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The transtibial versus the anteromedial portal technique in the arthroscopic bone-patellar tendon-bone anterior cruciate ligament reconstruction

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Abstract The transtibial (TT) drilling of the femoral tunnel in the bone-patellar tendon-bone (BPTB) anterior cruciate ligament (ACL) reconstruction was found to place the tunnel non-anatomically. The use of the anteromedial portal (AMP) for the femoral drilling would provide the surgeon with more freedom to anatomically place the tunnel in the real femoral ACL footprint. The purpose of this study was to compare the clinical outcomes of BPTB ACL reconstruction using the AMP or the TT technique for the femoral tunnel drilling. A Medline search was not able to identify any study directly comparing the clinical outcomes of the AMP and the TT techniques. The literature search identified experimental and quasi-experimental studies published from 1966 to March 2009 where at least one group underwent arthroscopic autologous BPTB ACL reconstructions using either the AMP or the TT technique for the femoral tunnel drilling. Overall IKDC, Lysholm score, activity level, range of motion, single-leg hoop test, Lachman test, Pivot shift sign test, KT-1000 arthrometer measurements, and radiographic assessments were indirectly compared between the two groups (AMP versus TT). Twenty-one studies, involving a total of 859 patients (257 in the AMP and 602 in the TT group), were included in this analysis. The AMP group demonstrated significantly earlier return to run and significantly greater range of motion, Lachman test values, and KT-1000 arthrometer measurements in the 1–2-year follow-up, although no differences were found for both the 3–5 and the 6–10-year follow-ups for any of these parameters. In contrast, the TT group demonstrated significantly higher activity level for the 3–5 and 6–10-year follow-up. The use of the AMP elicited greater knee stability and range of motion values, and earlier return to run compared to the TT technique. These results may indicate a potential benefit of the AMP over the TT technique. However, as the benefits of the AMP were not obtained in the mid and long-term follow-ups, overall there is no definitive evidence at this point to conclude that one technique is superior to the other. Randomized controlled trials directly comparing the use of both techniques with long-term follow-ups will help clarify which one, if any, provides best clinical outcomes.

Keywords ACL reconstruction · Femoral tunnel drilling · Anteromedial portal · Transtibial

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Introduction

Anterior cruciate ligament (ACL) tears are one of the most common severe injuries in sports medicine, accounting for a high personal and economic cost [16, 56]. An injured ACL causes knee pain, functional impairment, and an increased risk of meniscus tear and early knee osteoarthritis [12]. Despite there has been a considerable scientific effort focused on ACL reconstruction, the increased risk of early knee osteoarthritis and functional impairment is not solved

[33, 39, 52]. Therefore, excellence in the surgical management of this injury is needed to better contribute to optimal long-term results.

Three main surgical procedures are available to repair the ACL: mini-arthrotomy open technique, two-incision arthroscopically assisted technique, and one-incision endoscopic technique [14, 53]. The surgery in the ACL also depends on graft selection, morphology of the reconstructed ACL, fixation methods, and femoral tunnel drilling technique [14]. The actual most commonly preferred procedure is the one-incision endoscopic technique [14]. Autograft is also preferred over allograft, and bone-patellar tendon-bone (BPTB) over other types of graft like semitendinous and gracilis tendons, quadriceps tendon, Achilles tendons, distal iliotibial tract or fascia lata [14, 26]. Depending on the morphology of the reconstructed ACL, the surgical procedure is classified in anatomical (double-bundle) and non-anatomical (single-bundle) reconstruction [27, 40, 57]. The BPTB graft only allows for a single-bundle technique, whereas the semitendinous and gracilis tendon can be used either for a single-bundle or double-bundle procedures. It was postulated that an anatomical ACL reconstruction would produce greater knee stability due to the higher similarity with the normal double-bundled ACL [41]. However, this hypothesis is not supported by the existing evidence [38]. Overall, the most commonly used technique is the one-incision arthroscopically assisted autologous BPTB (single-bundle) ACL reconstruction [14].

The main cause of ACL reconstruction failure has been the non-anatomical femoral tunnel placement [19, 55]. It was demonstrated that an anterior and vertically oriented femoral tunnel results in an anterior-posterior and rotational knee laxity, respectively [30, 36, 49]. The transtibial (TT) technique is considered to place the femoral tunnel in a non-anatomical position with respect to the tunnel orientation and real femoral ACL footprint [10, 13, 18, 22, 24, 51]. The surgeon would have less chance to modify the location and orientation of the femoral tunnel with the use of the TT technique [24]. However, it has been shown that a relatively independent femoral tunnel placement is possible with a TT drilling [20, 47]. Whether drilling the femoral tunnel through the TT or the anteromedial portal (AMP) technique has been the focus of recent publications [10, 18, 22, 24, 34], but it has not been yet studied if one technique elicits better clinical outcomes compared to the other.

The purpose of this study was to compare the outcomes between the TT versus the AMP technique for the femoral drilling in the one-incision arthroscopically assisted autologous BPTB (single-bundle) ACL reconstruction. Based on several publications [10, 13, 18, 22, 24], it was hypothesized that the use of the AMP would produce greater knee stability values compared to the TT technique.

Methods

Literature search

The literature search was performed through MEDLINE database (1966 to March 2009). The following subject headings and text words were used in separate searches: anterior cruciate ligament reconstruction, bone-patellar tendon-bone anterior cruciate ligament reconstruction, anteromedial portal, transtibial drilling, femoral tunnel placement, femoral drilling technique, and anatomical femoral tunnel placement. The searches were restricted to English-language articles and human subjects. Abstracts were reviewed for relevance. To ensure that no relevant studies were missed by the Medline search, a manual cross-reference review of the citations of each selected article was carried out to determine all potential relevant articles.

Selection of studies

For inclusion, studies were required to be: (1) prospective experimental and quasi-experimental studies; (2) using the one-incision arthroscopic autologous BPTB ACL reconstruction; (3) have mentioned the femoral tunnel drilling technique; (4) a minimum 1-year follow-up; and (5) have similar rehabilitation protocols. Studies including revisions, allografts, and autografts other than BPTB were excluded.

Surgical technique

The arthroscopic single-incision BPTB ACL reconstruction technique has been described in great detail [23]. The surgery is performed under general or regional anesthesia. A first physical examination of the knee under anesthesia and a diagnostic arthroscopy are performed prior to any reconstruction. The BPTB autograft is harvested after a longitudinal skin incision is made extending from just medial to the midline of the inferior pole of the patella distally to 2 cm below and medial to the tibial tubercle [23]. The central third of the patellar tendon is harvested with 2.0 cm bone block at each end. After the remainder of the native ACL is shaved in both the tibial and femoral attachments, the tibial tunnel is performed. A guide wire is drilled from the medial side of the tibial tubercle and advanced to the tibial ACL footprint. Then a cannulated drill is employed for the tibial tunnel drilling. Two main techniques for the femoral tunnel drilling do exist: TT versus AMP techniques. The femoral drilling in the arthroscopic single-incision BPTB ACL reconstruction was initially described through the TT technique [23], where the femur is drilled through the tibial tunnel. The femoral tunnel drilling through the AMP was first published by Bottoni et al. [8]. A guide wire is placed through the AMP into the starting point, which was previously marked as the center of the femoral tunnel. The knee is then flexed to at least 120° as the wire is advanced through the anteromedial portal by use of a drill [8, 24, 34]. Once the wire is drilled, a reamer is passed over the guide wire and initially advanced by hand to atraumatically pass by the articular surface of the medial femoral condyle, assess bone quality, and avoid possible violation of the posterior cortex of the femur. After the tunnel is provisionally started, the reamer is drilled under power to a depth of 27 mm [8, 24, 34].

Data extraction

All studies were summarized by the use of a data extraction form aimed to identify the femoral drilling technique, study design, sample size, follow-up, and fixation techniques. Supplementary information regarding rehabilitation, additional required procedures, and complications was extracted from all studies. Data on the overall IKDC, Lysholm scores, activity level, range of motion (ROM), strength assessments, knee stability (Lachman and Pivot Shift sign tests, and KT-1000 arthrometer measurements), and knee radiographic changes were collected and stratified by short- (1–2 years), mid- (3–5 years), and long-term (6–10 years) follow-ups. Each study was carefully analyzed by two independent reviewers. Discrepancies between reviewers were scrutinized to arrive at consensus data. For those studies not conducting the follow-up at a single point in time, the mean follow-up time was reported.

Statistical analysis

Descriptive statistics were used to summarize the demographic characteristics of the subjects participating in all studies, and an independent *t*-test was used to compare demographic data between the two groups. The Chi-square statistical test was employed to compare categorical variables between groups. The statistical analysis was stratified for the length of follow-up in 3 groups: 1–2 years, 3–5 years, and 6–10 years. Statistical analyses were performed with SPSS v.15.0 (SPSS, Inc. Chicago, IL). For all statistical tests, the α level was set at 0.05.

Results

Of 256 articles initially identified from MEDLINE relating to the ACL reconstruction, 21 fulfilled the inclusion criteria and were included in the study. Any study directly compared the clinical outcomes of the AMP and TT techniques. Eight studies using the AMP technique and 13 using the TT technique were found. Four of the 8 studies using the AMP were published by the group of Pinczewski and refer to the same sample of patients [11, 44–46]. Thus, AMP studies involved 257 patients in five different studies [7, 11, 48, 50, 54]. For each follow-up period, data from the studies of the group of Pinczewski was only taken once. All 13 TT studies involved 602 patients. A total of 859 patients were involved in this analysis. Table 1 summarizes the main characteristics of the included studies. The follow-up only refers to those patients undergoing autologous BPTB ACL reconstruction using the AMP or the TT technique. Mean age was 27.5 years for the AMP group and 25.8 years for the TT group (n.s.). The male:female ration was 1.7 for the AMP group and 1.8 for the TT group (n.s.).

