with a third reviewer (TD).

Data collection and analysis

The level of evidence of included studies was evaluated through the adjusted Oxford Centre For Evidence-Based Medicine 2011 Levels of Evidence [18]. The quality of the studies was defined using the grading of recommendations assessment, development, and evaluation (GRADE) system [19], rating the quality of evidence in systematic reviews. After the evidence is collected and summarized, the GRADE system provides explicit criteria for rating the quality of evidence that include study design, risk of bias, imprecision, inconsistency, indirectness, and magnitude of effect.

The risk of bias was assessed with the revised tool to assess the risk of bias in randomized trials (RoB 2) and are reported in Fig. 2 [20].

Stepwise analysis of study design, aim of the study, level of evidence, journal, year of publication, country, number of procedures included in the study, graft type, femoral and tibial fixation, mean age, and follow-up were independently conducted by each reviewer. Discrepancies in data extraction were discussed and resolved by a consensus meeting between the authors.

All studies were assessed for the primary and secondary outcome measures.

The analysis was conducted separately for patients with an AM or transportal ACL reconstruction (study group) and patients with a TT or conventional technique (comparator).

Data were extracted and recorded for a stepwise analysis. Basic information about each study including population features, country, number of patients, mean age at surgery, study design, level of evidence, and mean follow-up was extracted and is summarized in Table 1.

Specific features of measured outcomes were accurately assessed, and data are summarized in Table 2.

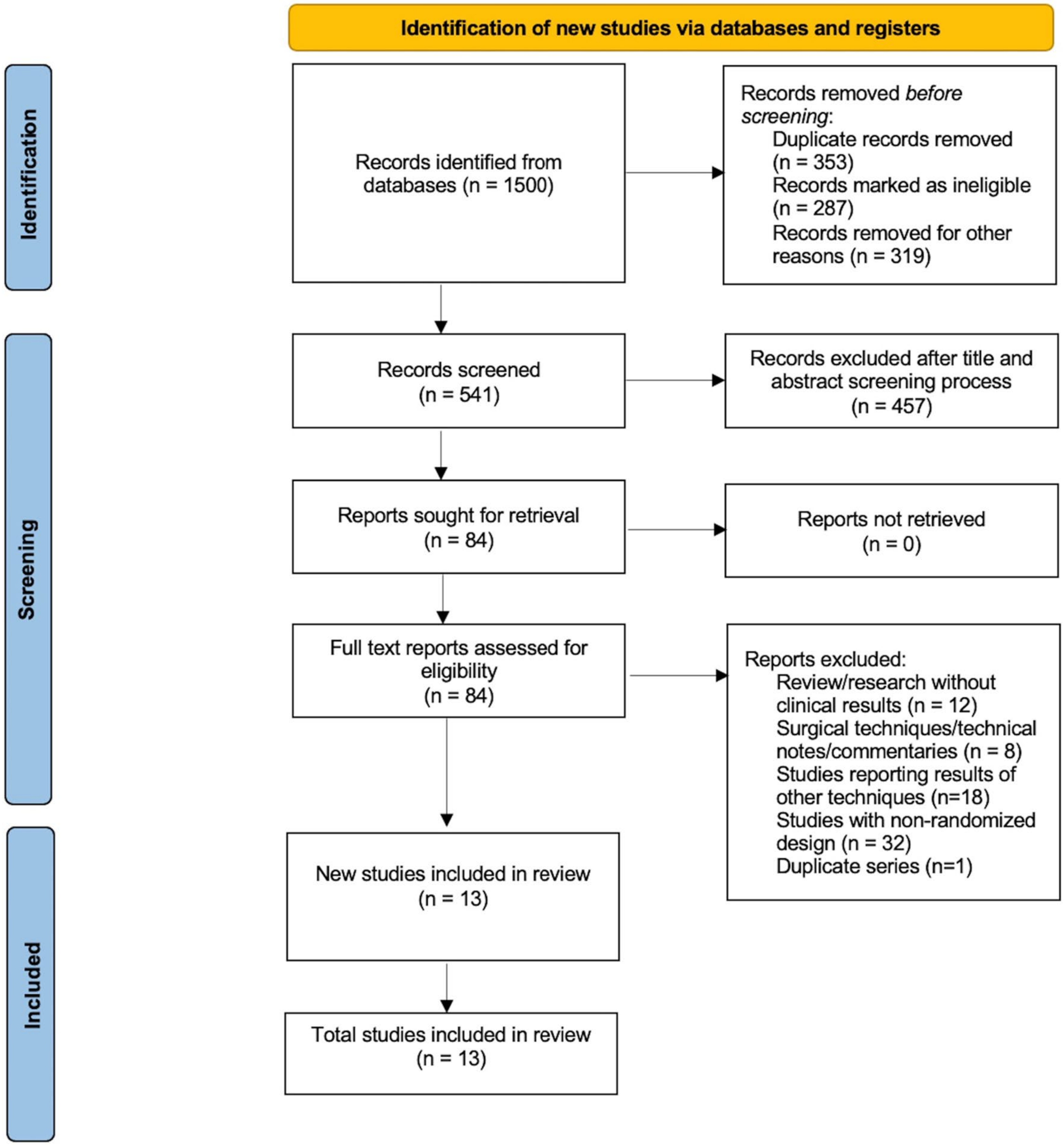

Fig. 1 The PRISMA flowchart for study selection

Statistical analysis

All analyses were completed with Review Manager 5.4.1 software (Cochrane Collaboration, Oxford, UK), and a *p* value funnel plot was used to analyze the existence of publication bias for the primary outcome measure (Fig. 3).

For each included study, mean differences (MD) and 95% CI were calculated for continuous outcomes, while risk ratio (RR) and 95% CI were calculated for dichotomous outcomes.

Statistical heterogeneity among the studies was assessed using the χ^2 test and I^2. A fixed-effect model was applied when $I^2 < 40\%$, and a random-effect model when $I^2 \geq 40\%$.

A *p* value of less than 0.05 was considered statistically significant.

