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Double-bundle versus single-bundle anterior cruciate ligament reconstruction in preventing the progression of osteoarthritis

A protocol for systematic review and meta-analysis of randomized controlled trials

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Abstract

Background: The knee has a high incidence of osteoarthritis (OA) following the anterior cruciate ligament (ACL) injury, which was reduced by ACL reconstruction including double-bundle (DB) techniques and single-bundle (SB) techniques. However, the effectiveness of preventing the progression of OA after the ACL reconstruction using DB and SB techniques is controversial.

Methods: This meta-analysis was performed following the preferred reporting items for systematic reviews and meta-analyses guidelines. The databases, including PubMed, Embase, and Cochrane Library, were searched. Randomized controlled trials comparing DB with SB ACL reconstruction and reporting clinical outcomes of radiological OA were included. Quality of the included studies was assessed using the Cochrane Collaboration's risk of bias tool. The outcome was analyzed using the risk ratio (RR) and its corresponding 95% confidence interval (CI).

Results: Ten Randomized controlled trials studies were included in this meta-analysis (accounting 1062 knees: 475 SB and 587 DB). The rate of radiological OA after the ACL reconstruction was 39% in SB group and 34% in DB group. The results of meta-analysis showed no difference in the occurrence of radiological OA between DB group and in SB group (RR, 1.05; 95% CI, 0.85–1.30, $P = .63$), including subgroup of radiological scores of OA (subgroup of Minimal OA: RR, 0.95; 95% CI, 0.61–1.48; $P = .82$; subgroup of Notable OA: RR, 1.16; 95% CI, 0.75–1.78; $P = .51$), subgroup of follow-up time in 5 years and more than 5 years (RR, 0.98; 95% CI, 0.80–1.20; $P = .85$), and subgroup of autograft graft for ACL (RR, 0.97; 95% CI, 0.79–1.19; $P = .77$). However, the DB group had less incidences of knee OA than the SB group in subgroup of less than 5 years (RR, 1.48; 95% CI, 1.13–1.92; $P = .004$) and subgroup of allograft type (RR, 1.42; 95% CI, 1.06–1.91; $P = .02$).

Conclusion: Overall, this meta-analysis showed that the DB technique was no more effective in preventing the progression of OA than the SB technique in ACL reconstruction at midterm follow-up.

Abbreviations: ACL = anterior cruciate ligament reconstruction, CI = confidence interval, DB = double-bundle, IKDC = international knee documentation committee, OA = osteoarthritis, RCTs = randomized controlled trials, RR = risk ratio, SB = single-bundle.

1. Introduction

Anterior cruciate ligament reconstruction (ACL) injury accounts for approximately 80,000 ACL injuries each year in the United States and is one of the most common sports injuries for active people.[1] The native ACL is composed of 2 bundles, the anteromedial and posterolateral bundles, which provide the key anterior-posterior and rotational stability of the knee.[2,3] ACL injury can result in deteriorated kinetics of the knee and lead to pain, meniscal tears, destruction of articular cartilage, and eventually to progressive osteoarthritis (OA). Some studies, with 10 to 20 years of follow-up, have found an OA prevalence of 50% to 82% after ACL injury.[4–6]

To restore knee stability and reduce the occurrence of OA, the standard treatment of ACL injury is ACL reconstruction, including the double-bundle (DB) technique and the single-bundle (SB) technique.[3,7,8] Some biomechanical studies have shown that the DB technique led to the better restoration of knee biomechanics than did the SB technique.[9–11] A few meta-analysis,[12,13]

YZ and LL contributed equally to this work.

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however, have confirmed that superior knee-stability provided by the DB ACL reconstruction and there was no difference between technique reconstruction in clinical outcomes and risk of graft failure, which led to the SB ACL reconstruction preferred by most of surgeons.[14] But Gong Reported that the DB ACL reconstruction led to less cartilage damage at the femoral trochlea at short-term follow-up.[15] Therefore, the DB ACL reconstruction potentially is more effective at preventing the progression of OA than the SB ACL reconstruction according to the biomechanical studies, but this possibility remains controversial. A randomized controlled trials (RCTs) by Zaffagnini[16] in 2011 found DB ACL reconstruction had lower degenerative knee changes than SB ACL reconstruction at a minimum of 8 years after surgery. Another RCTs by Jarvela[17] reported that the rates of OA were similar at 10 years between SB and DB ACL reconstruction. However, Karikis[18] found a more significant increase in the development of OA in DB than SB technique at the 5 years follow-up in a RCTs.

There were a few meta-analyses assessing OA progression between DB ACL and SB ACL technique so far, but the results of meta-analyses were controversial.[19–21] Moreover, these meta-analyses have certain limitations, for example, less articles were included and no detailed subgroup analysis were performed. It is well known that there are some factors, such as type of graft, fixation of graft, the time of follow-up and tunnel drilling, may greatly influence the incidence of knee OA after the ACL reconstruction. Therefore, deliberate subgroup analysis is very important for incidence of OA with ACL reconstruction in the systematic review and meta-analysis. These uncertainties imply an intense need for further high-quality evidence. In recently there were some new RCTs comparing OA progression between DB ACL and SB ACL reconstruction, which provided new evidence.[17,22,23] It would be beneficial to pool new evidence to form a more robust conclusion.

The main purpose of this meta-analysis with detailed subgroup analysis was to review all RCTs to determine if OA progression is more effectively prevented by DB ACL reconstruction than by SB ACL reconstruction. We hypothesized that there was no difference in OA progression between DB and SB ACL reconstruction.