All 21 studies had similar rehabilitation protocols (Table 2). Patients from the AMP group began running significantly earlier than those from the TT group (mean 7.5 weeks and 11.8 weeks, respectively; $P = 0.04$). Also, the AMP group returned to full sports earlier than the TT group, although the existing difference was not statistically significant (mean 20 weeks and 30.3 weeks, respectively; n.s.). Most studies encouraged full ROM and full weight-bearing from the first day after surgery, and did not use post-operative braces.

Table 3 shows the additional procedures and the complications after the ACL reconstruction. Only 2 studies (one in each group) did not report an additional surgery after the ACL reconstruction [1, 48]. Partial meniscectomies, cyclops excisions, and screw removal are among the most common additional surgeries required after the ACL reconstruction. Fourty-one of all 859 patients (4.77%) sustained a contralateral ACL tear. The graft failure rate was 5.7% in the AMP and 2.3% in the TT group ($P = 0.012$). Intra-articular infections, deep venous thrombosis, or nerve injuries were only seen in 2 studies (both in the TT group) [15, 31].

All studies reporting the Overall IKDC score expressed the outcomes as a percentage of patients with grades AB and CD (Table 4). Only 3 studies (1 in the AMP and 2 in the TT group) [6, 25, 50] did not assess the IKDC score and were not included in the statistical analysis. This analysis involved a total of 409 patients in the 1–2-year follow-up period, 296 for the 3–5-year period, and 277 for the 6–10-year period. No statistically significant differences were found for any follow-up period in Overall IKDC between groups (Table 5). Four studies in the AMP [11, 45, 48, 50] and 2 in the TT [21, 25] group reported the Lysholm scores as the percentage of patients with Excellent (95–100), Good (84–94), Fair (65–83), or Poor (< 65) scores. Six studies in the AMP [7, 11, 44, 46, 50, 54] group and 7 in

Table 1 Summary of studies

Study	Femoral drilling[a]	Design[b]	Patients	Follow-up		Femoral fixation	Tibial fixation
				N (%)	Time		
Corry et al. [11]	AMP	PNRCT; PT versus HT	PT: 90 patients (mean age 25; 48 m; 42f)	PT: 24 mo: 77/90 (85%)	12 mo; 24 mo	Round-headed cannulated interference screw	Round-headed cannulated interference screw
Beard et al. [7]	AMP	PRCT; PT versus HT	PT: 30 patients	PT: 23/30 (76%)	6 mo; 12 mo	7 × 25 mm Interference screw	9 × 25 mm Interference screw
Pinczewski et al. [44]	AMP	PNRCT (cohort); PT versus HT[c]	PT: 90 patients (mean age 25; 48 m; 42f)	PT: 12 mo: 83/90 (92%); 24 mo: 77/90 (85%); 36 mo: 71/87 (782%); 48 mo: 68/87 (75%); 60 mo: 80/87 (88%)	12 mo; 24 mo; 36 mo; 48 mo; 60 mo	7 × 25 mm Cannulated interference screw	7 × 25 mm Cannulated interference screw
Shaieb et al. [50]	AMP	PRCT; PT versus HT	Total of 82 patients; PT: 33 patients (mean age 32, weight 78.9Kg, height 170.4 cm; 26 m; 7f)	Total: 70/82 (85%); Questionnarie evaluations 70/82; Clinical evaluation 57/82 (69.5%)	Minimum 24 mo Mean 33 mo.	Interference screw	Interference screw
Roe et al. [46]	AMP	PNRCT (cohort); PT versus HT[d]	PT: 90 patients (mean age 25; 48 m; 42f)	PT: 84 mo: 59/90 (65%) full clinical assessment, 63/90 (70%) only subjective evaluation	12 mo; 24 mo; 60 mo; 84 mo	7 × 25 mm Cannulated interference screw	7 × 25 mm Cannulated interference screw
Wagner et al. [54]	AMP	PNRCT (cohort); PT versus HT	PT: 72 patients; at follow-up: mean age 33.6; 40 m; 15f	PT: 55/72 (76.4%)	40 mo (mean)	Biodegradable 8 × 23 mm interference screw	Biodegradable 8 × 23 mm interference screw
Sajovic et al. [48]	AMP	PRCT; PT versus HT	PT: 32 patients; at follow-up: mean age 27, 14 m, 12f	PT: 26/32 (81.3%)	60 mo (5 years)	Cannulated interference screw	Bioabsorbable interference screw
Pinczewski et al. [45]	AMP	PNRCT (cohort); PT versus HT[e]	PT: 90 patients (Mean age 25; 48 m; 42f)	PT: 74/90 (82%)	24 mo; 60 mo; 84 mo; 120 mo	7 × 25 mm Cannulated interference screw	7 × 25 mm Cannulated interference screw
O'Neill [42]	TT	PRCT; 3 groups: 2-incision HT, 2-incision PT, 1-incision PT	1-incision PT: 45 patients; at follow-up: mean age 28, 28 m, 17f	1-incision PT: 45/45 (100%)	39 mo (mean)	9 × 25 mm Cannulated interference screw	9 × 25 mm Cannulated interference screw
Kleipool et al. [28]	TT	PNRCT; PT allograft versus PT autograft	PT autograft: 29 patients; at follow-up: mean age 28, 9 m, 17f	PT autograft: 26/29 (89.7%)	52 mo (mean)	Interference screw	Interference screw
Anderson et al. [4]	TT	PRCT; 3 groups: PT, HT + extraarticular procedure, HT	PT: 35 patients; at follow-up: mean age 23.6, 23 m, 12f	PT autograft: 35/35 (100%)	34 mo (mean)	7 × 25 mm Interference screw	Two barbed staples

Table 1 continued

Study	Femoral drilling[a]	Design[b]	Patients	Follow-up		Femoral fixation	Tibial fixation
				N (%)	Time		
Aune et al. [6]	TT	PRCT; PT versus HT	PT: 35 patients (mean age 25; 19 m; 16f)	PT: 29/35 (82.9%)	6 mo, 12 mo, 24 mo	7 × 25 interference screw	7 × 25 interference screw
Ejerhed et al. [15]	TT	PRCT; PT versus HT	PT: 34 patients; at follow-up: mean age 26, 11 m, 21f	PT: 32/34 (94%)	24 mo	7 mm Interference screw	9 mm Interference screw
Feller and Webster [17]	TT	PRCT; PT versus HT	PT: 31 patients (mean age 25.8; 23 m; 8f)	PT: 8 mo: 30/31 (96%); 12 mo: 29/31 (93%); 24 mo: 23/31 (74%); 36 mo: 26/31 (83%)	8 mo, 12 mo, 24 mo, 36 mo	EndoButton	Cannulated metallic interference screw
Aglietti et al. [1]	TT	PRCT; PT versus HT	PT: 60 patients; at follow-up: mean age 25, weight 74, height 175, 46m, 14f	PT: 60/60 (100%)	4 mo, 12 mo, 24 mo	Transcondylar fixation through Tunneloc screw	Soft threaded interference screw
Gorschewsky et al. [21]	TT	PNRCT (cohort); Tutoplast allograft PT versus autograft PT	Autograft PT: 136 patients	Autograft PT: 24 mo: 104/136 (76.5%); 71 mo: 101/136 (74%)	24 mo, 71 mo (mean)	Bioabsorbable interference screw	Bioabsorbable interference screw
Ibrahim et al. [25]	TT	PRCT; PT versus HT	Total of 110 patients (mean age 22.3)	Total: 85/110 (77%); PT: 40 patients	81 mo (mean)	Interference screws	Interference screws
Laxdal et al. [29]	TT	PRCT; PT versus ST versus HT	PT: 40 patients; at follow-up: mean age 28, 29 m, 11f	Total: 118/134 (88%)	26 mo (mean)	7 mm Sharp-threaded interference screws	9 mm Sharp-threaded interference screws
Matsumoto et al. [37]	TT	PRCT; PT versus BHTB	Total of 80 patients. PT: 37 patients; at follow-up: mean age 23.7, 21 m, 16f	Total: 72/80 (90%)	87 mo (mean)	7 × 20 mm Interference screw	7 × 20 mm Interference screw
Lidén et al. [31]	TT	PRCT; PT versus HT	PT: 34 patients (mean age 28, 23 m, 11f)	PT: 30/34 (88%)	86 mo (mean)	7 mm Interference screw	9 mm Interference screw
Maletis et al. [35]	TT	PRCT; PT versus HT	PT: 46 patients; at follow-up (24 mo): mean age 27.2, 31 m, 15f	PT: 6 mo: 39/46 (85%); 12 mo: 43/46 (93%); 24 mo: 46/46 (100%)	6 mo, 12 mo, 24 mo	7 × 23 mm Bioabsorbable screw	9 × 28 mm Bioabsorbable interference screw

AMP Anteromedial portal technique, *TT* transtibial technique, *PNRCT* prospective non-randomized clinical trial, *PRCT* prospective randomized clinical trial, *PT* bone-patellar tendon-bone (central third) graft, *HT* hamstrings tendon (semitendinosus/gracilis) graft, *ST* semitendinosus graft alone, *BHTB* bone-hamstring tendon-bone graft, *m* males, *f* females, *mo* months