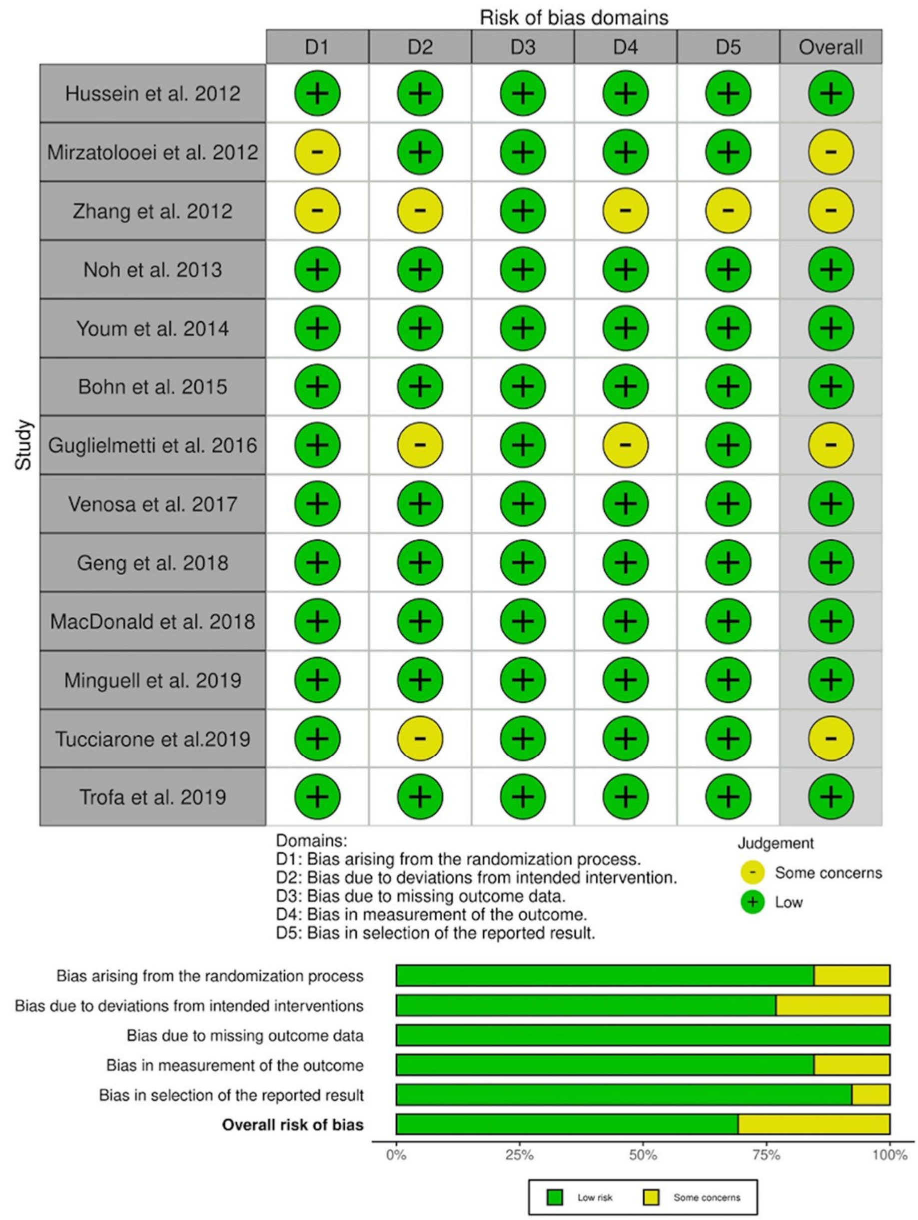

Fig. 2 Risk of bias assessment with RoB 2 tool

Results

Description of the studies

A total of 1500 records were identified from the electronic database research. After initial screening, 87 studies were retrieved for a full assessment. A total of 13 prospective randomized studies [21–33] involving 989 patients who underwent arthroscopic single bundle ACL reconstruction (486 in the TT group and 503 in the AM group) were finally included in this systematic review. The summary of the selection process is reported in Fig. 1.

The analysis of the risk of bias revealed that 4 studies [22, 23, 27, 31] had some concerns and 9 studies [21, 24–26, 28–30, 32, 33] had a low risk of bias (Fig. 2).

The analysis of the quality of the studies according to the GRADE system revealed that 5 studies [21, 29, 30, 32, 33] had high quality, 2 studies [23, 28] had moderate quality, and the remaining 6 studies [22, 24–27, 31] had low quality.

The details of GRADE assessment are reported in electronic supplemental materials (ESM).

Table 1 General characteristics of the included studies

Author	Year	Country	Total number of patients	TT group/ AM group	Mean age TT group/ AM group	Gender (male/female)	Study design	Level of evidence	Mean follow-up (months)	Risk of bias (Rob 2.0)
Hussein et al. [21]	2012	Slovenia	150	72/78	32.6/34.2	TT 45/27 AM 46/32 91/59	RCT	Level I	TT 52 (39–36) AM 50.5 (39–63)	Low
Mirzatolooei et al. [22]	2012	Iran	168	88/80	26.8/26.6	TT 84/4 AM 79/1 163/5	RCT	Level I	24	Some concern
Zhang Q et al. [23]	2012	China	65	34/31	28 (17–48)*	–	RCT	Level I	12	Some concern
Noh et al. [24]	2013	Korea	61	30/31	24 (18–45)/22(19–44)	61/0	RCT	Level I	30.2	Low
Youm et al. [25]	2014	Korea	40	20/20	$29.7 \pm 11.9/27.6 \pm 9.9$	39/1	RCT	Level I	24 (19–31)	Low
Bohn et al. [26]	2015	Denmark	23	11/12	27.5 ± 7.2*/24.3 ± 4.9*	–	RCT	Level I	13 (12–18)	Low
Guglielmetti et al. [27]	2016	Brazil	71	34/37	24.33/23.63*	–	RCT	Level I	24	Some concern
Venosa et al. [28]	2017	Italy	52	26/26	26.4(16–40)/25.2(16–40)	38/14	RCT	Level I	NA	Low
Geng et al. [29]	2018	China	104	48/56	$31.8 \pm 11.0/29.6 \pm 11.7$ (19–69)/(18–65)	TT 40/8 AM 46/10 86/18	RCT	Level I	TT 24.9 ± 6.0 (12–37) AM 25.7 ± 6.8 (12–36.5)	Low
MacDonald et al. [30]	2018	Canada	88	42/46	$32.4 \pm 8.9/30.7 \pm 9.3$	TT 27/15 AM 31/15 58/30	RCT	Level I	24	Low
Minguell et al. [33]	2019	Spain	106	51/55	$29.8 \pm 8.8/31.0 \pm 9.7$	TT 38/13 AM 36/19	RCT	Level I	24	Low
Tucciarone et al. [31]	2019	Italy	20	10/10	NR	20/0	RCT	Level I	12	Some concern
Trofa et al. [32]	2020	USA	20	10/10	$30.1 \pm 9.6/26.2 \pm 6.5$	TT 5/5 AM 7/3 12/8	RCT	Level II	1.5	Low

*Data are referred to the entire population, sub-group data are not reported

Table 2 Details of methods and outcomes of included studies

Author	Methods	Inclusion/exclusion criteria	Participants	Interventions	Outcomes	Results
Hussein et al. [21]	Dec 2005–Dec 2007 Min 3-y follow-up (39–60 months) 330 patients prospectively randomized into 3 groups: 85 TT SB, 85 AM SB, 160 AM DB	*Inclusion criteria*: ACL rupture in active patients with a closed growth plate *Exclusion criteria*: multiligament, severe OA (grade 3 or greater) total/subtotal meniscectomy, contralateral ACL-deficient knee, and partial ACL rupture	281 patients 72 TT SB 78 AM SB 131 AM DB	*Graft type*: ST-G *Femoral fixation*: Endobutton (Smith & Nephew) *Tibial fixation*: not specified	Lachman Anterior drawer Pivot-shift test KT-1000 IKDC Lysholm	Better ATT-SSD in AM than TT ($p = 0.002$) Better deficit of extension in AM than TT ($p = 0.05$) Higher percentage of grade 0 pivot-shift in AM than TT ($p = 0.003$) No difference between TT and AM in Lysholm score and IKDC The outcome of the AM DB group was better than the TT SB group for all measured parameters except objective IKDC
Mirzatolooei et al. [22]	Jan 2007–Feb 2009 Min 18 months follow-up (18–26 months) 223 patients Prospectively randomized into 2 groups: TT, AM	*Inclusion criteria*: ACL tear in young active patients with knee instability, concomitant meniscal injury and osteochondral lesions *Exclusion criteria*: Infection, previous Surgery, bilateral injuries or other ligament injuries needing reconstruction, patients over-40 years old	168 patients 88 TT 80 AM	*Graft type*: autologous hamstring tendon *Femoral fixation*: TransFix® suspension fixation system *Tibial fixation*: not specified	IKDC Lysholm Tegner activity scales Lachman Pivot-shift test Laxity measurement using a Rolimeter X-ray	Better ATT-SSD in AM than TT ($p = 0.002$) Better subjective IKDC and Lysholm score in AM group No difference in Tegner activity scales More intraoperative complications in terms of graft passage difficulties and posterior wall blow-up in the AM group
Zhang et al. [23]	Jun 2008–Oct 2010 1-y follow-up 76 patients prospectively randomized into 2 groups: 38 TT, 38AM	*Inclusion criteria*: Injury causes included sport injuries, military training injuries and traffic accident	65 Patients 34 TT 31 AM	*Graft type*: ST-G *Femoral fixation*: Rigidfix system *Tibial fixation:* Intrafix system	Lysholm KT-1000	No difference in the Lysholm knee score and the KT-1000 between the TT and AM groups