2. Methods

2.1. Search strategy

This review was performed following the preferred reporting items for systematic reviews and meta-analyses guideline.[24] The PubMed, Embase, and Cochrane Library were searched for the studies that evaluated the radiological osteoarthritis of the patients with ACL injury treated by the SB and DB on December 12, 2020. Search terms used the following terms in the title, abstract, MeSH, and keywords: ("anterior cruciate ligament" OR "ACL") AND ("single-bundle" OR "SB") AND ("double-bundle" OR "DB"). Moreover, we also manually searched the relevant articles and their bibliographies. The search was limited to English language and human subjects.

2.2. Study identification and eligibility criteria

Study inclusion was performed independently by 2 investigators according to the flowchart: firstly, removed the duplicate papers. Secondly, the inappropriate papers were dislodged after reading the titles and abstracts. Finally, the inappropriate papers were removed after reading the full papers. Studies were selected following these criteria: The studies were randomized controlled trial; Patients: the age > 16 years old and a symptomatic rupture of the ACL; Intervention: DB ACL reconstruction was compared to SB ACL reconstruction; Outcomes: osteoarthritis occurrence after ACL reconstruction. The definition of OA in this meta-analysis was based on the standard of radiological criteria, such as Kellgren–Lawrence grade,[25] Ahlback classification,[26] and radiographic changes based on the International Knee Documentation Committee (IKDC) guidelines,[27] of which Table 1 deliberately showed grading radiological osteoarthritis grade of the knee. The exclusion criteria included nonrandomized studies, studies with no evaluation of knee OA based on the radiological criteria. To analyze we conversed 3 score grades of radiographic OA into 1. IKDC grade A was considered to be normal, while Kellgren–Lawrence grade 1 and IKDC grade B were considered as being Minimal OA (nearly normal), and Kellgren–Lawrence grade 2 to 4, Ahlback classification 1 to 5, and IKDC grade C-D belonged to Notable OA according to Claes' opinion[28] (Table 1). When several publications reported findings for the same patients, the most recent or most complete study was chosen. Letters, comments, abstracts for conferences, case reports, retrospectively designed trials, study protocols, reviews, and animal studies were excluded.

2.3. Data extraction and methodological quality assessment

The data of each study was independently recorded by 2 authors acting on the data extraction form. Two authors reached the

Table 1

The standard of radiological osteoarthritis grade of the knee.

New grade	Method of grade		
	Kellgren–Lawrence grade	**Ahlback classification**	**IKDC grade**
Normal	Grade 0: normal		Grade 1: normal.
Minimal OA	Grade 1: doubtful narrowing of the joint space with possible osteophyte formation.		Grade 2: mild (minimal evidence of arthritis and joint space narrowing that is just detectable).
Notable OA	Grade 2: possible narrowing of the joint space with definite osteophyte formation. Grade 3: definite narrowing of joint space, moderate osteophyte formation, some sclerosis, and possible deformity of bony ends. Grade 4: large osteophyte formation, severe narrowing of the joint space with marked sclerosis, and definite deformity of bone ends.	Grade 1: joint space narrowing (less than 3 mm). Grade 2: joint space obliteration. Grade 3: minor bone attrition (0–5 mm). Grade 4: moderate bone attrition (5–10 mm). Grade 5: severe bone attrition (more than 10 mm).	Grade 3: moderate (evidence of arthritis and up to 50 % joint space narrowing). grade 4: severe (joint space narrowing 50 %).

IKDC = international knee documentation committee, OA = osteoarthritis.

agreement by discussion. If they could not reach an agreement, then referred to consult the third author, and finally made a decision.

The information was obtained according to following protocol: name of first author, year of publication, study design, country location, demographic information (age and sex), numbers of 2 groups, operative intervention, type of graft, fixation of graft, the time of follow-up, tunnel drilling, evaluating methods of radiological osteoathritis grade, and the baseline data related osteoarthritis (gender, age, Body Mass Index, smoking, delay between the injury and ACL reconstruction, meniscal tear, preoperative OA, preoperative articular cartilage status).

The methodological quality including 7 aspects (random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other biases) was assessed according to Cochrane Handbook for Systematic Reviews of Interventions.[29] The scores for each bias domain and the final scores for the risk of systematic bias were graded by using RevMan software (version 5.3; The Cochrane Collaboration).

2.4. Statistical analysis

While Relative risk ratio (RR) with the 95% confidence interval (CI) was applied for dichotomous data (radiological osteoarthritis grade). The heterogeneity of the included studies was estimated by the I^2 test. A random effects model was used for all meta-analysis in this study. Since previous studies suggested that follow-up time, fixation of grafts (such as suspensory or screws fixation), and type of grafts may be associated with the incidence of OA after ACL reconstruction.[30–32] A predefined subgroup analysis was applied, which would also make sense to identify the potential source of heterogeneity. Publication bias was assessed by a funnel plot. RevMan5.3 software was used for all statistical analysis.

This review has been registered in PROSPERO (registration ID: CRD42020199564) and reported in line with preferred reporting items for systematic reviews and meta-analyses[24] and assessing the methodological quality of systematic reviews (AMSTAR) guidelines.[33]

3. Results

3.1. Identification of studies and selection

A total of 952 references were acquired from the PubMed, Embase, and Cochrane library. 435 references were removed for duplication. There were 62 references left after carefully examining the titles and abstracts. Finally, we got 10 RCTs[16–18,22,23,34–38] meeting inclusion criteria after carefully reading the papers. Details of study identification, inclusion, and exclusion were shown in Figure 1.

