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REVIEW ARTICLE

Single Bundle Versus Double Bundle Anterior Cruciate Ligament Reconstruction: A Systematic Review and Meta-analysis

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Abstract

Background Anterior cruciate ligament (ACL) tear is considered as one of the most common sport-related musculoskeletal injuries. Double bundle (DB) and single bundle (SB) surgical techniques has been widely adopted for ACL reconstruction. This systematic review aimed to provide updated evidence by comparing the short-term, mid-term, and long-term knee stability and functional outcomes of DB and SB reconstruction techniques.

Methods We searched Medline, Web of Science, and CENTRAL. We have selected randomized controlled trials (RCTs) that compared DB and SB ACL reconstruction techniques for primary isolated ACL tear. We have assessed the following outcomes: pivot shift test, Lachman test, KT-1000/2000 knee ligament arthrometer, Lysholm knee function score, Tegner activity score, and graft failure. We have used the standardized mean difference (SMD) was to summarize the continuous outcomes while risk ratio (RR) was used to summarize the dichotomous outcomes.

Results A total of 34 RCTs that enrolled 2,992 participants deemed eligible. Overall, DB showed significantly better outcomes in terms of pivot shift test (RR = 0.61, 95% confidence interval (CI) 0.49–0.75), Lachman test (RR = 0.77, 95% CI 0.62 to 0.95), and KT 1000/2000 arthrometer (SMD = − 0.21, 95% CI − 0.34 to − 0.08). No discernible difference was found between DB and SB techniques in the overall Lysholm score (SMD = 0.12, 95% CI − 0.03 to 0.27), Tegner score (SMD = 0.03, 95% CI − 0.17 to 0.24), or graft failure rate (RR = 0.78, 95% CI 0.33 to 1.85).

Conclusions Our review suggests that DB ACL reconstruction technique shows significantly better knee stability and functional outcomes than SB at short-term follow-up. However, both techniques exhibit similar outcomes at mid-term and long-term follow-up.

Keywords Anterior cruciate ligament · Surgical technique · Double bundle · Single bundle · Reconstruction

Abbreviations

ACL	Anterior cruciate ligament
DB	Double bundle technique
SB	Single bundle technique
RCT	Randomized controlled trial
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis

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IKDC	International Knee Documentation Committee score
CENTRAL	Cochrane Central Register of Controlled Trials
SMD	Standardized mean difference
RR	Risk ratio
OA	Osteoarthritis

Introduction

Anterior cruciate ligament (ACL) tear is considered one of the most common sport-related musculoskeletal injuries, representing 50% of all the acute traumatic knee injuries [1]. ACL reconstruction is the standard management approach to restore the biomechanical function of the knee following ACL tears in young active patients [2, 3]. Double bundle (DB) and single bundle (SB) are widely adopted surgical techniques for the anatomical reconstruction of ACL. DB technique involves the anatomical restoration of the anteromedial and posterolateral bundles of the native ACL whereas SB technique in involves the anatomical restoration of the either anteromedial or posterolateral bundle of the native ACL. Recently, there has been a debate about the superiority of DB or SB technique in restoring the knee stability and function following ACL reconstruction [4–6].

A recent systematic review by Kong et al. revealed significantly better knee stability and functional outcomes in favor of DB compared to SB. However, most of the included studies in this review provided short-term follow-up data [7]. More recently, a systematic review by Chen et al. showed that both DB and SB reconstruction techniques confer similar outcomes at mid-term and long-term follow-up. Nonetheless, a small number of studies and relatively small sample size were inherent limitations of this review [8]. In addition, many randomized controlled trials (RCTs) providing mid-term and long-term follow-up data were further introduced to the literature since Chen et al. review [9–12].

The aim was to perform an updated systematic review and meta-analysis by comparing the short-term, mid-term, and long-term knee stability and functional outcomes of DB and SB reconstruction techniques.

Methods

This review was performed according to a pre-established protocol reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [13].