Table 2 (continued)

Author	Methods	Inclusion/exclusion criteria	Participants	Interventions	Outcomes	Results
Noh et al. [24]	2008–2010 Min 1-y follow-up 64 patients prospectively randomized into 2 groups: 32 TT, 32AM	*Inclusion criteria*: Acute or chronic ACL rupture *Exclusion criteria*: female patients, age > 45 years, reconstruction with graft other than Achilles allograft, other ligament injuries on the same knee needing surgical treatment, revision ACL reconstruction, double bundle ACL reconstruction, subtotal or total meniscectomy, meniscus repair, full-thickness cartilage injury needing cartilage repair surgery, history of injury on either knee, unable to undergo follow-up MRI	61 patients 30 TT 31 AM	*Graft type*: Fresh-frozen Achilles allograft *Femoral fixation*: Endobutton (Smith & Nephew) *Tibial fixation:* augmentation using a 7 × 23-mm Bio-interference screw	IKDC Lysholm Tegner SLH Lachman Pivot-shift test MRI	Better Lysholm score and ATT-SSD results in AM group than in TT group ($p = .025$, $p = 008$) No significant differences in Lachman test, pivot-shift test, IKDC, Tegner activity scale, and SLH test Increase PCL index in TT group than in AM group ($p < 0.001$) Femoral tunnel more posterior in AM group than in TT group ($p < 0.001$)
Youm et al. [25]	July 2011–June 2012 Min 2-y follow-up (19–31 months) 40 patients prospectively randomized into 2 groups: 20 TT, 20 AM	*Exclusion criteria*: previous ACL reconstruction, posterior cruciate ligament ruptures or PL rotatory instability, fractures around the knee joint	40 patients 20 TT 20 AM	*Graft type*: fresh-frozen Achilles tendon allograft *Femoral fixation*: metal interference screw *Tibial fixation:* bioabsorbable interference screw (25 mm long and the same diameter as the tibial tunnel) and a spiked washer and screw	Lachman Anterior drawer Pivot-shift test 3D CT KT-1000 Lysholm IKDC Tegner activity scale	No difference in IKDC score, Lysholm knee scores, Tegner activity scale scores, No difference in pivot-shift test, Lachman test and ATT-SSD Femoral tunnel location comparable to TT

Table 2 (continued)

Author	Methods	Inclusion/exclusion criteria	Participants	Interventions	Outcomes	Results
Bohn et al. [26]	June 2009–Jan 2012 Min 1-y follow-up 45 patients prospectively randomized into 3 groups: 14 TT SB, 15 AM SB, 16 AM DB	*Inclusion criteria*: age 18–50 years, MRI verified ACL injury with symptoms of instability, no previous knee ligament surgery, no concomitant knee ligament injuries, and an uninjured contralateral knee *Exclusion criteria*: cartilage injuries of International Cartilage Research Society grade 3 or 4, meniscus injury requiring resection of more than 50% of a meniscus	36 patients 11 TT SB 12 AM SB 13 AM DB	*Graft type*: ST-G *Femoral fixation*: Endobutton continuous loop (Smith & Nephew) *Tibial fixation*: 30-mm Inion HexalonTM interference screw	KT-1000 KOOS IKDC Lysholm Tegner score Lachman Pivot-shift test Hop test Three-dimensional motion analysis for tibial rotation	No difference in IKDC, KOOS and Tegner scores, KT-1000 knee laxity, Lachman test, pivot-shift test, and hop tests There was no difference between SB-TT, SB-AM, and DB groups regarding tibial rotation and rotational stiffness at 1-year follow-up using three-dimensional motion analysis

Table 2 (continued)

Author	Methods	Inclusion/exclusion criteria	Participants	Interventions	Outcomes	Results
Guglielmetti et al. [27]	Aug 2010–May 2012 2-y follow-up 80 patients prospectively randomized into 2 groups: 40 TT, 40 AM	*Inclusion criteria*: unilateral ACL Injury, patients with mature skeletons and closed physes, age below 40 years, *Exclusion criteria*: previous surgery on the injured side (except arthroscopic meniscectomy), degenerative changes on arthroscopy, time of injury more than 1 year and less than 2 weeks associated ligament injuries (except grades I and II medial collateral ligaments), morbid obesity	71 patients 34 TT 37 AM	*Graft type*: ST-G *Femoral fixation*: ETD® *Tibial fixation:* metal interference screw	Lachman Anterior drawer Pivot-shift test KT-1000 Lysholm IKDC	Comparable IKDC score, Lysholm score and re-rupture rate No difference in Lachman, pivot-shift test and the anterior drawer test between TT and AM
Venosa et al. [28]	Jan 2012–June 2014 6 months after surgery follow-up 52 patients prospectively randomized into 2 groups: 26 TT, 26 AM	*Inclusion criteria*: history of knee traumatic accident, subjective knee laxity/instability, clinical evaluation (jerk test/pivot-shift test, Lachman test), MRI scan positive for complete ACL lesion	52 patients 26 TT 26 AM	*Graft type*: autologous hamstring tendon *Femoral fixation*: EndoButton CL Ultra-Fixation (Smith & Nephew *Tibial fixation:* bioabsorbable screw (BIORCI-HA, Smith & Nephew) and a metallic staple	3D-CT scan to evaluate femoral tunnel position	The AM portal technique provides more anatomical graft placement than TT techniques in ACL reconstruction Differences were significant in all comparisons ($p < 0.0001$)

Table 2 (continued)

Author	Methods	Inclusion/exclusion criteria	Participants	Interventions	Outcomes	Results
Geng et al. [29]	Aug 2014–Feb 2015 Min 1-y follow-up 120 patients prospectively randomized into 2 groups: 57 TT, 63 AM	*Inclusion criteria*: 1 year post-operative follow-up, normal contralateral knee joint, no accompanying fracture *Exclusion criteria*: combined anterior and posterior cruciate ligament injury, collateral ligament Injury, osteoarthritis and revision surgery	104 patients 48 TT 56 AM	*Graft type*: autologous hamstring tendon *Femoral fixation*: EndoButton CL Ultra-Fixation (Smith & Nephew *Tibial fixation:* Intrafix (Depuy)	Lachman Pivot-shift test KT-1000 Lysholm IKDC Tegner 3D-CT to evaluate femoral tunnel location	No significant difference in Lachman test, Pivot-shift test, KT-1000 and PROMs Shorter femoral tunnel in AM group Tunnel location was significantly lower and deeper in AM group
MacDonald et al. [30]	Aug 2007–Aug 2011 Min 3-m follow-up 96 patients prospectively randomized into 2 groups: 47 TT, 49 AM	*Inclusion criteria*: men and women between the ages of 18 and 50 diagnosed with a complete ACL tear confirmed on MRI *Exclusion criteria:* concomitant collateral ligament tears, significant chondromalacia (with loss of more than 50% thickness based on MRI), previous lower limb surgery, history of arthritis, unable to comply with rehabilitation protocols (e.g., bucket handle, simple vertical or radial meniscal tears requiring repair and different postoperative protocol) or study follow-ups, pregnant	88 patients 42 TT 46 AM	*Graft type*: ST-G *Femoral fixation*: suspensory button device *Tibial fixation*: biocomposite interference screw	ACL-QOL KT-1000 IKDC X-ray-Tunnel orientation	No differences in clinical outcomes A significant difference was found between groups with respect to femoral tunnel orientation in the coronal plane ($p < 0.001$)

Table 2 (continued)