3.2. Study characteristics and patient populations

The characteristics of the 10 RCTs (published from 2011 to 2018) included in this meta-analysis were shown in Table 2. Adding up to 1062 knees were treated by the ACL reconstruction including 475 knees with SB group and 587 knees with DB group. The time of follow-up ranged from 2 years to 10 years, 3 studies[23,36,37] with less than 5 years. The SB ACL reconstruction group had tibialis anterior allograft in 2 studies[36,38] and autologous graft in 8 studies, including semitendinosus/ gracilis tendon,[17,18,22,23,34,35] hamstring tendons,[37] and bone-patellar tendon-bone in 1 study.[16] The DB ACL reconstruction group had autologous semitendinosus/gracilis tendon in 8 studies,[16–18,22,23,34–36] hamstring tendons in 1 study,[37] and tibialis anterior allografts in 1 study.[38] The fixation of graft included metal interference screws, bioabsorbable interference screws, endobutton, biodegradable cross pins, and transosseus suture knot. There were 8 studies with anatomy tunnel drilling techniques except 2 studies with non-anatomy tunnel drilling techniques.

3.3. Radiographic outcomes

There were 3 radiological classification systems for OA in this review, including Kellgren–Lawrence grade in 7 studies, IKDC grade in 2 studies,[16,36] and Ahlback classification in 1 study.[37] The detailed description of the score was shown in Table 3. The rate of radiological OA after the ACL reconstruction was 39% in the SB group and 34% in the DB group. Three studies had fewer patients with radiographic osteoarthritis than other studies, 1 study[23] only had 2 years of follow-up time and the other 2 studies[22,37] had no meniscal tear and partial meniscectom.

3.4. Assessment of risk of bias

Figure 2 showed the details of the assessment of the risk of bias on studies included in this meta-analysis. The study by song[38] used an alternating fashion to randomly assign the patients and the random of another study by Morey[37] was based on the thickness of hamstring graft, which both resulted in a high risk of selection bias. There were 3 studies[17,18,38] with a high risk of attrition bias for more than 20% of patients lost to follow-up. Only 2 studies by Karikis[18] and Beyaz[35] reported the patients were blind to the type of treatment with low risk of performance bias, the others were rated the unclear risk of performance bias without sufficient data. Two studies[16,37] were judged as having a high risk of reporting bias because 1 study reported postoperative pain and radiological assessment, another study reported postoperative pivot-shift test, which was not referred to in the outcome of evaluations predefined. Two studies had a high risk of other bias, 1 study[37] with only male patients in the SB group, and another study[35] with only male patients in both DB and SB group.

3.5. Outcome meta-analysis

Firstly, all radiological osteoarthritis grades of the knees were analyzed including subgroup of Minimal OA and Notable OA based different grade system.[28] The heterogeneity was moderate in ten RCT studies ($P = .03$; $I^2 = 52\%$). The random-effects model was used to analyze the studies, which of the results revealed that there was no difference in the occurrence of radiological osteoarthritis between the DB group and the SB group (RR, 1.05; 95% CI, 0.85–1.30, $P = .63$), Figure 3. Then subgroup analysis of radiological scores of OA (Minimal OA and Notable OA) was performed. The heterogeneity of subgroup was moderate (subgroup of Minimal OA: $P = .01$; $I^2 = 66\%$; subgroup of Notable OA: $P = .05$; $I^2 = 48\%$). the subgroup results of meta-analysis showed there was no difference between DB group and SB group (subgroup of Minimal OA: RR, 0.95; 95% CI, 0.61–1.48; $P = .82$; subgroup of Notable OA: RR, 1.16; 95% CI, 0.75–1.78; $P = .51$), Figure 4.

Secondly, the subgroup analysis was finished in follow-up time and devices for graft, which was included patients with both Notable OA and Minimal OA. Follow-up time was divided into 2 subgroups (less than 5 years; 5 years and more than 5 years). The DB group had less incidence of knee OA than the SB group (RR, 1.48; 95% CI, 1.13–1.92; $P = .004$) in subgroup of less than 5 years, which had no heterogeneity ($P = .90$; $I^2 = 0\%$). The subgroup of 5 years and more than 5 years had moderate heterogeneity ($P = .03$; $I^2 = 43\%$), which had no difference between the SB group and the DB group (RR, 0.98; 95% CI, 0.80–1.20; $P = .85$), Figure 5. The subgroup of autograft type showed there was no difference in incidences of knee OA between the DB