[a] All through endoscopic single-incision technique, [b] all autografts, unless otherwise specified; [c] follow-up continuation of Corry et al. [11], [d] follow-up continuation of Pinczewski et al. [44], [e] follow-up continuation of Roe et al. [46]

Table 2 Rehabilitation aspects

Study	Drilling technique	PostOp brace	Crutches	Full ROM	Full WB	Closed chain	Run	Sport specific	Full sports	Functional brace	Continuous passive motion
Corry et al. [11]	AMP	No	D 10 days	B Day 1	B Day 1	Yes	B Week 6	B Week 12	B Week 36	No	–
Beard et al. [7]	AMP	–	–	B Day 1	B Day 1	Yes	B Week 4	B Week 8	–	–	–
Pinczewski et al. [44]	AMP	No	D 10 days	B Day 1	B Day 10	Yes	B Week 6	–	B Week 24	–	–
Shaieb et al. [50]	AMP	No	–	B Week 1	B Week 1	B Day 21	B Week 8	–	B Week 20	No	No
Roe et al. [46]	AMP	No	B Day 1	B Day 1	–	–	B Week 6	–	B Week 24	–	–
Wagner et al. [54]	AMP	D 1 week	B Day 1	B Week 6	D 4 weeks	–	B Week 12	–	B Week 24	D 2 weeks	–
Sajovic et al. [48]	AMP	D 3 weeks	–	B Day 1	B Day 1	B Day 1	D 8 weeks	–	B Week 12	–	–
Pinczewski et al. [45]	AMP	No	B Day 1	B Day 1	–	–	B Week 6	–	B Week 24	–	–
O'Neill DB [42]	TT	No	No	B Day 1	B Day 1	B Day 42	B Week 12	B Week 16	B Week 24	No	No
Kleipool et al. [28]	TT	No	–	–	B Day 2	–	B Week 16	B Week 24	B Week 48	D 6 weeks	B Day 1
Anderson et al. [4]	TT	Yes	B Day 1	B Week 6	B Week 3	No	B Week 12	B Week 16	B Week 24	B Week 3	No
Aune et al. [6]	TT	No	–	B Day 1	B Day 1	B Day 14	B Week 6	B Week 10	B Week 24	No	No
Ejerhed et al. [15]	TT	No	–	B Day 1	B Day 1	B Day 1	B Week 12	–	B Week 24	No	No
Feller and Webster [17]	TT	No	–	B Day 1	B Day 1	B Day 42	B Week 10	B Week 16	B Week 36	No	No
Aglietti et al. [1]	TT	No	–	B Day 1	B Week 3	B Week 4	B Week 12	B Week 16	B Week 24	–	–
Gorschewsky et al. [21]	TT	No	Yes	–	B Day 1	B Week 2	B Week 6	B Week 10	B Week 40	–	B Day 1
Ibrahim et al. [25]	TT	–	–	B Day 2	B Day 2	–	–	–	–	–	–
Laxdal et al. [29]	TT	No	–	B Day 1	B Day 1	B Day 1	B Week 12	–	B Week 24	–	–
Matsumoto et al. [37]	TT	Yes	–	–	B Week 4	B Week 2	B Week 16	–	B Week 24	–	B Day 1
Lidén et al. [31]	TT	No	–	B Day 1	B Day 1	B Day 1	B Week 12	–	B Week 24	–	–
Maletis et al. [35]	TT	D 4 weeks	D 30 days	B Day 1	B Day 1	–	B Week 16	–	B Week 48	–	–

AMP Anteromedial portal technique, *TT* transtibial technique, *ROM* range of motion, *WB* weight-bearing, *D* duration, *B* beginning

Table 3 Additional procedures and complications

Studies	Drilling technique	Additional surgeries after ACL reconstruction	Contralateral ACL tear[a]	Graft rupture	Intra-articular infections	DVT	Nerve injury
Corry et al. [11]	AMP	1 Arthrolysis; 1 cyclops excision	2/90 (2.2%)	3/90 (3.3%)	–	–	–
Beard et al. [7]	AMP	–	–	–	–	–	–
Pinczewski et al. [44]	AMP	1 Meniscectomy in a graft failure patient; 2 ipsilateral partial meniscectomy; 1 PT cyst excision; 1 arthroscopic chondroplasty	10/90 (11%)	3/90 (3.3%)	–	–	–
Shaieb et al. [50]	AMP	1 Arthrolysis; 1 tibial screw removal for superficial infection	3/82 (3.6%)[b]	4/82 (4.8%)[b]	0	–	–
Roe et al. [46]	AMP	4 Ipsilateral and 2 contralateral meniscectomy, 1 excision of patellar tendinitis, 1 removal of tibial screw, 1 arthrolysis, 1 contralateral arthroscopy, 1 chondroplasty, 1 cyclops excision	16 (18%)	4 (4%)	–	–	–
Wagner et al. [54]	AMP	–	9/72 (12.5%)	3/72 (4.1%)	–	–	–
Sajovic et al. [48]	AMP	0	3/32 (9.3%)	2/32 (6.2%)	0	0	0
Pinczewski et al. [45]	AMP	5 Meniscectomy, 2 contralateral meniscectomy, 1 excision of patellar tendinitis, 2 removal of tibial screw, 1 arthrolysis, 1 chondroplasty, 1 cyclops excision	20/90 (22.2%)	7/90 (7.7%)	–	–	–
O'Neill [42]	TT	1 Removal of metallic foreign body, 1 repair of medial meniscus, 1 debridement of adhesions + lateral retinacular release, 1 removal of deep hardware	–	1/45 (2.2%)	–	–	–
Kleipool et al. [28]	TT	8 Hardware removal, 2 meniscectomy, notch plasty	–	0%	–	–	–
Anderson et al. [4]	TT	1 Plica and staple removal	–	1/35 (2.8%)	0	0	0
Aune et al. [6]	TT	1 Meniscal surgery, 1 cyclops excision	3/72 (4.1%)[b]	1/29 (3.4%)	0	0	0
Ejerhed et al. [15]	TT	–	–	1/34 (2.9%)	1/34 (2.9%)	–	–
Feller and Webster [17]	TT	1 Debridement of superficial infection, 2 notchplasty, 1 partial meniscectomy, 2 diagnostic arthroscopies for pain and swelling with no clear conclusions	–	1/31 (3.2%)	0	–	–
Aglietti et al. [1]	TT	0	0%	0%	0	0	0
Gorschewsky et al. [21]	TT	–	–	6/101 (5.9%)	–	–	–
Ibrahim et al. [25]	TT	–	–	–	–	–	–
Laxdal et al. [29]	TT	–	1/42 (2.3%)	1/42 (2.3%)	–	–	–
Matsumoto et al. [37]	TT	8 Partial meniscectomies, 4 notchplasty or cyclops excision	0%	0%	0	0	0
Lidén et al. [31]	TT	2 Meniscal surgeries, 2 screw-related surgeries, 2 other surgeries	–	2/34 (5.8%)	1/34 (2.9%)	–	–
Maletis et al. [35]	TT	–	2/46 (4.3%)	0%	–	–	–

Complications referred to the PT group, unless otherwise indicated

AMP Anteromedial portal technique, *TT* transtibial technique, *ACL* anterior cruciate ligament, *DVT* deep venous thrombosis, *PT* patellar tendon

[a] After ACL reconstruction; [b] percentage referred to all patients included in the study

the TT [15, 21, 25, 28, 29, 31, 35] group reported their Lysholm score as the mean of the group. Five studies (all from the TT group) did not report the Lysholm score (Table 4) [1, 4, 6, 17, 37]. This analysis involved a total of 251 patients in the 1–2-year follow-up period, and 241 for the 6–10-year period. No statistically significant differences were found for any follow-up period in Lysholm scores between groups (Table 5).

The activity level was mainly reported as the percentage of patients able to perform strenous exercise, moderate exercise, light exercise, or just being sedentaries (Table 6). Seven studies used the Tegner score to assess the activity

Table 4 Overall IKDC and Lysholm scores

1st Author	Follow-up								
	Pre-Op	4–8 Months	1 Years	2 Years	3 Years	4 Years	5 Years	6–7 Years	10 Years
Overall IKDC for AMP technique studies									
Corry et al. [11]	–	–	–	AB 86% CD 14%	–	–	–	–	–
Beard et al. [7]	AB 4.5% CD 95.5%	AB 28.6% CD 71.4%	AB 45.5% CD 54.5%	–	–	–	–	–	–
Pinczewski et al. [44]	–	–	AB 93%	AB 96%	AB 92%	AB 87%	AB 90%	–	–
Shaieb et al. [50]	–	–	–	–	–	–	–	–	–
Roe et al. [46]	–	–	AB 93%	AB 96%	–	–	AB 90%	AB 85%	–
Wagner et al. [54]	AB 2% CD 98%	–	–	–	AB 89% CD 11%	–	–	–	–
Sajovic et al. [48]	–	–	–	–	–	–	AB 97% CD 3%	–	–
Pinczewski et al. [45]	–	–	–	–	–	–	–	–	AB 75% CD 25%
Overall IKDC for TT technique studies									
O'Neill [42]	–	–	–	–	AB 95% CD 4%	–	–	–	–
Kleipool et al. [28]	–	–	–	–	–	AB 70% CD 30%	–	–	–
Anderson et al. [4]	–	–	–	–	AB 97% CD 3%	–	–	–	–
Aune et al. [6]	–	–	–	–	–	–	–	–	–
Ejerhed et al. [15]	AB 0% CD 100%	–	–	AB 53% CD 47%	–	–	–	–	–
Feller and Webster [17]	–	AB 27% CD 73%	AB 45% CD 55%	AB 65% CD 35%	AB 71% CD 29%	–	–	–	–
Aglietti et al. [1]	–	–	–	AB 100% CD 0%	–	–	–	–	–
Gorschewsky et al. [21]	–	–	–	AB 92.3%	–	–	–	AB 83.2%	–
Ibrahim et al. [25]	–	–	–	–	–	–	–	–	–
Laxdal et al. [29]	–	–	–	AB 50% CD 50%	–	–	–	–	–
Matsumoto et al. [37]	–	–	–	–	–	–	–	AB 73% CD 27%	–
Lidén et al. [31]	AB 0% CD 100%	–	–	–	–	–	–	AB 48% CD 52%	–
Maletis et al. [35]	–	–	–	AB 91%	–	–	–	–	–
Lysholm[a] scores for AMP technique studies									
Corry et al. [11]	–	–	–	95[b] E 65% G 25% F 9% P 1%	–	–	–	–	–
Beard et al. [7]	73.7	85.8	91.5	–	–	–	–	–	–
Pinczewski et al. [44]	–	–	–	95[b]	–	–	96[b]	–	–