Eligibility Criteria

Patients: adult patients with primary isolated ACL tear; intervention: ACL reconstruction through anatomical DB technique; comparison: ACL reconstruction through anatomical SB technique; outcomes: rotational stability (i.e., pivot shift test), anterior stability (i.e., subjective tests; Lachman test, objective tests; KT-1000/2000 knee ligament arthrometer), functional outcomes including Lysholm knee function score, Tegner activity scale, International Knee Documentation Committee (IKDC) subjective score, and IKDC objective score, return to pre-injury sports activity, and graft failure; study design: RCT. Trials that enrolled participants with concomitant ipsilateral or contralateral posterior cruciate ligament, medial collateral ligament, lateral collateral ligament injury, or previous ligament surgery in the index knee were excluded. DB technique was defined as the individual anatomical restoration of anteromedial and posterolateral bundles of native ACL regardless of the source of the graft or the reconstruction technique. SB technique was defined as the anatomical restoration of the either anteromedial or posterolateral bundle of the native ACL regardless of the source of the graft or the reconstruction technique.

Search Strategy

We searched Medline, Web of Science, Evidence-Based Medicine Review databases via Ovid, and Cochrane Central Register of Controlled Trials (CENTRAL). No restrictions on date or language was applied. We used MeSH terms and keywords for each electronic database when available. Search terms used can be found in the supplementary material. We have also explored the following trial registries for potentially relevant ongoing or recently finished RCTs: ISRCTN registry, Australian New Zealand Clinical Trials Registry, UMIN Clinical Trials Registry, ClinicalTrials.gov, and MetaRegister of Controlled Trials. The last search was performed on August 6, 2020. The bibliographic references of the included RCTs were manually explored for potentially relevant RCTs missed through the electronic search.

Study Selection and Data Extraction

Independently and in duplicate, two reviewers did the eligibility screening for titles and abstracts; full text assessment; and data extraction from the eligible studies. Disagreements were resolved by discussion or the decision of a third reviewer.

Subgroup Analysis

It was pre-specified to perform a subgroup analysis based on different follow-up periods. The different follow-up periods were divided into short-term (≤ 2 years), mid-term (3–5 years), and long-term (> 5 years) follow-up.

Meta-analysis

We used Comprehensive Meta-Analysis version 3 (Biostat, Inc. Eaglewood, New Jersey, USA) for the meta-analysis. The random-effects model was used for all statistical analyses. I^2 and the P of the χ^2 test were used to assess the statistical heterogeneity. We adopted 95% confidence level as a confidence level and $P < 0.05$ as a threshold. We have used the standardized mean difference (SMD) was to summarize the continuous outcomes while risk ratio (RR) was used to summarize the dichotomous outcomes. Trials with multiple publications (i.e., follow-up publications for the original trials) were only counted once, but data were derived from all available publications to obtain the longest available follow-up.

Risk of Bias Assessment

Two reviewers, independently and in duplicate, assessed the risk of bias of the eligible RCTs using the Revised Cochrane Risk of Bias Assessment Tool [14]. Any disagreement was resolved by consensus or the decision of a third reviewer. We assessed the publication bias for the primary outcome (pivot shift test) by visual inspection of the funnel plot with RR and standard error. The significance of the funnel plot asymmetry was examined using Egger's test. Publication bias was further assessed for two of the secondary outcomes Lachman test and Lysholm score.

Results

The literature search yielded 10,710 articles, of which 5188 duplicates were excluded. A total of 66 were deemed eligible for full-text assessment, of 27 articles were further excluded, leaving 39 eligible articles which represent 34 RCTs (Fig. 1) [9–12, 15–49].

Trial Characteristics

The 34 eligible RCTs enrolled 2992 participants with ACL tear who received ACL reconstruction through DB ($n = 1524$) or SB ($n = 1468$). Of the 2992 participants, 68% were male ($n = 2{,}034$) and 32% were female ($n = 958$). The characteristics of the included RCTs are summarized in Table 1.