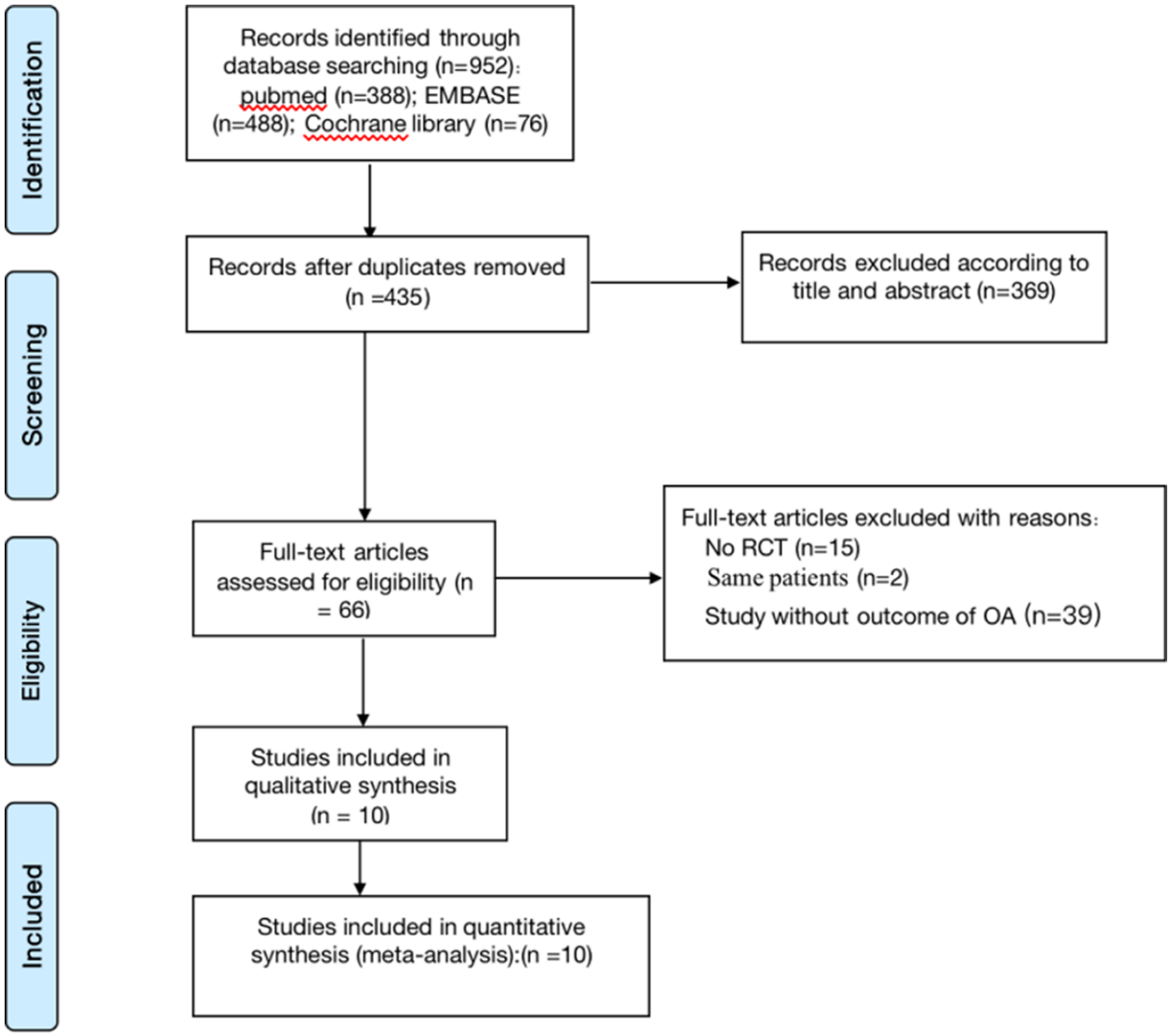

Figure 1. The study selection flow diagram.

group and SB group (RR, 0.97; 95% CI, 0.79–1.19; $P = .77$) with low heterogeneity ($P = .15$; $I^2 = 34\%$), Figure 6. The DB group had less incidences of knee OA than the SB group in subgroup of allograft type (RR, 1.42; 95% CI, 1.06–1.91; $P = .02$) with no heterogeneity ($P = .35$; $I^2 = 0\%$), Figure 6.

3.6. Publication bias

Figure 7 was a funnel plot of ten studies pooled for radiological osteoarthritis. We judged there was no significant publication because symmetry was shown in the funnel plot showed.

4. Discussion

A meta-analysis of RCTs was performed to compare SB ACL reconstruction with DB ACL reconstruction in preventing the progression of OA. This meta-analysis included ten RCT studies accounting for 1062 knees (the most studies included in any meta-analysis to date) and showed that there was no difference in the prevented progression of OA between the DB technique and the SB technique in all patients. This meta-analysis was consistent with the results of Chen [20] in 2018 (meta-analysis without subgroup analysis, including 4 RCTs with 215 knees) and John in 2019 (systematic review without meta-analysis and subgroup analysis, including 7 RCTs). However, the heterogeneity was moderate ($I^2 = 52\%$) in this study, which showed there were possible confounding factors. Therefore, we made the most deliberate subgroup analysis according to the plan of meta- analysis so far. there was no difference in incidences of knee OA in subgroup of radiological scores of OA, subgroup of 5 years and more than 5 years, and subgroup of autograft type. These findings (the most detailed subgroup analysis so far) provide useful information for surgeons when making clinical decisions.

ACL deficiency leads to anteroposterior and rotational instability of the knee, alteration of joint contact, and a repetitive gait cycle with contact stresses in the knee (millions of cycles each year), which can contribute to the progression of OA after ACL injury, especially in young active people.[39–43] A study by Segawa[6] found that 63% of patients with non-operative treatment of ACL injuries had OA and 37% had knee joint space narrowing at the 12 years follow-up examination. Another 12 years follow-up study[5] found that 82% of female soccer players with ACL injuries had radiographic changes in the knee and 42% had symptomatic radiographic knee OA. Lohmander[4] reported that an average of 50% of patients with ACL injuries and meniscus tears had OA after 10 to 20 years. However, the incidence

Table 2

Demographic characteristics of included studies.