Author	Methods	Inclusion/exclusion criteria	Participants	Interventions	Outcomes	Results
Minguell et al. [33]	2013–2016 24 months follow-up	*Inclusion criteria:* Patients aged > 18 and < 45 years. Patients with a chronic ACL rupture, more than 12 months of injury evolution. Patients with ACL rupture diagnosed by physical exam and confirmed by magnetic resonance images (MRI) *Exclusion criteria:* revision surgery. Concomitant ligaments lesions. A grade 2 or higher osteoarthrosis in the Kellgren–Lawrence scale	107 patients (51 TT; 56 AM) were available for final followup at 24 months	*Graft type*: autologous 4-bundle hamstring tendon *Femoral fixation:* RetroButton (Arthrex, Naples, Florida, USA), *Tibial fixation*: delta bioabsorbable screw (Arthrex, Naples, Florida) with an extracortical supplementary metal staple	IKDC Lysholm Tegner activity scales SF-36 Likert Scale Lachman Pivot-shift test Laxity measurement using navigation MRI analysis tunnel inclination	AM technique achieve a more anatomical position No differences in clinical outcomes

Table 2 (continued)

Author	Methods	Inclusion/exclusion criteria	Participants	Interventions	Outcomes	Results
Tucciarone et al. [31]	Jan 2016–July 2016 12 months follow-up 20 patients prospectively randomized into 2 groups: 10 TT, 10 AM	*Inclusion criteria*: isolated primary ACL Injury, male sex, healthy contralateral knee *Exclusion criteria:* previous surgery on the affected limb, open physes on the femur and/or tibia, associated capsular and meniscal lesions of any type, associated chondral lesion of grade III to IV according to ICRS classification, smoking habit, obesity (BMI higher than 30), intra- and peri-articular lesions on the contralateral limb, early osteoarthritis, endocrine, collagen, neurological, infective, rheumatological pathologies	20 patients 20 TT 20 AM	*Graft type*: ST-G *Femoral fixation*: not specified *Tibial fixation*: not specified	Lachman Pivot-shift test KT-1000 VAS IKDC KSS KOOS Tegner-Lysholm Tegner Activity Level Scale MRI X-ray	Reduced time to return to play ($p > 0.05$) and higher Tegner Activity Level Scale at 1-year follow-up ($p > 0.05$) in AM group No difference in post-operative PROM and ATT-SSDs More anatomical placement of the femoral tunnel in AM group ($p < 0.05$)

Table 2 (continued)

Author	Methods	Inclusion/exclusion criteria	Participants	Interventions	Outcomes	Results
Trofa et al.[32]	Dec 2016–Apr 2017 6 weeks follow-up 31 patients prospectively randomized into 3 groups: 11 TT, 10 AM, 10 HTT	*Inclusion criteria*: skeletally mature patients requiring primary ACL reconstruction with or without associated partial meniscectomy or meniscal repair for an acute or subacute (within 6 months of injury) ACL tear *Exclusion criteria:* chronic ACL deficiency (> 6 months), multiligamentous injuries (defined as grade I medial collateral ligament, lateral collateral ligament, or posterior cruciate ligament laxity), revision surgery, or degenerative joint disease	30 patients 10 TT 10 AM 10 HTT	*Graft type*: autologous hamstring tendon *Femoral fixation*: not specified *Tibial fixation*: not specified	3D-CT for femoral tunnel analysis	Significantly shorter tunnel in AM group ($p > .001$) More angulated graft in both sagittal and coronal plane in AM group ($p < 0.01$)

AM, anteromedial; DB, double bundle; ETD®, endo tunnel device; HTT, hybrid TT; IKDC, International Knee Documentation Committee; ATT-SSD, anterior tibial translation side to side difference; SB, single bundle; ST-G, semitendinosus gracilis tendon; TT, transtibial; PROM, patient-reported outcome measures

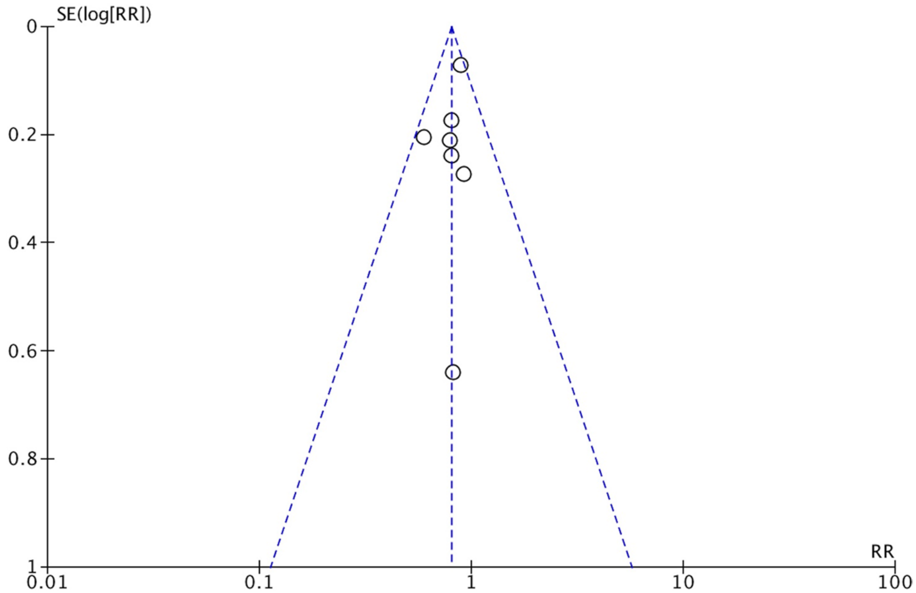

Fig. 3 Funnel plot for the primary outcome measure (IKDC objective score) reporting the risk of publication bias of the assessed studies

Results of meta-analysis

Functional outcome scores

IKDC objective

Among the 13 investigations, only 7 studies [21, 22, 24–27, 30] reported qualitative data on objective IKDC score.

These studies involved 601 patients including 297 TT and 304 AM ACL reconstructions.

Statistical heterogeneity was $\chi^2 = 4.65$; $I^2 = 0\%$; $p = 0.59$, and a fixed-effect model was used for analysis.

Although all studies reported no significant differences in IKDC objective scores between AM and TT groups, the meta-analysis of pooled data showed a significant difference in IKDC objective scores at the final follow-up assessment (RR = 0.80; 95% CI 0.70–0.91; $p < 0.001$) (Fig. 4).

Precisely, 63.8% of patients in AM group versus 50.2% of patients in the TT group had IKDC grade A ($p < 0.001$).

IKDC subjective

Among the 13 investigations, only 5 studies [21, 25, 26, 29, 33] reported quantitative data on subjective IKDC score and 2 studies [27, 31] did not provide standard deviations.

These studies involved 410 patients including 196 TT and 214 AM ACL reconstructions.

Statistical heterogeneity was $\chi^2 = 1.09$; $I^2 = 0\%$; $p = 0.90$, and a fixed-effect model was used for analysis.

All studies reported no significant differences in IKDC subjective scores between AM and TT groups and the meta-analysis confirmed this finding (MD = −0.11; 95% CI −0.31 to 0.08; $p = 0.26$) (Fig. 5).

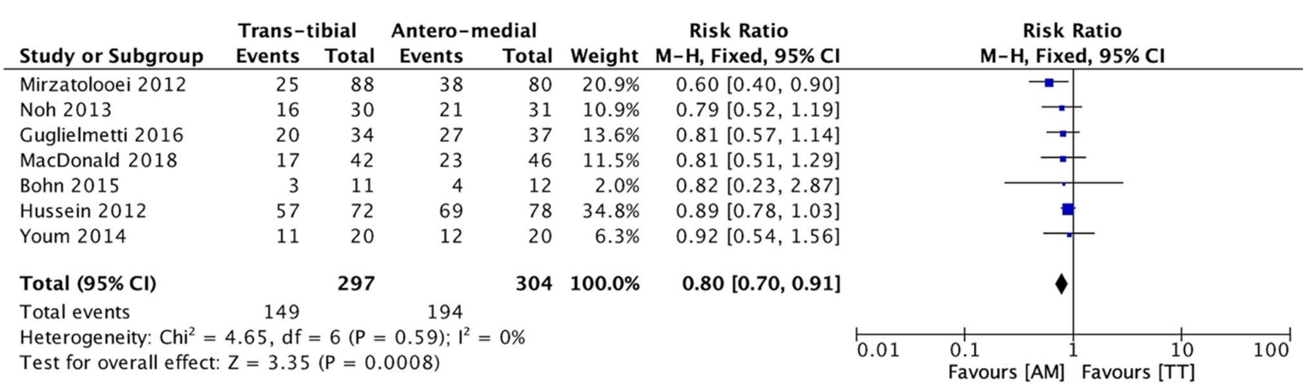

Fig. 4 Forest plot for IKDC objective score

Lysholm score

Among the 13 investigations, only 7 studies [21–23, 25, 26, 29, 33] reported quantitative data on Lysholm score and 2 studies [28, 31] did not provide standard deviations.