Risk of Bias Assessment

Out of 34 RCTs, 7 had an overall low risk of bias, 17 had some concerns, and the remaining 10 had an overall high risk of bias. The risk of bias assessment of the included RCTs is summarized in Table 2.

The funnel plot for pivot shift test was asymmetrical on visual inspection and Egger's test showed significant plot asymmetry ($p < 0.001$) (Supplementary Fig. A). The funnel plot for Lachman test was also asymmetrical. However, Egger's test showed that plot asymmetry was not of statistical significance ($P = 0.08$) (Supplementary Fig. B). Lysholm score had symmetrical funnel plot on visual inspection, and Egger's test showed no statistical significance ($P = 0.26$) (Supplementary Fig. C).

Pivot Shift Test

A total of 26 studies reported data on pivot shift test [9–12, 17, 20–23, 25, 27–36, 38–41, 43–49]. Overall, DB showed significantly better results than SB (RR = 0.61, 95% CI 0.49–0.75, $P < 0.001$; $I^2 = 62\%$). However, subgroup analysis showed that the improvements in pivot shift test in favor of DB became insignificant at mid-term and long-term follow-up (Fig. 2).

Lachman Test

Sixteen studies reported on Lachman test [9, 12, 17, 22, 23, 25, 29, 32, 34–36, 36–41, 43–45]. DB showed a significant reduction in overall the risk of developing positive Lachman test compared to SB (RR = 0.77, 95% CI 0.62 to 0.95, $P = 0.01$; $I^2 = 34\%$). However, subgroup analysis showed that both groups had similar risk of developing positive Lachman test in the mid-term and long-term follow-up (Fig. 3).

KT1000/2000 Arthrometer

Twenty-three studies reported on KT1000-2000 [12, 15–17, 19, 21–24, 27, 28, 30, 32–34, 36, 38–40, 42–49]. Overall, DB showed significantly better results than SB in terms of KT1000/2000 arthrometer (SMD = − 0.21, 95% CI − 0.34 to − 0.08, $P < 0.01$; $I^2 = 61\%$). However, Subgroup analysis showed comparable results in the mid-term and long-term follow-up (Fig. 4).

Lysholm Score

Twelve studies reported on Lysholm score [10, 12, 17–20, 27, 29, 30, 34, 38, 39, 42]. There was no significant difference between DB and SB in terms of overall Lysholm score (SMD = 0.12, 95% CI − 0.03 to 0.27, $P = 0.12$; $I^2 = 74\%$). Similarly, subgroup analysis did not show any statistical