		SB group						DB group							
Author (yr)	Country	Begin sample Size (M/F)	Final sample size. (M/F)	Age	Tunnel drilling	Graft	Fixation	Begin sample size (M/F)	Final sample size (M/F)	Age	Techinique of tunnels	Graft	Fixation (B/Me)	Follow-up	Level of evidence
Mayr 2018	Germany	30	25 (12/13)	38.5 ± 9.8	anatomy	STG	F: BCP T: BIS	34	28 （15/13）	38.5 ± 9.8	anatomy	STG	F: BCP T: BIS	5y	1
Aga 2018	Norway	62 (41/21)	60	27.1 ± 5.5	anatomy	STG	F:End T:BIS	58 (47/11)	53	27.4 ± 6.3	anatomy	STG	F:End T:BIS	2y	1
Jarvela[26] 2017	Finland	60 (40/20)	46 (23/23)	33. 6 ± 10	anatomy	STG	F: MIS(23) or BIS(23) T: MIS (23) or BIS (23)	30 (21/9)	24	34. 6 ± 10	anatomy	STG	F: BIS T: BIS	10 y	2
Beyaz[9] 2017	Turkey	18	16 (16/0)	31.06 ± 5.5	anatomy	STG	F: End T: BIS	16	15 (15/0)	33.53 ± 5.47	anatomy	STG	F: End T: BIS	8y	2
Adravanti[1] 2017	Italy	30 (17/13)	26	28.3 ± 6.2	Non-anat-omy	STG	F: End T: BIS + staples	30 (17/13)	27	26.4 ± 8.5	Non-anat-omy	STG	F: End + BS T: BIS + staples	6y	1
Karikis[29] 2016	Sweden	50 (35/15)	41	28 ± 8.5	anatomy	STG	F: MIS T: BIS	53 (35/18)	46	30 ± 9.2	anatomy	STG	F: MIS T: BIS	64 m	1
Sun[54] 2015	China	158	142 (101/41)	28.2 (19–52)	anatomy	TAA	F: End T: BIS	AU:169 AL:144	AU:154 AL:128	27.5 (19–52)	anatomy	AU: STG AL: TAA	F: End T: BIS	3y	1
Morey[42] 2015	USA	20	20 (20/0)	28.3 ± 6.08	anatomy	HT	F: End T: BIS	20	20 (19/1)	26.4 ± 5.93	anatomy	HT	F: End T: BIS	4y	1
Song[53] 2013	Korea	65	60 (38/22)	35.5 (19-58)	anatomy	TAA	F: End T: BIS	65	52 (44/8)	30.3 (17–50)	anatomy	TAA	F: End T: BIS	5y	2
Zaffagnini[59] 2011	Italy	45	39 (20/19)	26 ± 9.5	Non-anat-omy	BPTB	F: MIS T: MIS	45	40 (22/18)	27 ± 9	Non-anat-omy	STG	F: staples T: TSK or staples	8.6 y	2

F = femoral side, T = tibial side, MIS = metal interference screws, BIS = bioabsorbable interference screws, End = Endobutton, HT = hamstring tendons, TAA = tibialis anterior allografts, GT = gracilis tendon.

BCP = Biodegradable cross pins, DB = double-bundle, STG = semitendinosus and gracilis tendons grafts, BPTB = bone-patellar tendon-bone, TSK = transosseus suture knot, SB = single-bundle.

Table 3

Radiographic Outcomes.

	Scores of OA	
Author	SB	DB
Aga	K-L: 0/1/0/0	K-L: 0/1/0/0
Jarvela	K-L: 15/10/4/0	K-L: 6/6/6/0
Beyaz	K-L: 0/5/0/0	K-L: 0/7/0/0
Adravanti	K-L: 2/0/0/0	K-L: 3/0/0/0
Mayr	K-L: 11/11/2/0	K-L: 9/9/1/0
Karikis	K-L: 7/5/1/2	K-L: 10/10/1/0
Sun	IKDC: 44/16/0	IKDC(AU): 37/8/0 IKDC(AL):26/9/0
Morey	Ahlback: 1/0/0/0	Ahlback: 1/0/0/0
Song	K-L: 12/4/2/0	K-L: 9/3/2/0
Zaffagnini	IKDC: 18/11/3	IKDC: 33/2/1

Ahlback = Ahlback classification, K-L = Kellgren-Lawrence grade, IKDC = international knee documentation committee, OA = osteoarthritis, SB = single-bundle.

rate of clinical OA between the ACL reconstruction and conservative treatment remains controversial. One study by Kessler[44] revealed that there were no differences in OA evolution between the conservative and operational treatments at a follow-up of 11.1 years. Another cohort study[45] by Van confirmed this result in high-level athletes at a 20-years follow-up. In contrast, a retrospective study[46] found that 16.5% of patients had severe OA in ACL reconstruction, whereas 56% had severe OA in a conservation group. A meta-analysis[47] of 6 studies (no RCTs included) concluded that knees with ACL injuries predispose patients to OA and that ACL reconstruction could reduce the 10 years risk. In this study, the occurrence of radiological OA in knees was relatively low (22.1% in minimal OA and 13.8% in the Notable OA) after ACL reconstruction, which showed that ACL reconstruction can reduce the development of knee OA. A meta-analysis by Chen only included 1 RCTs with 5 years follow -up and 2 RCTs with less than 5 years in 2015,[19] showed that the DB technique led to fewer occurrences of OA than did the SB technique in ACL reconstruction. However, another meta-analysis in 2018 included 4 RCTs with 5-years minimum follow-up, and