Table 4 continued

1st Author	Follow-up								
	Pre-Op	4–8 Months	1 Years	2 Years	3 Years	4 Years	5 Years	6–7 Years	10 Years
Shaieb et al. [50]	–	–	–	91.2 E 52% G 36% F 6% P 6%	–	–	–	–	–
Roe et al. [46]	–	–	–	94	–	–	94	93	–
Wagner et al. [54]	59.7	–	–	–	89.7	–	–	–	–
Sajovic et al. [48]	55	–	–	–	–	–	E 43% G 50% F 7%	–	–
Pinczewski et al. [45]	–	–	–	EG 89%[c]	–	–	EG 94%[c]	EG 90%[c]	EG 84%[c]
Lysholm scores for TT technique studies									
O'Neill DB [42]	–	–	–	–	93%[d]	–	–	–	–
Kleipool et al. [28]	61	–	–	–	–	95	–	–	–
Anderson et al. [4]	–	–	–	–	–	–	–	–	–
Aune et al. [6]	–	–	–	–	–	–	–	–	–
Ejerhed et al. [15]	70[b]	–	–	95[b]	–	–	–	–	–
Feller and Webster [17]	–	–	–	–	–	–	–	–	–
Aglietti et al. [1]	–	–	–	–	–	–	–	–	–
Gorschewsky et al. [21]	–	–	–	92.8 EG 90.4%[c]	–	–	–	93.6 EG 94.1%[c]	–
Ibrahim et al. [25]	–	–	–	–	–	–	–	91.6 E 50% G 40% F 10%	–
Laxdal et al. [29]	74	–	–	94	–	–	–	–	–
Matsumoto et al. [37]	–	–	–	–	–	–	–	–	–
Lidén et al. [31]	70[b]	–	–	–	–	–	–	81[b]	–
Maletis et al. [35]	63.6	–	95	97	–	–	–	–	–

IKDC International Knee Documentation Committee, *AMP* anteriomedial portal technique, *TT* transtibial technique, *A* normal, *B* nearly normal, *C* abnormal, *D* severely abnormal, *AB* % of patients with grades A + B, *CD* % of patients with C + D, *E* excellent (95–100), *G*, good (84–94); *F* fair (65–83), *P* poor (<65)

[a] Lysholm scores are expressed as mean values, unless otherwise indicated; [b] result expressed as median; [c] % of patients with E + G results; [d] % of patients with >90 score

level [7, 15, 25, 28, 29, 31, 35], whereas 3 did not report data on activity level [6, 48, 50]. The activity level analysis involved a total of 264 patients in the 1–2-year follow-up period, 141 for the 3–5-year period, and 175 for the 6–10-year period. Patients from the TT group were exercising at a higher intensity compared to the AMP group for the 3–5 and 6–10-year follow-up period ($P < 0.0001$ for both cases) (Table 5).

The percentage of patients with grades A, B, and C for both extension and flexion ROM was reported in 16 studies [1, 4, 6, 11, 15, 21, 25, 28, 29, 37, 42, 44–46, 48, 54], whereas 4 gave the values in degrees (Table 6) [17, 31, 35, 50]. All but one [7] study reported data on ROM, and 238 patients for the 1–2-year follow-up, 267 patients for the 3–5-year follow-up, and 136 patients for the 6–10-year follow-up were involved in the analysis. Greater extension and flexion ROM values for the AMP compared to the TT group were found for the short-term follow-up ($P = 0.01$ for extension and $P < 0.0001$ for flexion values) (Table 5). The significant differences were not seen in the 3–5 and 6–10-year follow-ups.

The strength assessment was reported through the SLH test graded as percentage of patients with A, B, and C in 8 studies (Table 7) [11, 21, 28, 42, 44, 45, 48, 54]. Five studies reported the mean percentage of distance reached with the injured compared to uninjured leg [6, 15, 29, 31,

Table 5 Comparison of outcomes

	Follow-up 1–2 years			Follow-up 3–5 years			Follow-up 6–10 years		
	AMP	TT	*P*	AMP	TT	*P*	AMP	TT	*P*
Overall IKDC			n.s.			n.s.			n.s.
Normal or nearly normal	86 (85%)[a]	253 (82%)		146 (89%)	113 (85%)		56 (75%)	151 (74%)	
Abnormal or severely abnormal	15 (15%)	55 (18%)		15 (11%)	19 (15%)		18 (25%)	52 (26%)	
No. of studies/patients involved	2/101	6/308		3/163	4/133		1/74	3/203	
Lysholm score			n.s.			–			n.s.
100–84	131 (89%)	94 (90%)		–	–		86 (86%)	131 (93%)	
<84	16 (11%)	10 (10%)		–	–		14 (14%)	10 (7%)	
No. of studies/patients involved	2/147	1/104		–	–		2[b]/100	2/141	
Activity level			n.s.			<0.0001			<0.0001
Strenous or moderate	65 (84%)	150 (80%)		55 (68%)	57 (93%)		33 (44%)	92 (91%)	
Light or sedentary	12 (16%)	37 (20%)		25 (32%)	4 (7%)		41 (56%)	9 (9%)	
No. of studies/patients involved	1/77	3/187		1/80	2/61		1/74	1/101	
Range of motion									
Extension: normal or <5 deficit	77 (100%)	148 (92%)	0.01	160 (99%)	102 (96%)	n.s.	59 (100%)	74 (96%)	n.s.
Extension: >6° deficit	0	13 (8%)		1 (1%)	4 (4%)		0	3 (4%)	
No. of studies/patients involved	1/77	4/161		3/161	3/106		1/59	2/77	
Flexion: normal or < 5° deficit	75 (97%)	120 (74%)	<0.0001	153 (95%)	67 (93%)	n.s.	–	–	–
Flexion: 6°–15° deficit	2 (3%)	41 (26%)		7 (4%)	2 (3%)		–	–	
Flexion: >16° deficit	0	0		1 (1%)	3 (4%)		–	–	
No. of studies/patients involved	1/77	4/161		3/161	3/72		–	–	
Single-leg hoop distance			n.s.			n.s.			n.s.
>90% Compared to uninjured leg	71 (92%)	86 (83%)		133 (83%)	65 (91%)		64 (86%)	80 (79%)	
<90% Compared to uninjured leg	6 (8%)	18 (17%)		28 (17%)	6 (9%)		10 (14%)	21 (21%)	
No. of studies/patients involved	1/77	1/104		3/161	2/71		1/74	1/101	
Lachman test			0.02			n.s.			n.s.
No side-to-side differences or <2 mm	62 (80%)	86 (63%)		123 (76%)	51 (72%)		60 (81%)	120 (70%)	
3–5 mm side-to-side differences	15 (20%)	48 (35%)		34 (21%)	16 (22%)		14 (19%)	50 (29%)	
6–10 mm Side-to-side differences	0	2 (2%)		4 (3%)	4 (6%)		0	1 (1%)	
No. of studies/patients involved	1/77	2/136		3/161	2/71		1/74	3/171	
Pivot shift sign			n.s.			n.s.			n.s.
No side-to-side differences	115 (86%)	180 (85%)		131 (81%)	71 (81%)		67 (90%)	121 (86%)	
Mild-to-moderate side-to-side differences	19 (14%)	30 (15%)		30 (19%)	16 (19%)		7 (10%)	20 (14%)	
No. of studies/patients involved	2/134	3/210		3/161	3/87		1/74	2/141	

Table 5 continued

	Follow-up 1–2 years			Follow-up 3–5 years			Follow-up 6–10 years		
	AMP	TT	*P*	AMP	TT	*P*	AMP	TT	*P*
KT-1000 (values at 134 N to manual max)			<0.0001			n.s.			n.s.
<3 mm side-to-side differences	114 (85%)	89 (69%)		99 (70%)	107 (81%)		56 (75%)	64 (83%)	
3–5 mm side-to-side differences	13 (9%)	38 (29%)		37 (26%)	22 (16%)		18 (25%)	11 (14%)	
>5 mm side-to-side differences	7 (6%)	2 (2%)		4 (4%)	3 (3%)		0	2 (3%)	
No. of studies/patients involved	2/134	3/129		3/140	4/132		1/74	2/77	
Radiographic assessment			n.s.			n.s.			n.s.
Normal or minimal changes	77 (100%)	124 (97%)		104 (98%)	106 (100%)		72 (97%)	163 (91%)	
Space narrowing (clearly detectable)	0	3 (3%)		2 (2%)	0		2 (3%)	15 (9%)	
No. of studies/patients involved	1/77	2/127		2/106	3/106		1/74	3/178	

[a] Results expressed as number of patients (% of patients with respect to the group)

[b] Study of Sajovic (with a 5-year follow-up) was included in the 6–10 year-follow-up group

35]. Nine studies reported the strength assessment using other than SLH test method [1, 4, 6, 7, 15, 17, 35, 37, 42], whereas only 3 studies did not report any strength assessment [25, 46, 50]. The statistical analysis for the SLH test involved a total of 181 patients for the 1–2-year follow-up period, 232 patients for the 3–5-year follow-up, and 175 for the 6–10-year follow-up. No statistically significant differences were found for any follow-up period in SLH test values between groups (Table 5).