These studies involved 640 patients including 315 TT and 325 AM ACL reconstructions.

Statistical heterogeneity was $\chi^2 = 4.91$; $I^2 = 0\%$; $p = 0.56$, and a fixed-effect model was used for analysis.

Only 2 studies [22, 23] reported better Lysholm scores in AM ACL reconstruction, and the meta-analysis confirmed this significant finding (MD = − 0.73; 95% CI − 1.20 to − 0.26; $p = 0.002$) (Fig. 6).

Tegner activity scale

Among the 13 investigations, only 5 studies [22, 25, 26, 29, 31] reported quantitative data on the Tegner activity scale.

These studies involved 355 patients including 177 TT and 178 AM ACL reconstructions.

Statistical heterogeneity was $\chi^2 = 11.45$; $I^2 = 65\%$; $p = 0.002$, and a random-effect model was used for analysis.

There were no differences in the post-operative Tegner activity scale in TT and AM groups (MD = − 0.27; 95% CI − 0.66 to 0.13; $p = 0.18$) (Fig. 7).

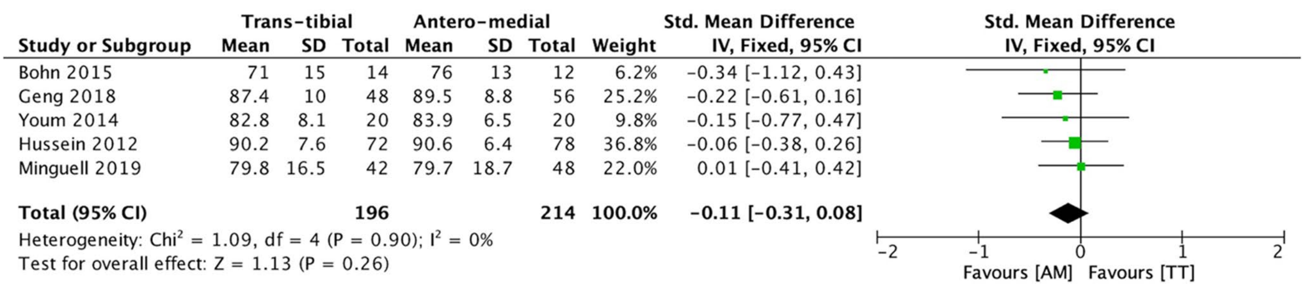

Fig. 5 Forest plot for IKDC subjective score

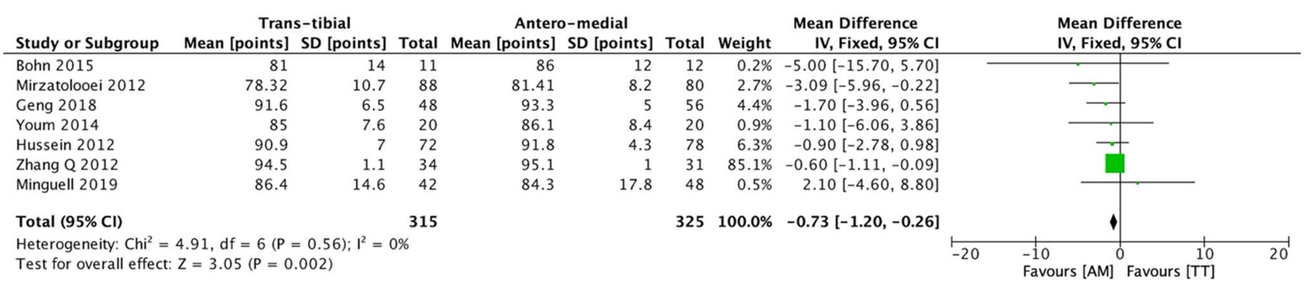

Fig. 6 Forest plot for Lysholm score

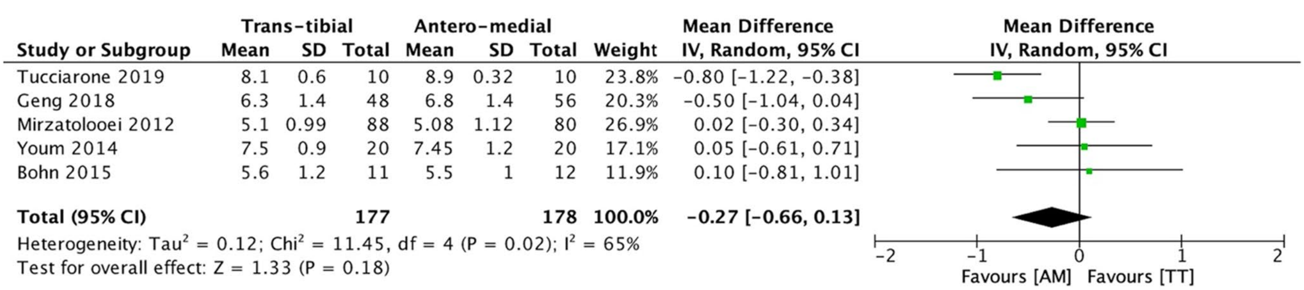

Fig. 7 Forest plot for Tegner activity scale

Objective Knee laxity tests

Anterior tibial translation

Among the 13 investigations, 9 studies [21–24, 26, 29–31, 33] investigated instrumental anterior tibial translation.

These studies involved 780 patients including 385 TT and 395 AM ACL reconstructions.

Statistical heterogeneity was $\chi^2 = 12.20$; $I^2 = 34\%$; $p = 0.14$, and a fixed-effect model was used for analysis.

Meta-analysis revealed that patients of AM group had significantly less anterior tibial translation (MD = 0.36; 95% CI 0.21 to 0.52; $p < 0.001$) (Fig. 8).

Pivot-shift test

Among the 13 investigations, 10 studies [21, 22, 24–27, 29–31, 33] investigated manual pivot-shift test.

These studies involved 801 patients including 394 TT and 407 AM ACL reconstructions.

Statistical heterogeneity was $\chi^2 = 4.80$; $I^2 = 0\%$; $p = 0.85$, and a fixed-effect model was used for analysis.

Meta-analysis revealed that patients of AM group had significantly lower grade pivot-shift test than the TT group (OR = 0.46; 95% CI 0.32–0.65; $p < 0.001$) (Fig. 9).

Graft failure

Among the 13 investigations, 8 studies [21, 22, 24, 26, 27, 29, 30, 33] investigated graft failure.

These studies involved 771 patients including 397 TT and 374 AM ACL reconstructions.

Statistical heterogeneity was $\chi^2 = 2.68$; $I^2 = 0\%$; $p = 0.85$, and a fixed-effect model was used for analysis.

Meta-analysis revealed that patients of AM group had lower but not significant failure rate when compared to the TT group (RR = 0.54; 95% CI 0.28–1.06; $p = 0.07$) (Fig. 10). Precisely, the graft failure rate was 2.8% for the AM group and 5.3% for the TT group.