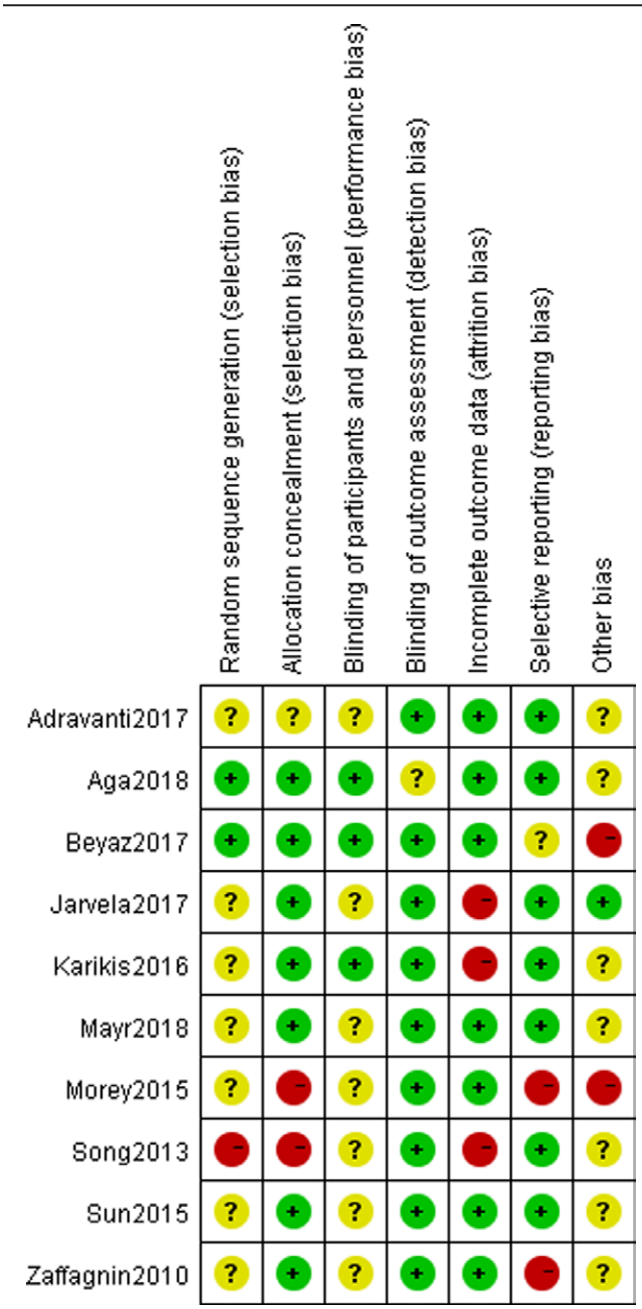

Figure 2. Risk of bias summary.

found no significant differences in OA changes between the DB and SB technique group.[20] In present meta-analysis showed the DB technique had fewer occurrences of OA than the SB technique in the subgroup of less than 5 years follow-up time (3 studies included) and no significant differences in OA changes in the subgroup of 5-years minimum follow-up time (7 studies included). In general, most patients with ACL injuries are young and it may take years or longer for them to develop osteoarthritis. In view of this, we believe that the pooled results of studies with 5-years minimum follow-up time are more reliable.

Whether there are biomechanical and clinical differences between the SB and DB ACL reconstruction methods remains controversial. A study by Gadikota[10] tested 8 human cadaveric knee specimens and compared anatomical DB reconstruction with non-anatomical SB ACL and found that the DB ACL technique could better restore anterior tibial translations than that of the SB technique at low flexion angle (≤30°). Bedi[9] revealed that DB reconstruction had better stability of the pivot-shift kinematics of the knee than did central anatomical SB ACL reconstruction. However, there were no significant differences in Lachman examination results between the 2 techniques. Kim[11] conducted a study comparing anatomical SB and DB reconstruction techniques in 4 different types (using the quadriceps tendon) and found that the DB technique could mostly restore the anterior tibial translation and the in situ forces under the anterior load of the knee caused by ACL injury, whereas the SB technique had lower stability at 30°, 60°, and 90° of flexion ($P < .05$). However, some studies have reported different biomechanical results of ACL reconstruction. A study by Goldsmith[48] compared anatomical SB with DB ACL reconstruction and found no significant differences in pivot shift, anterior tibial loading, and anterior translation. Kondo[49] reported that there were no significant differences in rotational and pivot-shift laxity between the anatomical DB reconstruction and laterally placed SB reconstruction. In a 3-dimensional gait analysis study, Whitehead[50] found no difference in controlling tibio-femoral rotation and adduction moments between SB and DB reconstruction. Approximately 10% to 30% of patients treated by SB ACL reconstruction reported persistent instability, and only 60% to 70% could return to sport.[51] Some meta-analyses[12,52] have found that DB ACL reconstruction could provide a better stability of the knee than could SB reconstruction, but no differences were found in clinical outcomes and complications. In the present meta-analysis, analysis of pooled data demonstrated that the DB technique could not better prevent the progression of knee OA than SB technique, which indicated DB technique did not provide better clinical outcomes although DB technique with better biomechanical stability.