Knee laxity was assessed in all studies (Tables 8, 9). Thirteen studies reported the Lachman test values as the percentage of patients with grades 0, 1, and 2 [1, 11, 15, 21, 25, 28, 31, 42, 44–46, 48, 54], 1 study gave the mean Lachman test as a 0–1–2 scale [50], and 7 studies did not report data on Lachman test (Table 8) [4, 6, 7, 17, 29, 35, 37]. The statistical analysis for the Lachman test involved 213 patients for the 1–2-year follow-up, 232 patients for the 3–5-year follow-up, and 245 patients for the 6–10-year follow-up. The AMP group demonstrated greater anterior-posterior knee stability measured through the Lachman test compared to the TT group for the 1–2-year follow-up ($P = 0.02$), although the difference was not maintained for the rest of follow-up periods (Table 5). Rotational knee stability was measured through the pivot shift sign test in 14 studies (Table 8) [1, 4, 11, 17, 21, 25, 28, 35, 44–46, 48, 50, 54]. The other 7 studies did not report data on the rotational knee stability [6, 7, 15, 29, 31, 37, 42]. The statistical analysis involved a total of 344 patients for the 1–2-year follow-up period, 248 patients for the 3–5-year follow-up, and 215 patients for the 6–10-year follow-up. No statistically significant differences were found for any follow-up period in the pivot shift sign test between groups (Table 5). The anterior-posterior instrumented knee laxity was measured with the KT-1000 arthrometer in all studies (Table 9). KT-1000 values were reported for 67 N, 89 N, 134 N, and manual maximum applied force. The statistical analysis involved a total of 263 patients for the 1–2-year follow-up, 272 patients for the 3–5-year follow-up, and 151 patients for the 6–10-year follow-up. The AMP group demonstrated greater instrumented knee stability values compared to the TT group for the 1–2-year follow-up ($P < 0.0001$), although the difference was not maintained for the rest of the follow-ups (Table 5).

The radiographic assessment graded as A (normal), B (minimal changes and barely detectable joint space narrowing), C (minimal changes and joint space narrowing up to 50%), and D (more than 50% joint space narrowing), according to IKDC recommendations, was reported in 11 studies [4, 11, 17, 21, 25, 37, 42, 44–46, 48], whereas 10 studies did not evaluate knee osteoarthritic changes (Table 10) [1, 6, 7, 15, 28, 29, 31, 35, 50, 54]. The statistical analysis involved 204 patients for the 1–2-year

Table 6 Activity level and range of motion

1st Author	Follow-up								
	Pre-Op	4–8 Months	1 Years	2 Years	3 Years	4 Years	5 Years	6–7 Years	10 Years
Activity level for AMP technique studies									
Corry et al. [11]	SM 30% LSe 70%	–	SM 73% LSe 27%	SM 84% LSe 16%	–	–	–	–	–
Beard et al. [7]	T 3.8	T 4.3	T 5.7	–	–	–	–	–	–
Pinczewski et al. [44]	–	–	SM 73%	SM 84%	SM 74%	SM 68%	SM 69%	–	–
Shaieb et al. [50]	–	–	–	–	–	–	–	–	–
Roe et al. [46]	–	–	SM 73%	SM 84%	–	–	SM 69%	SM 52%	–
Wagner et al. [54]	–	–	–	–	A 67%[a] B 29% C 4%	–	–	–	–
Sajovic et al. [48]	–	–	–	–	–	–	–	–	–
Pinczewski et al. [45]	–	–	–	SM 85%	–	–	SM 68%	SM 55%	SM 45%
Activity level for TT technique studies									
O'Neill [42]	–	–	–	–	89%[b]	–	–	–	–
Kleipool et al. [28]	T 3	–	–	–	–	T 6	–	–	–
Anderson et al. [4]	M 13.8% L 86.2%	–	–	–	S 82.8%[b] M 14.3% L 2.9%	–	–	–	–
Aune et al. [6]	–	–	–	–	–	–	–	–	–
Ejerhed et al. [15]	T 3	–	–	T 6	–	–	–	–	–
Feller and Webster [17]	–	SM 70% LSe 30%	SM 76% LSe 24%	SM 83% LSe 17%	SM 88% LSe 12%	–	–	–	–
Aglietti et al. [1]	–	–	–	SM 57% LSe 43%	–	–	–	–	–
Gorschewsky et al. [21]	–	–	–	NL 93.2% CNP 6.8%	–	–	–	NL 91.1% CNP 8.9%	–
Ibrahim et al. [25]	–	–	–	–	–	–	–	77.6%[b] T 7.9	–
Laxdal et al. [29]	T4	–	–	T6	–	–	–	–	–
Matsumoto et al. [37]	–	–	–	–	–	–	–	75.7%[b]	–
Lidén et al. [31]	T 3	–	–	–	–	–	–	T 5	–
Maletis et al. [35]	T 2.7	–	T 5.5	51%[b] T 5.9	–	–	–	–	–
Range of motion for AMP technique studies									
Corry et al. [11]	–	–	–	EA 97% EB 3% FA 99% FB 1%	–	–	–	–	–
Beard et al. [7]	–	–	–	–	–	–	–	–	–
Pinczewski et al. [44]	–	–	EA 92% EB 8%	EA 92% EB 8% FA 99% FB 1%	EA 85% EB 15%	EA 68% EB 32%	EA 69% EB 31% FA 100%	–	–
Shaieb et al. [50]	–	–	–	52%[c] LF 3.4°	–	–	–	–	–
Roe et al. [46]	–	–	EA 92% EB 8%	EA 92% EB 8%	–	–	EA 69% EB 31%	EA 86% EB 14%	–

Table 6 continued

1st Author	Follow-up								
	Pre-Op	4–8 Months	1 Years	2 Years	3 Years	4 Years	5 Years	6–7 Years	10 Years
Wagner et al. [54]	–	–	–	–	EA 91% EB 7% EC 2% FA 86% FB 13% FC 2%	–	–	–	–
Sajovic et al. [48]	–	–	–	–	–	–	EA 100% FA 89% FB 11%	–	–
Pinczewski et al. [45]	–	–	–	EA 92%	–	–	EA 68%	EA 75%	EA 72%
Range of motion for TT technique studies									
O'Neill [42]	–	–	–	–	EA 100% FA 95.5% FB 4.5%	–	–	–	–
Kleipool et al. [28]	–	–	–	–	–	EA 92.4% EB 3.8% EC 3.8% FA 92.4% FC 7.6%	–	–	–
Anderson et al. [4]	–	–	–	–	EAB 91.4% EC 8.6% FAB 97.2% FC 2.8%	–	–	–	–
Aune et al. [6]	–	–	–	EA 100% FA 100%	–	–	–	–	–
Ejerhed et al. [15]	–	–	–	EAB 59.4% EC 40.6% FA 50% FB 50%	–	–	–	–	–
Feller and Webster [17]	–	Ed 2.8° Fd 9.8°	Ed 2.8° Fd 7°	Ed 3° Fd 7°	Ed 2.7° Fd 4°	–	–	–	–
Aglietti et al. [1]	–	EA 95% EB 5%	–	EA 98.4% EB 1.6% FA 100%	–	–	–	–	–
Gorschewsky et al. [21]	–	–	–	EFA 82.7%	–	–	–	EFA 96%	–
Ibrahim et al. [25]	–	–	–	–	–	–	–	EA 65% EB 30% EC 5% FA 87.5% FB 12.5%	–
Laxdal et al. [29]	–	–	–	EA 66% EB 34% FA 37% FB 63%	–	–	–	–	–

Table 6 continued

1st Author	Follow-up								
	Pre-Op	4–8 Months	1 Years	2 Years	3 Years	4 Years	5 Years	6–7 Years	10 Years
Matsumoto et al. [37]	–	–	–	–	–	–	–	EA 89.2% EB 8.1% EC 2.7% FA 94.6% FB 5.4%	–
Lidén et al. [31]	E[d] −5° F[d] 145°	–	–	–	–	–	–	E[d] −5° F[d] 140°	–
Maletis et al. [35]	–	–	–	Ed 0.3° Fd 0.7°	–	–	–	–	–

AMP Anteromedial portal technique, *TT* transtibial technique, *T* Tegner score; *S* strenous (rugby, basketball, soccer), *M* moderate (skiing, tennis, heavy manual labor), *L* light (jogging), *Se* sedentary, *A* normal, *B* nearly normal, *C* abnormal, *D* severely abnormal, *NR* % of patients with no restrictions for return to sports (N) + Light restrictions (L), *CNP* % of patients with clear restriction for return to sports (C) + no possibility to return to sports (NP), *EA* extension grade A (full extension or <3° of side-to-side differences), EB extension grade B (loss of extension 3°–5° compared to contralateral knee), *EC* extension grade C (loss of extension 6°–10° compared to contralateral knee), *FA* flexion grade A (full flexion or <5° side-to-side differences); *FB* flexion grade B (loss of flexion 6°–15° compared to contralateral knee), *FC* flexion grade C (loss of flexion 16°–25° compared to contralateral knee), *LF* loss of flexion (average), *Ed* extension deficit (mean in °), *Fd* flexion deficit (mean in °), *EFA* extension graded A + flexion graded A

[a] Assessed with the question "How does your knee affect your activity level?, [b] % of patients returning to pre-injury activity level, [c] % of patients with loss of motion; [d] values expressed as median

follow-up, 212 patients for the 3–5-year follow-up, and 252 for the 6–10-year follow-up. The proportion of patients with grades AB and CD did not differ for any follow-up period between groups (Table 5). When only analyzing the radiographic assessment of those studies included in the KT-1000 arthrometer measurements, it was found that the TT group demonstrated significantly greater tibiofemoral space narrowing compared to the AMP group at the 6–10-year follow-up ($P = 0.034$).