Publication bias

A funnel plot was performed with the IKDC objective score as the indicator. A total of 7 studies [21, 22, 24–27, 30]

	Trans-tibial			Antero-medial				Mean Difference
Study or Subgroup	Mean [mm]	SD [mm]	Total	Mean [mm]	SD [mm]	Total	Weight	IV, Fixed, 95% CI
Bohn 2015	3.9	2.6	11	2.8	2.1	12	0.6%	1.10 [−0.84, 3.04]
Geng 2018	1.6	0.8	48	1.5	0.9	56	22.3%	0.10 [−0.23, 0.43]
Hussein 2012	2	0.9	72	1.6	0.8	78	31.8%	0.40 [0.13, 0.67]
MacDonald 2018	1	3	41	1	3	43	1.4%	0.00 [−1.28, 1.28]
Minguell 2019	13.7	3.1	51	13.7	2.4	54	2.1%	0.00 [−1.06, 1.06]
Mirzatolooei 2012	2.2	1.13	88	1.73	0.85	80	26.3%	0.47 [0.17, 0.77]
Noh 2013	2.7	2.1	30	1.4	1.6	31	2.7%	1.30 [0.36, 2.24]
Tucciarone 2019	2.7	1.49	10	1.3	0.95	10	2.0%	1.40 [0.30, 2.50]
Zhang Q 2012	2.14	0.91	34	1.96	1.02	31	10.7%	0.18 [−0.29, 0.65]
Total (95% CI)			**385**			**395**	**100.0%**	**0.36 [0.21, 0.52]**

Heterogeneity: Chi² = 12.20, df = 8 (P = 0.14); I² = 34%
Test for overall effect: Z = 4.60 (P < 0.00001)

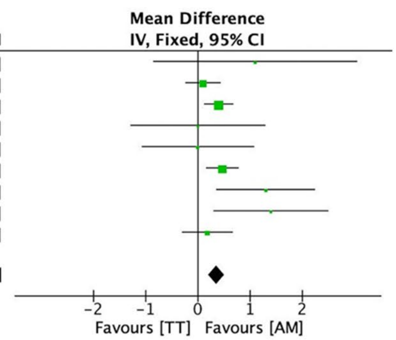

Fig. 8 Forest plot for anterior tibial translation

	Trans-tibial		Antero-medial			Odds Ratio
Study or Subgroup	Events	Total	Events	Total	Weight	M-H, Fixed, 95% CI
Bohn 2015	8	11	10	12	2.9%	0.53 [0.07, 4.01]
Geng 2018	32	48	44	56	15.3%	0.55 [0.23, 1.31]
Guglielmetti 2016	26	34	30	37	7.6%	0.76 [0.24, 2.38]
Hussein 2012	30	72	52	78	32.8%	0.36 [0.18, 0.69]
MacDonald 2018	21	30	24	29	8.2%	0.49 [0.14, 1.68]
Minguell 2019	49	51	55	55	2.9%	0.18 [0.01, 3.81]
Mirzatolooei 2012	70	88	70	80	16.9%	0.56 [0.24, 1.29]
Noh 2013	20	30	27	30	10.1%	0.22 [0.05, 0.91]
Tucciarone 2019	8	10	10	10	2.7%	0.16 [0.01, 3.85]
Youm 2014	20	20	19	20	0.5%	3.15 [0.12, 82.16]
Total (95% CI)		**394**		**407**	**100.0%**	**0.46 [0.32, 0.65]**
Total events	284		341			

Heterogeneity: Chi² = 4.80, df = 9 (P = 0.85); I² = 0%
Test for overall effect: Z = 4.26 (P < 0.0001)

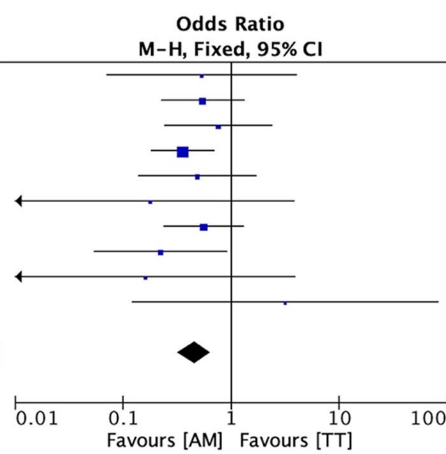

Fig. 9 Forest plot for pivot–shift test

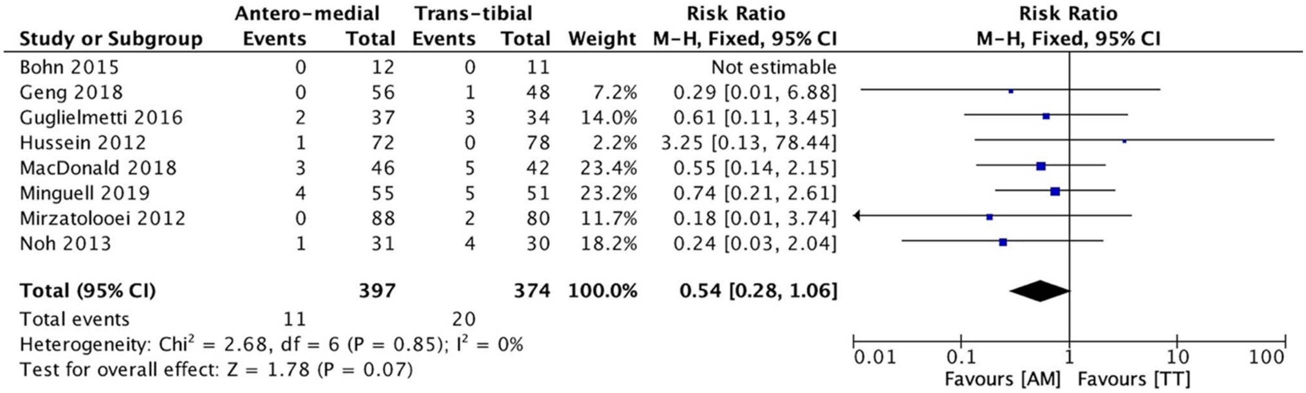

Fig. 10 Forest plot for graft failure

were included in the analysis. The 7 points in the funnel plot suggest a lower impact of publication bias on the results (Fig. 3). According to Cook's distances, none of the studies could be considered to be overly influential. Neither the rank correlation nor the regression test indicated any funnel plot asymmetry ($p = 0.88$ and $p = 0.77$, respectively).

Radiological outcomes

Radiological outcomes were reported in 10 studies [22, 24, 25, 27–33] and were assessed with different imaging techniques. Four studies [22, 27, 30, 31] evaluated femoral tunnel position with X-rays, 4 studies [25, 28, 29, 32] performed a 3D-CT scan, and 3 studies [24, 31, 33] investigated post-operative ACL positioning with MRI. There was a high heterogeneity of assessed outcomes and meta-analysis was not possible, except for femoral tunnel length. A descriptive analysis of radiological outcomes is summarized in Table 3.

Femoral tunnel length

Only 4 studies [25, 29, 32, 33] reported detailed quantitative data with standard deviations of femoral tunnel length. One study [27] reported only mean values without standard deviations.

These studies involved 218 patients including 107 TT and 111 AM ACL reconstructions.

Statistical heterogeneity was $\chi^2 = 46.62$; $I^2 = 98\%$; $p < 0.001$, and a random-effect model was used for analysis.

Four studies [27, 29, 32, 33] reported a significantly longer femoral tunnel in the TT group than in AM group and 1 study [25] did not report a significant difference in tunnel length between the two techniques.

Meta-analysis of pooled data showed that patients who underwent the TT technique had significantly longer femoral tunnel (MD: 8.11; 95% CI 1.22 to 15.01; $p = 0.02$) (Fig. 11).

The femoral tunnel length was not associated with better clinical outcomes or reduction of failure rate in any included research article.