The type of graft used in ACL reconstruction includes autografts (patellar tendon, hamstring tendon, and quadriceps tendon grafts) and allografts. Some studies have shown that the

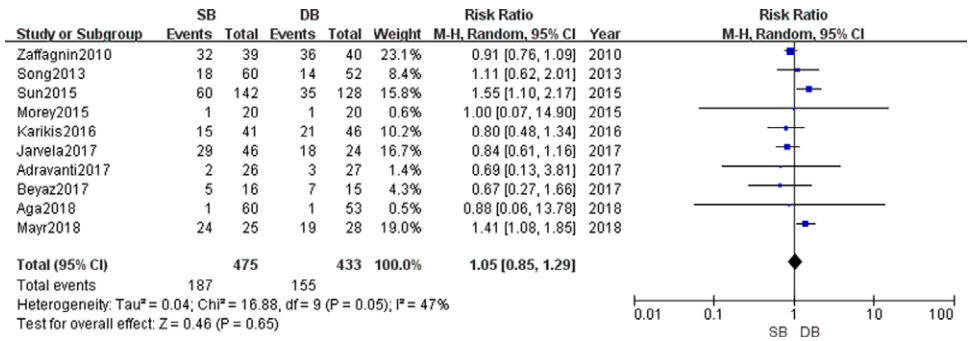

Figure 3. Forest plot showing the comparison of overall the occurrence of OA between the SB group and the DB group. DB = double-bundle, OA = osteoarthritis, SB = single-bundle.

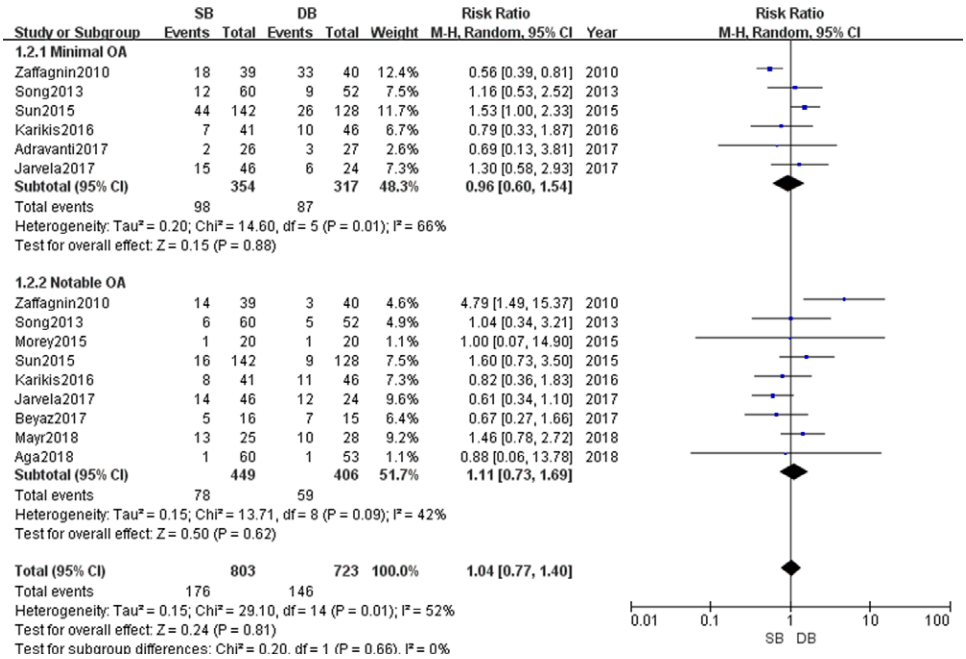

Figure 4. Forest plot showing the subgroup of scores of OA (Minimal OA and Notable OA) between the SB group and the DB group in occurrence of OA. DB = double-bundle, OA = osteoarthritis, SB = single-bundle.

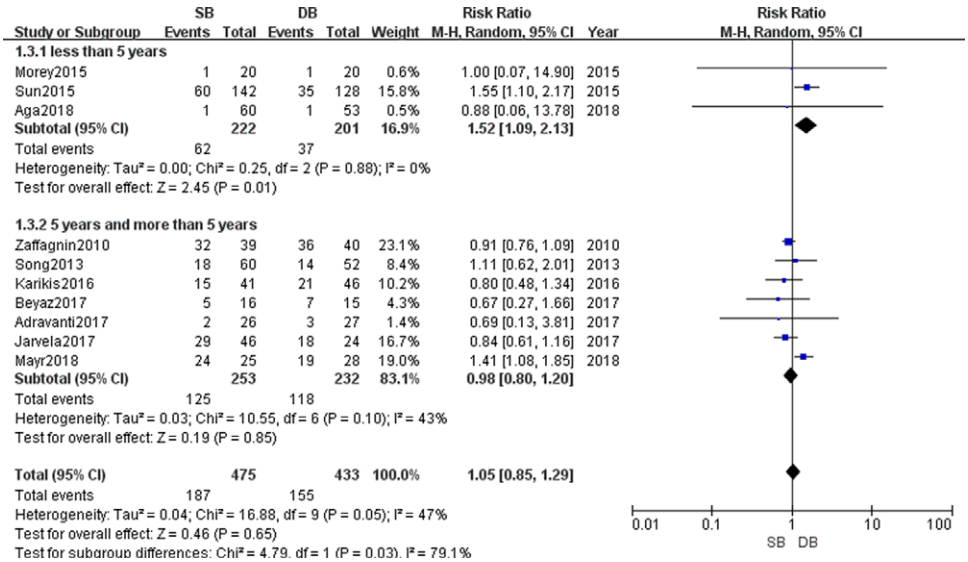

Figure 5. Forest plot showing the subgroup of follow-up time (less than 5 years; 5 years and more than 5 years) between the SB group and the DB group in occurrence of OA. DB = double-bundle, OA = osteoarthritis, SB = single-bundle.