Discussion

The purpose of this study was to compare the clinical outcomes between the TT versus the AMP technique for the femoral tunnel drilling in the one-incision arthroscopically assisted autologous BPTB (single-bundle) ACL reconstruction. Given the absence of any direct comparison between both techniques, this was a meta-analysis based on indirect comparisons. The most important finding of the present study was that the AMP group began running significantly earlier and had significantly greater ROM (for both knee extension and knee flexion) and anterior-posterior knee stability assessed through both the Lachman test and the KT-1000 arthrometer at the 1–2-year follow-up compared to the TT group, although these differences were not maintained for the rest of the follow-up. In contrast, the TT group demonstrated greater activity level at 3–5-year and 6–10-year follow-up compared to the AMP group. No differences were found for overall IKDC, Lysholm scores, single-leg hop test, pivot shift sign test, and radiographic assessment. These results may indicate a potential benefit of the AMP over the TT technique for knee stability, ROM, and return to run, although there is no definitive evidence, at this point, to conclude that one technique is superior to the other. Randomized controlled trials directly comparing the use of both techniques with long-term follow-ups will help clarify which one, if any, provides best clinical outcomes.

It was recently published that 85% of USA orthopedic surgeons members of the AOSSM were employing the TT technique and 15% the AMP technique [14]. This study elicited a slightly higher proportion; however, not all studies specified the femoral drilling method. The number of TT technique studies might increase if the drilling method was systematically described in all published articles. This review included 13 studies using the TT technique and involved a total of 602 patients. Thus, this sample should be representative of the patients undergoing ACL reconstruction using the TT drilling of the femoral tunnel.

Both groups were highly comparable in terms of demographic characteristics, thus limiting potential confounding factors related to age and male:female ratios. Patients from the AMP group returned to run and full sports earlier than the TT group despite both groups had similar rehabilitation protocols. Early return to run and sports may be explained by a greater knee function and stability during first months after ACL reconstruction in the AMP group. The higher graft failure rates that were found in the AMP compared to the TT group should be interpreted with caution. Almost all

Table 7 Strength assessments

1st Author	Follow-up							
	Pre-Op	4–8 Months	1 Years	2 Years	3 Years	4 Years	5 Years	6–7 Years	10 Years
Strength assessments in AMP technique studies									
Corry et al. [11]	–	–	–	SLHA 92.2% SLHB 5.2% SLHC 2.6%	–	–	–	–	–
Beard et al. [7]	Q^{a} 103 H^{a} 98	Q^{a} 89 H^{a} 90	Q^{a} 107 H^{a} 100 Qd 19% Hd 5%	–	–	–	–	–	–
Pinczewski et al. [44]	–	–	–	SLHA 92.2%	–	–	SLHA 89%	–	–
Shaieb et al. [50]	–	–	–	–	–	–	–	–	–
Roe et al. [46]	–	–	–	–	–	–	–	–	–
Wagner et al. [54]	–	–	–	–	SLHA 69% SLHB 27% SLHC 4%	–	–	–	–
Sajovic et al. [48]	–	–	–	–	–	–	SLHA 92%	–	–
Pinczewski et al. [45]	–	–	–	SLHA 90%	–	–	SLHA 89%	SLHA 89%	SLHA 87%
Strength[a] assessments in TT technique studies									
O'Neill [42]	–	–	–	–	SLHA 89% Qd10 40% Qd20 11.1% Hd 0%	–	–	–	–
Kleipool et al. [28]	–	–	–	–	–	SLHA 96.1% SLHB 3.9%	–	–	–
Anderson et al. [4]	–	–	–	–	Q^{b} 86%[c] H^{b} 96%[c]	–	–	–	–
Aune et al. [6]	–	SLH 87.7%[d] Q^{b} 78%[c] H^{b} 90%[c]	SLH 92.1%[d] Q^{b} 90%[c] H^{b} 93%[c]	SLH 95.7%[d] Q^{b} 90%[c] H^{b} 92%[c]	–	–	–	–	–
Ejerhed et al. [15]	SLH 84%[e] Q^{b} 73%[c] H^{b} 60%[c]	–	–	SLH 92%[e] Q^{b} 85.7%[c] H^{b} 120%[c]	–	–	–	–	–
Feller and Webster [17]	–	Q^{b} 74.5%[c] H^{b} 96.6%[c]	Q^{b} 77.3%[c] H^{b} 98.3%[c]	–	–	–	–	–	–
Aglietti et al. [1]	–	Q^{b} 76%[c] H^{b} 92%[c]	Q^{b} 89%[c] H^{b} 97%[c]	Q^{b} 99.5%[c] H^{b} 102%[c]	–	–	–	–	–
Gorschewsky et al. [21]	–	–	–	SLHA 82.7%	–	–	–	SLHA 79.2%	–
Ibrahim et al. [25]	–	–	–	–	–	–	–	–	–
Laxdal et al. [29]	SLH 90%[d]	–	–	SLH 94%[d]	–	–	–	–	–
Matsumoto et al. [37]	–	–	–	–	–	–	–	Q^{b} 86.4%[c] H^{b} 100%[c]	–
Lidén et al. [31]	SLH 84%[e]	–	–	–	–	–	–	SLH 96%[e]	–
Maletis et al. [35]	–	–	SLH 82%[d] Q^{b} 70%[c] H^{b} 95%[c]	SLH 94%[d] Q^{b} 85%[c] H^{b} 99%[c]	–	–	–	–	–

AMP Anteromedial portal technique, *TT* transtibial technique, *SLH* single-legged hop test, classified as A (SLHA) when 90% or more distance compared with the opposite side, B (SLHB) when 89–76% distance compared with opposite side, C (SLHC) when 75–50% distance compared with opposite side, *Q* quadriceps strength, *H* hamstrings strength, *Qd* quadriceps strength deficit compared with uninjured limb, *Hd* hamstrings strength deficits compared with uninjured limb, *Qd10 (Qd20)* quadriceps strength deficit of >10% (>20%) compared with uninjured limb (in % of patients)

[a] Values expressed as Nm; [b] results assessed at 60°/s; [c] % of strength compared with uninjured side; [d] mean % of injured compared with uninjured limb; [e] median % of the injured compared with uninjured limb

Table 8 Knee stability: Lachman and Pivot shift tests

1st Author	Follow-up							
	Pre-Op	4–8 Months	1 Years	2 Years	3 Years	4 Years	5 Years	6–7 Years	10 Years
Lachman test for AMP technique studies									
Corry et al. [11]	L12 100%	–	–	L0 80.5% L1 19.5%	–	–	–	–	–
Beard et al. [7]	–	–	–	–	–	–	–	–	–
Pinczewski et al. [44]	L12 100%	–	L0 85%	L0 81%	L0 93%	L0 90%	L0 90%	–	–
Shaieb et al. [50]	L1 6% L2 69.8% L3 24.2% LM 2.3	–	–	LM 0.35	–	–	–	–	–
Roe et al. [46]	–	–	L0 85%	L0 91%	–	–	L0 90%	L0 76%	–
Wagner et al. [54]	–	–	–	–	L(0–2) 55% L(3–5) 40% L(6–10) 6%	–	–	–	–
Sajovic et al. [48]	–	–	–	–	–	–	L(0–2) 79% L(3–5) 18% L(6–10) 3%	–	–
Pinczewski et al. [45]	L23 100%	–	–	L0 79%	–	–	L0 86%	L0 76%	L0 81% L1 19%
Lachman test for TT technique studies									
O'Neill [42]	–	–	–	–	L0 76% L01 87%	–	–	–	–
Kleipool et al. [28]	L1 11.5% L2 65.4% L3 23.1%	–	–	–	–	L0 65.4% L1 19.2% L2 15.4%	–	–	–
Anderson et al. [4]	–	–	–	–	–	–	–	–	–
Aune et al. [6]	–	–	–	–	–	–	–	–	–
Ejerhed et al. [15]	L1 6.3% L2 31.2% L3 62.5%	–	–	L0 56.2% L1 37.5% L2 6.3%	–	–	–	–	–
Feller and Webster [17]	L + 100%	–	–	–	–	–	–	–	–
Aglietti et al. [1]	L1 15% L2 78% L3 7%	–	–	L01 100%	–	–	–	–	–
Gorschewsky et al. [21]	–	–	–	L0 65.4%	–	–	–	L0 76.2%	–
Ibrahim et al. [25]	L + 100%	–	–	–	–	–	–	L0 87.5% L1 10%	–
Laxdal et al. [29]	–	–	–	–	–	–	–	–	–
Matsumoto et al. [37]	–	–	–	–	–	–	–	–	–
Lidén et al. [31]	L1 6.6% L2 30% L3 63.4%	–	–	–	–	–	–	L0 26.6% L1 70% L2 3.4%	–
Maletis et al. [35]	–	–	–	–	–	–	–	–	–
Pivot shift sign for AMP technique studies									
Corry et al. [11]	PS + 93.5%	–	–	PS0 91% PS1 9%	–	–	–	–	–
Beard et al. [7]	–	–	–	–	–	–	–	–	–