Discussion

The main finding of this study was the significant difference in terms of objective IKDC, Lysholm score, TAS, anterior tibial translation and pivot-shift test in favor of AM technique in comparison with TT technique. No statistically significant difference in terms of subjective IKDC score and graft failure was reported.

Chen et al. [34], in a meta-analysis considering 5 RCT studies on 479 patients, evaluated the clinical outcome and complications rate between AM and TT techniques in single-bundle ACL reconstruction. The authors reported higher functional outcomes in patients undergoing AM technique, as well as a lower incidence of pathological side-to-side difference (SSD), pivot-shift and Lachman test in the AM group in comparison with the TT group.

In a recent meta-analysis including 10 RCTs and 8 Prospective Comparative Trials, Mao et al. [35] reported the clinical and radiological outcomes of both the TT and the AM techniques in single bundle ACL reconstruction. The study considered a population of 53,888 ACL reconstructed patients, 729 of them extracted from RCT studies and 53,159 from prospective controlled trials, including national registry data. Higher values of passive range of motion were reported in favor of the AM technique, despite no difference in subjective outcomes and postoperative activity level. Furthermore, an increased SSD was recorded in the TT group notwithstanding a comparable risk of ACL failure between AM and TT patients.

These findings are consistent with the current literature, reporting a more anatomic tunnel placement associated with the AM technique leading to a biomechanical behavior

Table 3 Radiological outcomes

Author	Outcome assessment	Radiologically assessed patients	TT group/AM group	Imaging technique	Results
Hussein et al. [21]	NR	NR	NR	NR	NR
Mirzatolooei et al. [22]	Standard AP notch and lateral radiography of the knee before and after the operation The position of the tunnels assessed using the Sommer's radiological parameters method and ruler	105	47/58	X-rays	90% of femoral tunnels in the TT group in Zone B (between 11 and 12 o'clock) 80% percent of tunnels in the AM group in Zone A (10 to 11 o'clock of the intercondylar notch), and the remaining tunnels were in Zone B and Zone D (9 o'clock) Interobserver reliability: 85%
Zhang Q et al. [23]	NR	NR	NR	NR	NR
Noh et al. [24]	1.5 Tesla MRI 4 days post-op and at 2 years after surgery (2.5-mm slice thickness) Position of the femoral tunnel aperture assessed relative to the reference point as the over-the-top point on sagittal image. The location of the posterior margin of the femoral tunnel aperture was expressed as x and y coordinates with the reference point as the zero point The posterior cruciate ligament (PCL) buckling on sagittal MRI. Shortest distance between the femoral and tibial attachments (a) and the longest perpendicular distance from this line to the arc of the PCL (b) PCL index defined as a/b	61	30/31	1.5 Tesla MRI	X coordinate: 8.6 ± 0.7 mm in TT group and 9.0 ± 1.9 mm in AM group ($p = 0.212$) Y coordinate: 1.4 ± 7 mm in TT group and 8.4 ± 0.7 mm in AM group ($p < .001$) Post-operative PCL index: 5.8 ± 0.9 in TT group and 5.7 ± 0.8 in AM group postoperatively ($p = 0.492$) Final follow-up PCL index: 4.7 ± 0.9 in TT group and 5.4 ± 0.7 mm at the last follow-up ($p < .001$)
Youm et al. [25]	3D-CT scans to analyze femoral tunnels according to the quadrant method by Bernard The study measured the tunnel position parallel and perpendicular to Blumensaat line, the coronal and sagittal obliquity of the femoral tunnels, the area of the femoral tunnel and the length of the femoral tunnel	40	20/20	3D-CT	Similar mean distances for the femoral tunnel center location along line t from the posterior condylar surface (30.2 ± 1.1% vs 31.0 ± 1.7%, respectively; 0.8% difference; $p = 0.167$) and along line h from the Blumensaat line (39.0 ± 2.2% vs 41.1 ± 1.9%; $p = 0.067$) Lower coronal obliquity of the femoral tunnel in TT group than in AM group: 42.5 ± 6.1 (range 36.3–49.0) degrees versus 49.3 ± 7.2 (range 41.9–54.6) degrees ($p = 0.001$) Similar sagittal obliquity between the 2 groups: 41.9 ± 6.1 (range 34.8–51.4) degrees versus 43.3 ± 5.4 (range 32.5–49.0) degrees ($p = 0.303$) Greater mean size of the tunnel orifice in the TT group (11.6 ± 1.4 × 9.2 ± 1.6 mm vs 10.3 ± 1.1 × 9.1 ± 1.4 mm; $p = 0.013$) Similar length of the femoral tunnel (24.6 ± 1.0 mm vs 24.7 ± 1.0 mm; $p = 0.752$)

Table 3 (continued)

Author	Outcome assessment	Radiologically assessed patients	TT group/AM group	Imaging technique	Results
Bohn et al. [26]	NR	NR	NR	NR	NR
Guglielmetti et al. [27]	Radiographic evaluation of intercurrences (soft tissue fixation of the ETD®, intratunnel fixation of the ETD®, chondral lesion of the femoral condyle, rupture of the posterior cortex of the femoral tunnel, short tunnel (less than 3.5 cm), and short graft length inside the tunnel (less than 2 cm)	71	34/37 patients	X-rays	More intraoperative intercurrences in the AM group In 6 cases, the ETD® was fixed in the soft tissues, which was verified by the immediate postoperative radiograph. Among these 6 patients, 5 were from the transportal group and 1 was from the transtibial group ($p = 0.201$) Length of the femoral tunnels: 4.98 cm in the TT group and 3.99 cm in the AM group ($p = 0.001$) Graft length inside the tunnel: 2.91 cm in the TT group and 2.27 cm in the AM group ($p < 0.001$)
Venosa et al. [28]	3D-CT 20 days after surgery Femoral tunnel position measured according to the quadrant method suggested by Bernard The location of the tunnels was quantified from the deepest subchondral contour to the center of the tunnel and provided as the percentage distance from the intercondylar notch roof Rectangular measurement frame (4 × 4 grid) formed by the Blumensaat's line, a parallel line tangent to the most inferior margin of the lateral condyle and two perpendicular lines tangent to the deepest/shallowest subchondral contour of the lateral femoral condyle The central point of the tunnel (k) was calculated as a/t and b/h, where t is the total sagittal diameter of the lateral femoral condyle along Blumensaat's line, a is the distance of k from the deepest subchondral contour, h is the maximum intercondylar notch height, and b the distance of k from Blumensaat's line. The ratios of a/t and b/h were expressed as percentage	52	26/26	3D-CT	Measurement of femoral tunnel placement from the subchondral contour of the lateral femoral condyle (a/t) was 28.1 ± 1.6% and 32.2 ± 3.3% for the TT and AM groups ($p < 0.001$) Measurement of femoral tunnel placement from the Blumensaat's line (b/h) was 15.1 ± 1.9% and 31.2 ± 1.7% for the TT and AM groups, respectively ($p < 0.001$)

Table 3 (continued)