type of graft influenced the biomechanical stability of ACL reconstruction. Noyes[30] reported that a single STG had 70% and 49% of the strength of the intact ACL, BPTB graft had 159% to 168% of the strength of the intact ACL, but the STG had much better elasticity. According to Hamner et al,[53] the 2- and 4-strand hamstring grafts had 250% strength of the intact ACL. A study by Biuk[54] revealed that the elongation levels were different among the quadruple tendon sample (0.31%), semitendinosus tendon sample (0.88%), gracilis tendon sample (1.48%), and patellar ligament sample (3.91%). Biuk[54] concluded that the quadruple tendon had greater strength and higher elasticity than those of the BPTB graft. A clinical meta-analysis[55] of patellar tendon versus hamstring tendon found that both autografts had similar stability and postoperative function. A meta-analysis[56] of 8 studies found that patients treated by ACL reconstruction with BPTB or hamstring tendon had similar incidences of OA in long-term follow-up. In recently a meta-analysis revealed that autograft had better functional outcomes than irradiated allograft in ACL reconstruction and there were no significant differences between autograft and nonirrated allograft in ACL reconstruction.[57] This meta-analysis showed that the DB group had less incidences of knee OA compared with the SB group in subgroup of allograft type and the subgroup of autograft type demonstrated there was no difference in incidences of knee OA between the DB group and SB group, which would help surgeons choose optimal grafts in the future.

This meta-analysis had several limitations related to the limitations of the studies included. The studies were searched in a few databases and limited to those published in English, which may have omitted some studies that otherwise met the inclusion criteria. There were uneven distributions in sample size, which

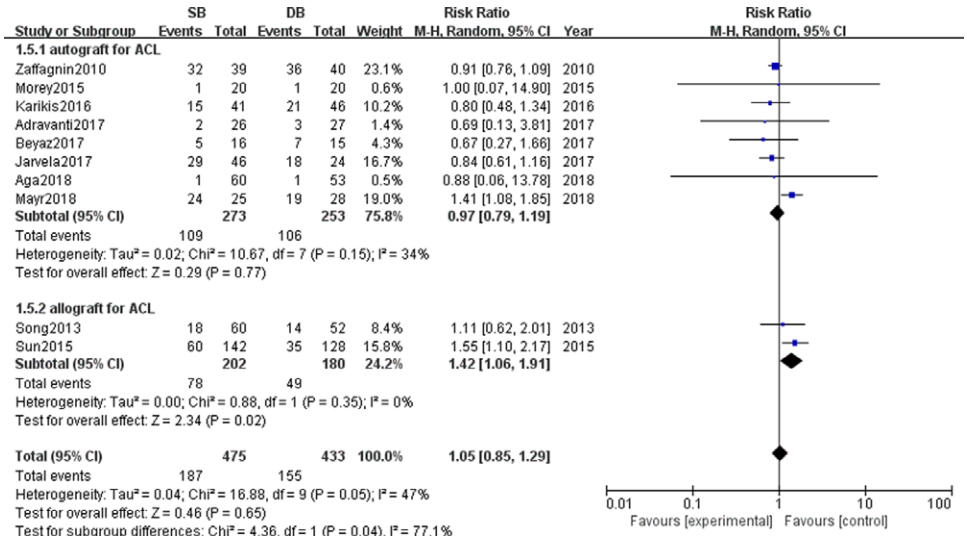

Figure 6. Forest plot showing the subgroup of subgroup of type of graft (autograft for ACL and allograft for ACL) between the SB group and the DB group in occurrence of OA. ACL = anterior cruciate ligament reconstruction, DB = double-bundle, OA = osteoarthritis, SB = single-bundle.

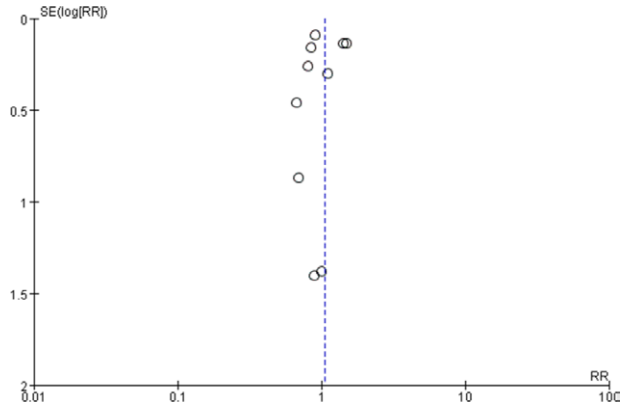

Figure 7. The funnel plot of 9 studies pooled, and the plot showed symmetry.

ranged from 31 to 424, and in the length of follow-up ranging from 2 to 10 years. Furthermore, the follow-up time was short (2–10 years), and the patients led active lives when they underwent ACL reconstruction, which may have affected the rate of OA because longer follow-up time would more likely have shown a higher rate of progression to OA after ACL reconstruction. A few studies included did not elaborate on some baseline factors that were closely related to the occurrence of OA, including Meniscal tear and articular cartilage.

In conclusion, this meta-analysis showed that the DB technique was no more effective in preventing the progression of OA than the SB technique in ACL reconstruction at midterm follow-up. This result must be interpreted with caution. In the future, higher-quality RCTs, such as those conducted in multiple centers, that include larger sample sizes, longer follow-up times, better designs, and a comprehensive set of baseline factors related to OA should lead to more reliable and consistent conclusions.

Author contributions

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