Table 8 continued

1st Author	Follow-up								
	Pre-Op	4–8 Months	1 Years	2 Years	3 Years	4 Years	5 Years	6–7 Years	10 Years
Pinczewski et al. [44]	PS + 100%	–	PS0 94%	PS0 91%	PS0 93%	PS0 94%	PS0 98%	–	–
Shaieb et al. [50]	PS + 100%	–	–	PS- 79.1% PS + 20.9%	–	–	–	–	–
Roe et al. [46]	–	–	PS0 94%	PS0 91%	–	–	PS0 98%	PS0 83%	–
Wagner et al. [54]	–	–	–	–	PS- 58% PS1 38% PS2 4%	–	–	–	–
Sajovic et al. [48]	–	–	–	–	–	–	PS0 83% PS1 14% PS2 3%	–	–
Pinczewski et al. [45]	PS23 100%	–	–	PS0 90%	–	–	PS0 94%	PS0 83%	PS0 91% PS1 9%
Pivot shift sign for TT technique studies									
O'Neill [42]	–	–	–	–	–	–	–	–	–
Kleipool et al. [28]	PS1 3.8% PS2 42.4% PS3 53.8%	–	–	–	–	PS0 73.1% PS1 23.1% PS2 3.8%	–	–	–
Anderson et al. [4]	PS0 48.6% PS1 8.5% PS2 22.9 PS3 20%	–	–	–	PS0 74.3% PS1 5.7% PS2 14.3% PS3 5.7%	–	–	–	–
Aune et al. [6]	–	–	–	–	–	–	–	–	–
Ejerhed et al. [15]	–	–	–	–	–	–	–	–	–
Feller and Webster [17]	–	–	–	–	PS0 100%	–	–	–	–
Aglietti et al. [1]	PS1 13% PS2 80% PS3 5%	–	–	PS0 83% PS1 17%	–	–	–	–	–
Gorschewsky et al. [21]	–	–	–	PS + 15%	–	–	–	PS + 15%	–
Ibrahim et al. [25]	PS + 100%	–	–	–	–	–	–	PS0 87.5% PS1 12.5%	–
Laxdal et al. [29]	–	–	–	–	–	–	–	–	–
Matsumoto et al. [37]	–	–	–	–	–	–	–	–	–
Lidén et al. [31]	–	–	–	–	–	–	–	–	–
Maletis et al. [35]	–	–	–	PS0 91.3% PS1 8.7%	–	–	–	–	–

AMP Anteromedial portal technique, *TT* transtibial technique, *L*, Lachman test scored graded 0 (no side–to-side differences: <2 mm), 1 (mild side-to-side differences:3–5 mm), 2 (moderate side-to-side differences: 6–10 mm), 3 (severe side-to-side differences: >10 mm), *L12* Lachman 1 + 2 (% of patients), *PS* Pivot shift sign graded 0 (no side-to-side differences), 1 (mild side-to-side differences), 2 (moderate side-to-side differences), 3 (severe side-to-side differences); *LM* Mean Lachman test (0, 1+, 2+, 3+), *L(0–2)* Lachman test with values between −1 and 2 mm side-to-side differences, *L(3–5)* Lachman test with values between 3 and 5 mm side-to-side differences, *L(6–10)* Lachman test with values between 6 and 10 mm side-to-side differences, *PS12* Pivot shift grades 1 and 2, *PS23* Pivot shift grades 2 and 3

Table 9 Instrumented knee stability measurements

1st Author	Follow-up								
	Pre-Op	4–8 Months	1 Years	2 Years	3 Years	4 Years	5 Years	6–7 Years	10 Years
KT-1000[a] scores for AMP technique studies									
Corry et al. [11]	–	–	–	KT(89) 1 KT(89) < 3 mm 91% KT(89) > 5 mm 8%	–	–	–	–	–
Beard et al. [7]	KT(20) 4.3	KT(20) 2.6	KT(20) 1.8	–	–	–	–	–	–
Pinczewski et al. [44]	–	–	–	KT(M) 0.8	KT(M) 1.3	KT(M) 1.5	KT(M) 1.3	–	–
Shaieb et al. [50]	–	–	–	KT(89) 1.4 KT(134) 1.8 KT(M) 1.51 KT(M) < 3 mm 79.1% KT(M)3–5 mm 8.3% KT(M) > 5 mm 12.5%	–	–	–	–	–
Roe et al. [46]	–	–		KT(M) < 3 mm 89%	–	–	KT(M) < 3 mm 82%	KT(M) < 3 mm 74% KT(M) 1.5	–
Wagner et al. [54]	KT(M) 5.98	–	–	–	KT(M) 2.6 KT(M)0–2 mm 55% KT(M)3–5 40% KT(M) –10 5%	–	–	–	–
Sajovic et al. [48]	–	–	–	–	–	–	KT(134) 1.9 KT(134)0–2 mm 80% KT(134)3–5 mm 17% KT(134)6–10 mm 3%	–	–
Pinczewski et al. [45]	–	–	–	KT(M) < 3 mm 88% KT (M) 0.8	–	–	KT(M) < 3 mm 81% KT (M) 1.5	KT(M) < 3 mm 74% KT (M) 1.5	KT(M) < 3 mm 76% KT(M) 1.2

Table 9 continued

1st Author	Follow-up								
	Pre-Op	4–8 Months	1 Years	2 Years	3 Years	4 Years	5 Years	6–7 Years	10 Years
KT–1000 scores for TT technique studies									
O'Neill [42]	–	–	–	–	KT[b](M)0 mm 55.5% KT(M)0–2 mm 22.2% KT(M)2–3 mm 8.9% KT(M)3–5 mm 11.2% KT(M) > 5 mm 2.2%	–	–	–	–
Kleipool et al. [28]	KT < 3 mm 3.8% KT3–5 mm 30.8% KT > 5 mm 65.4%	–	–	–	–	KT < 3 mm 69.2% KT3–5 mm 23.1% KT > 5 mm 7.7%	–	–	–
Anderson et al. [4]	KT(M) 5.3	–	–	–	KT(M) 2.1 KT(M) < 3 mm 71.4%	–	–	–	–
Aune et al. [6]	–	KT(M) 3.3	KT(M) 2.6	KT(M) 2.7	–	–	–	–	–
Ejerhed et al. [15]	KT(89) 3.75	–	–	KT(89) 2	–	–	–	–	–
Feller and Webster [17]	–	KT(67) 0.4 KT(67)0–2 mm 100% KT(134) 0.8 KT(134)0–2 mm 100%	KT(67) 0.6 KT(67)0–2 mm 96% KT(67)3–5 mm 4% KT(134) 1.2 KT(134)0–2 mm 89% KT(134)3–5 mm 11%	KT(67) 0.7 KT(67) 0–2 mm 100% KT(134) 1.1 KT(134)0–2 mm 96% KT(134)3–5 mm 4%	KT(67) 0.5 KT(67)0–2 mm 100% KT(134) 0.5 KT(134)0–2 mm 95% KT(134)3–5 mm 5%	–	–	–	–
Aglietti et al. [1]	KT(134) 7	–	–	KT(134) 1.95 KT(134,M)0–2 mm 65% KT(134,M)3–5 35%	–	–	–	–	–
Gorschewsky et al. [21]	–	–	–	KT(M) 1.57	–	–	–	KT(M) 2.42	–
Ibrahim et al. [25]	–	–	–	–	–	–	–	KT(M)0–2 mm 87.5% KT(M)3–5 7.5% KT(M) > 5 mm 5%	–

Table 9 continued

1st Author	Follow-up								
	Pre-Op	4–8 Months	1 Years	2 Years	3 Years	4 Years	5 Years	6–7 Years	10 Years
Laxdal et al. [29]	KT(89) 4	–	–	KT(89) 1 KT(89) < –1 mm 13% KT(89) (−1 mm to 3 mm) 71% KT(89)3–6 mm 11% KT(89) > 6 mm 5%	–	–	–	–	–
Matsumoto et al. [37]	–	–	–	–	–	–	–	KT(M) 1.7 KT(M)0–2 mm 78.4% KT(M)3–5 mm 18.9% KT(M) > 5 mm 2.7%	–
Lidén et al. [31]	KT(89) 4.5	–	–	–	–	–	–	KT(89) 1.7 KT(134) 2.3	–
Maletis et al. [35]	KT(134) 3.4 KT(M) 7.2	KT(M) 2.2	KT(M) 2.5	KT(M) 2.3 KT(M)0–2 mm 61.4% KT(M)3–5 mm 34.1% KT(M) > 5 mm 4.5%	–	–	–	–	–