Author	Outcome assessment	Radiologically assessed patients	TT group/AM group	Imaging technique	Results
Geng et al. [29]	3D-CT scan (intraoperative and 1 week postoperatively) Measure of length of femoral tunnel using the quadrant method described by Bernard M. et al	104	48/56	3D-CT	Tunnel length in TT and AM group: 42.0 ± 4.8 (range 32–55) mm versus 37.3 ± 3.9 (range 28–46) mm ($p < 0.01$) Tunnel position in TT and AM group: -depth ratio: 22.1 ± 2.1 (range 19–26) mm versus 20.3 ± 2.0 (range 17–23) mm, $p < .0.1$) -height ratio (30.2 ± 1.7 mm vs 33.3 ± 1.8 mm, $p < 0.1$) AM group had shorter tunnel length and lower and deeper placement compared to the TT group
MacDonald et al. [30]	12 months X-ray femoral and tibial tunnel orientation in the coronal plane	88	42/46	X-rays	A significant difference was found in femoral tunnel orientation with the TT group at 58 ± 8 degrees and the AM group at 43 ± 7 degrees in the coronal plane ($p < 0.001$)
Minguell et al. [33]	Two independent radiologists with expertise in musculoskeletal pathology measured the angulation of the graft in a coronal and sagittal plane. We took into account Illingworth's criteria for anatomic graft angulation	106	51/55	MRI	The AM technique achieves a more anatomic graft than TT technique in both sagittal and coronal planes (6° approximately) In a coronal plane, AM group showed a graft angulation of 73.7° ± 9.5° while the TT group 79.1° ± 6.1° ($p = 0.016$). In a sagittal plane, angulation in AM group was 53.2° ± 7.4° and 59.5° ± 5.11° in the TT group ($p = 0.002$) (Fig. 3). Mean tunnel length was significantly inferior with AM (39.4 ± 4.5 mm vs. 50.2 ± 5.2 mm $p = 0.000$). MRI measurements showed no intra- or inter-observer differences
Tucciarone et al. [31]	Using the standards established by Illingworth, radiological outcomes were assessed to determine whether or not ACL repair was anatomically appropriate. The femoral tunnel angle was measured on the anterior–posterior X-ray of the knee at 45° flexion, and the inclination angle of the graft measured in sagittal sections of magnetic resonance imaging (MRI) of the knee in extension ACL reconstruction was deemed to be outside of anatomical range when the femoral tunnel angle dropped below 33.9° and the inclination angle increased above 54.5° After the final follow-up data had been collected, tests were run to compare the two groups and look for correlations with the other findings	20	10/10	X-rays MRI	ACL reconstruction fell within an anatomical range in 9 patients (90%) in the AM group and in 4 patients (40%) in the TT group ($p < 0.001$)

Table 3 (continued)

Author	Outcome assessment	Radiologically assessed patients	TT group/AM group	Imaging technique	Results
Trofa et al. [32]	3D-CT 6 weeks after surgery to measure femoral and tibial tunnel lengths and femoral and tibial tunnel intra-articular aperture positioning using the quadrant method as described by Bernard	20	10/10	3D-CT	Mediolateral tibial aperture in TT and AM group (45.4 ± 2.9% vs 46.9 ± 1.1%) Anteroposterior Tibial aperture in TT and AM group (42.2 ± 3.3% vs 41.9 ± 3.6%) Depth of Femoral aperture in TT and AM group (37.6 ± 3.9% vs 33.5 ± 3.9%) Height of Femoral aperture in TT and AM group (13.1 ± 3.3% vs 32.8 ± 7.1%) Tibial tunnel length in TT and AM group (39.5 ± 2.8 mm vs 40.7 ± 3.4 mm) Femoral tunnel length in TT and AM group (54.1 ± 9.9 mm vs 35.2 ± 1.6 mm) Mean coronal graft bending angle in TT and AM group (164.0° vs 146.3°) Mean sagittal graft bending angle in TT and AM group (114.0° vs 100.5°)

closer to the native ACL, decreasing the risk of anterior translation and rotational instability [36, 37].

Some authors, in early studies reporting the results of the AM technique, rose concerns about an increased risk of graft failure in comparison with the traditional TT technique [11, 12]. The data of the current study evidenced no difference between AM and TT techniques in terms of graft failure. However, analysis of radiological outcomes revealed that AM group had a significantly shorter femoral tunnel leading to less graft-to-bone interface. As the femoral tunnel length was not related to significant changes of clinical outcome and re-rupture, the increased failure risk reported in the early studies [11, 12] could be also explained by the physiological learning curve related to the introduction of a new surgical technique, leading to an excessive posterior placement of the ACL femoral tunnel. Consistent with this hypothesis, Clatworthy et al. [38] reported a normalization of the ACL failure risk, comparable to TT, after slightly anteriorizing the femoral tunnel, as proposed by the anatomical study of Kawaguchi et al. [39] concerning the biomechanical role of the fan-shape-like fibers of the ACL.

Some authors proposed a modified TT technique [25] in order to overcome the limitations of the traditional TT, reporting a tunnel placement almost comparable to the independent tunnel technique. In a systematic review and meta-analysis, Li et al. [40] compared the clinical outcome between conventional TT, modified TT and AM techniques. The authors considered 10 RCTs and 16 retrospective/prospective controlled trials, including 2202 patients. No difference in clinical outcomes between modified TT and AM technique was reported, nevertheless, AM resulted superior to conventional TT in terms of functional outcomes, postoperative pivot-shift test and SSD. Due to limited sample size, the author was not able to report statistically significant data regarding the comparison between modified and conventional TT techniques. In comparison with the AM technique, the conventional TT could lead to a more anterior and superior graft femoral tunnel placement, different from the original ACL footprint, therefore determining a residual instability leading to lower clinical outcomes.

The results of the current meta-analysis seem to confirm this hypothesis, demonstrating higher results in terms of both objective clinical outcomes and knee stability in AM group, despite no difference in terms of subjective outcomes and graft failure risk.

To the best of our knowledge, this is the larger meta-analysis including only RCTs available in the literature. In comparison with the meta-analysis published by Chen et al. [34], including 5 RCTs and 479 patients, 916 patients from 13 RCTs were considered in the current paper. In the recent meta-analysis by Mao et al. [35], a large cohort was considered, including 729 patients from RCT studies and 53,159 patients from prospective studies. The inclusion of registries

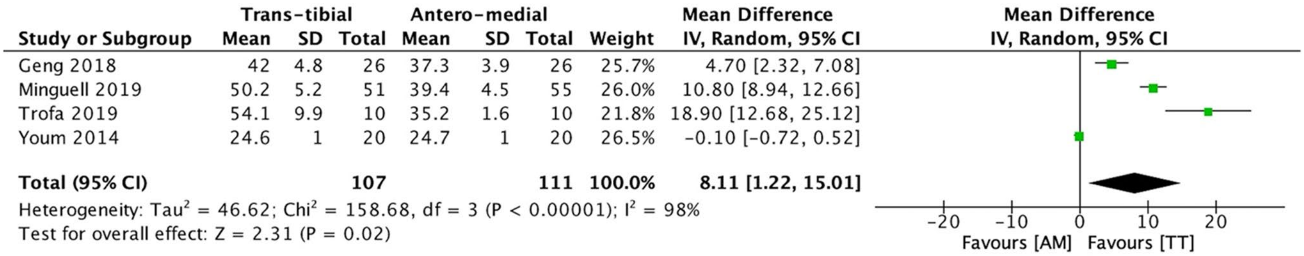

Fig. 11 Forest plot for femoral tunnel length

data [41, 42] exponentially increased the study population; nevertheless, these kinds of data could be affected by some bias such as confounders variables due to missing data regarding patient selection, no quality control on collected data and possible interference by medical industries [42]. In the current meta-analysis, only RCTs were considered and all the studies except one provided a Level of Evidence I.

Considering the current meta-analysis, the following limitations should be considered: The included trials have short to mid-term follow-up leading to a possible underestimation of graft failure. Moreover, the overall population is relatively limited mainly due to the small cohort of patients included in single RCTs and the assessed radiological outcomes are highly heterogeneous precluding a meta-analysis of outcomes (except for femoral tunnel length).

Furthermore, several confounding variables as antero-lateral complex injuries or low-grade posterolateral corner distractions, and combined procedures such as anterolateral reconstruction or lateral extra-articular tenodesis that significantly influence the anterior and rotational knee stability and the clinical outcomes have not been assessed and properly considered.

Finally, the majority of studies did not specify the difference between the conventional and the modified TT precluding a direct comparison of these techniques and relative sub-groups.

Conclusion

ACL reconstruction through AM portal technique provides better objective IKDC, Lysholm score, TAS, anterior tibial translation and pivot-shift test at mid-term follow-up.

No statistically significant difference in terms of subjective IKDC score and graft failure was reported.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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