AMP Anteromedial portal technique, *TT* transtibial technique, *KT(20)* KT-1000 values at 20 N, *KT(89)* KT-1000 values at 89 N, *KT(134)* KT-1000 at 134 N, *KT(M)* KT-1000 manual maximum values, *KT (<3) %* of patients with KT-1000 values <3 mm, *KT (>5) %* of patients with KT-1000 values >5 mm

[a] Values expressed as mean side-to-side differences in mm, unless otherwise indicated; [b] results obtained with KT-2000

Table 10 Radiographic assessment of knee osteoarthritic changes

1st Author	Follow-up								
	Pre-Op	4–8 Months	1 Years	2 Years	3 Years	4 Years	5 Years	6–7 Years	10 Years
Radiographic assessment[a] for AMP technique studies									
Corry et al. [11]	–	–	–	A 98.5% B 1.5%	–	–	–	–	–
Beard et al. [7]	–	–	–	–	–	–	–	–	–
Pinczewski et al. [44]	–	–	–	A 99% B 1%	–	–	A 82% B 15% C 3%	–	–
Shaieb et al. [50]	–	–	–	–	–	–	–	–	–
Roe et al. [46]	–	–	–	A 94% B 6%	–	–	A 70% B 30%	A 55% B 41% C 4%	–
Wagner et al. [54]	–	–	–	–	–	–	–	–	–
Sajovic et al. [48]	–	–	–	–	–	–	A 76.9% B 23.1% A 84.6%[b] B 15.4%[b]	–	–
Pinczewski et al. [45]	–	–	–	A 96% B 4%	–	–	A 74% B 26%	A 66% B 32% C 2%	A 61% B 36% C 3%
Radiographic assessment for TT technique studies									
O'Neill [42]	–	–	–	–	A 100%	–	–	–	–
Kleipool et al. [28]	–	–	–	–	–	–	–	–	–
Anderson et al. [4]	–	–	–	–	A 91.4% B 8.6%	–	–	–	–
Aune et al. [6]	–	–	–	–	–	–	–	–	–
Ejerhed et al. [15]	–	–	–	–	–	–	–	–	–
Feller and Webster [17]	–	A 100%	A 100%	A 100%	A 100%	–	–	–	–
Aglietti et al. [1]	–	–	–	–	–	–	–	–	–
Gorschewsky et al. [21]	–	–	–	A 90.4% B 6.7% C 1.9% D 1%	–	–	–	A 81.2% B 12.9% C 4.9% D 1%	–
Ibrahim et al. [25]	–	–	–	–	–	–	–	AB 85% C 15% B 20%[b]	–
Laxdal et al. [29]	–	–	–	–	–	–	–	–	–
Matsumoto et al. [37]	–	–	–	–	–	–	–	A 59.5% B 32.4% C 8.1%	–
Lidén et al. [31]	–	–	–	–	–	–	–	–	–
Maletis et al. [35]	–	–	–	–	–	–	–	–	–

AMP Anteromedial portal technique, *TT* transtibial technique, *A* normal X-ray study, *B* minimal changes and barely detectable joint space narrowing in X-ray study, *C* minimal changes and joint space narrowing of up to 50%, *D* more than 50% joint space narrowing

[a] X-rays referred to tibiofemoral joint, unless otherwise indicated; [b] patellofemoral joint

graft failures were traumatic in nature, so graft ruptures may be more related to the participation in contact sports than the technique itself.

In activity level, almost all studies did not report if the reason not to participate in sports was directly related to concerns about the operated knee. It remains unclear if the higher proportion of sedentary patients and patients participating in low intensity exercise in the AMP group is explained by a poor knee function or because of psychosocial factors (fear for return to sports, changes in life circumstances, etc.). The lack of differences in the overall IKDC or Lysholm scores may indicate that the lower activity level in the AMP group is related to psychosocial factors that limit the potential to participate in more demanding activities. However, the analysis of the activity level and the IKDC and Lysholm was not exactly based on the same sample, so care must be taken when establishing direct relationships among these variables. Details on the reason not to participate in sports are needed in all studies dealing with the ACL reconstruction in order to assure a correct interpretation of the return to sports parameter.

The success in ACL reconstruction surgery is mainly determined by similarities between the graft morphology, tension, position, and orientation compared to the native ACL. An anteriorly placed graft results in an anterior–posterior instability of the knee [36], whereas a vertically oriented graft in the coronal plane results in an increased internal rotation and positive pivot shift sign [30, 49]. Although it was found that a posteriorly located graft can be achieved through the TT technique, thus partially restoring the anterior–posterior knee stability [20, 32], a significantly greater short-term anterior–posterior knee stability in the AMP group compared to the TT group was found in this investigation. The findings of this study are in agreement with Arnold et al. [5], Paessler et al. [43], and Dargel et al. [13], who suggested that the TT technique may place the femoral insertion site of the graft more anterior with respect to the native ACL side. However, there were no anterior–posterior knee stability differences between groups for the 3–5 and 6–10-year follow-ups. Values of Lachman test and KT-1000 arthrometer for the AMP group were similar in all follow-ups, whereas values of anterior–posterior knee stability in the TT group improved in the 3–5 and 6–10 years compared to the 1–2-year follow-up. Increased knee stability in the mid- and long-term compared to the short-term follow-up may be explained by an increase in knee osteoarthritic changes, ligamentization phenomenons that would not yet be present during the first 2 years, and an improvement in the neuromuscular control (dynamic stabilizers) [3] that would compensate knee stability differences among groups. The most likely explanation may be an increase in knee osteoarthritic changes in the TT group that may decrease knee laxity with time. Although no differences in radiographic assessment were found between groups for any follow-up period, the radiographic analysis was not based on the same sample than the knee stability analysis. In fact, when statistically analyzing the radiographic parameter for only those patients that were analyzed with KT-1000 arthrometer, the TT group had greater long-term knee osteoarthritic changes (greater space narrowing) compared to the AMP group. Although no overall differences in knee osteoarthritis were reported between groups, this might be a potential explanation for the increased knee stability values in the TT group with time and, consequently, potentially explaining why knee stability differences found for the short-term follow-up were not maintained in the mid- and long-term follow-up.

The TT drilling may produce a more vertically oriented femoral tunnel compared to the AMP technique [13, 20, 22]. The oblique 10 o'clock position was found to better restore rotational knee stability compared to the 11 o'clock position [32, 49]. Although Rue et al. demonstrated that a 10:20 position was achievable with the TT technique [47], most studies report that only a 11 o'clock position is possible with the TT drilling, whereas a 10 o'clock position can be achieved with the AMP technique [2, 13, 22, 49]. One may expect from this evidence that the AMP group would demonstrate greater rotational knee stability over the TT group. However, no differences were identified for pivot shift sign values between both techniques. The pivot shift sign test may have a high inter-observer variability. Therefore, the higher the number of physicians performing the pivot shift test are involved in a study, the higher the variability of the reported results. Thus, the combination of different studies with different examiners may difficult to come with a significant difference. Randomized controlled trial directly comparing the AMP to the TT technique with less inter-observer variability would better elucidate if rotational knee stability values do differ between both techniques.

ROM at short-term follow-up was significantly better in the AMP compared to the TT group. It might be argued that a favorable tunnel placement would favor better restoration of ROM. However, mid- and long-term follow-up findings for ROM were not different between groups. It seems unlikely that differences in tunnel placement would explain a greater ROM in the 1–2-year follow-up if differences are not maintained with time.

There are several limitations to this study that must be kept in mind when interpreting these results. First, and foremost, this meta-analysis was based on indirect comparisons. The use of indirect comparisons is controversial [9], although the lack of direct comparative studies between both techniques makes this study to be the only guide at this point to compare the femoral drilling technique in the BPTB ACL reconstruction. Given the increasing interest of whether using the AMP or the TT technique for creating the femoral tunnel in the ACL reconstruction surgery, this study may be of interest for orthopedic surgeons. Second, there was a low homogeneity when reporting some of the outcomes. As a consequence, not all studies were able to be included in the statistical analysis of certain parameters because the calculation of effect sizes in the included studies was not possible given that they did not use the same comparators. However, the statistics for all the outcomes were done with a high number of patients, thus decreasing the risk of random error. Third, the half of the studies in the AMP group came from the same group of Pinczewski, and all of them referred to the same sample. It might be argued that the sample for the AMP group was highly homogeneous, thus decreasing the external validity of the results. However, the stratification of the outcomes in 3 follow-up periods and the inclusion of data from the group of Pinczewski once at each follow-up may have limited this concern. Finally, as different studies were involved, different surgeons and physicians performing the physical examination were enrolled. This may be a source of inter-study variability, particularly in parameters like the pivot shift sign test or the surgical technique itself (i.e., the femoral tunnel position in the coronal plane). Randomized controlled trials should be conducted to compare the AMP and the TT techniques to better elucidate the effects of the femoral tunnel drilling method on the clinical outcomes. The standardization of the drilling technique is required to decrease the inter-surgeon variability, and once several randomized controlled trials are published, direct meta-analysis will report definitive evidence to know, if any, which is the best technique.

Conclusion

The use of the AMP elicited greater knee stability and range of motion values, and earlier return to run compared to the TT technique. These results may indicate a potential benefit of the AMP over the TT technique. However, as the benefits of the AMP were not obtained in the mid and long-term follow-ups, overall there is no definitive evidence at this point to conclude that one technique is superior to the other. Randomized controlled trials directly comparing the use of both techniques with long-term follow-ups will help clarify which one, if any, provides best clinical outcomes.

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