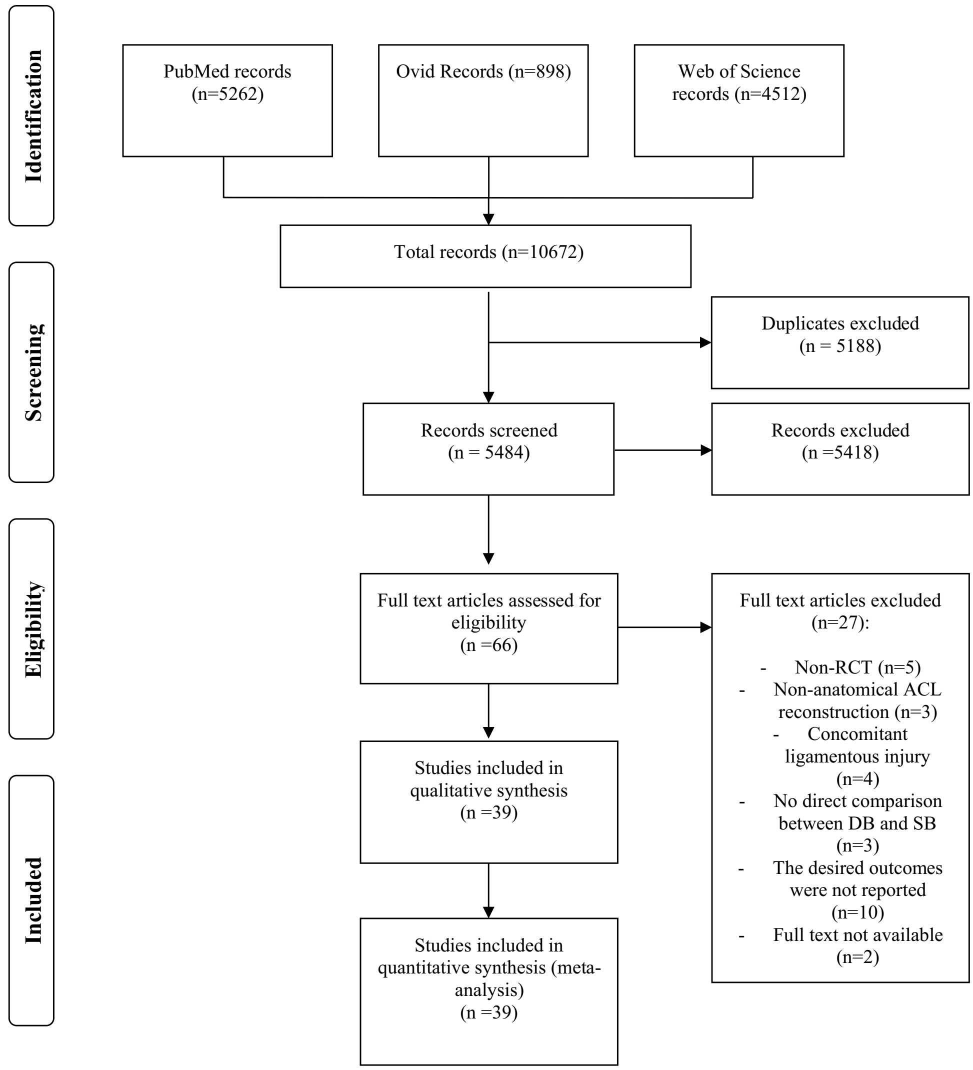


Fig. 1 Study flow diagram

significance in the short-term, mid-term and long-term follow-up (Fig. 5).

Tegner Score

Twelve studies reported on Tegner score [10, 12, 17–20, 27, 29, 30, 34, 38, 39, 42]. Overall, no significant difference was found between DB and SB in terms of Tegner score (SMD = 0.03, 95% CI − 0.17 to 0.24, $P = 0.74$; $I^2 = 70\%$). Similarly, subgroup analysis showed similar results between the two groups in the short-term, mid-term, and long-term follow-up (Supplementary Fig. D).

IKDC Subjective Score

Twenty-two studies reported on IKDC subjective score [9–12, 17–22, 24–26, 28, 30–35, 37, 42, 43]. Both DB and SB had similar overall IKDC subjective score (SMD = 0.09, 95% CI − 0.04 to 0.22, $P = 0.18$; $I^2 = 78\%$). Subgroup analysis also showed similar results (Supplementary Fig. E).

IKDC Objective Scale

Eleven studies reported on IKDC objective scale [9, 11, 20, 25, 28, 31, 34, 37, 41, 46–49]. No significant different was found between BD and SB in terms of overall IKDC objective scale. (RR = 0.82, 95% CI 0.64 to 1.04, $P = 0.19$; $I^2 = 5\%$). Likewise, subgroup analysis did not show any statistical significance (Supplementary Fig. F).

Graft Failure

Eight studies reported on graft failure [11, 12, 17, 23, 29, 43, 46–49]. The analysis revealed no significant difference between DB and SB in terms of graft failure rate (RR = 0.78, 95% CI 0.33 to 1.85, $P = 0.57$; $I^2 = 54\%$) (Supplementary Fig. G).

Table 1 Baseline characteristics of the included studies

Study name	Mean follow-up	Number of patients at baseline		Demographic data			Year data collected	Reconstruction technique (i.e., All-inside, Outside- in, Accessory anteromedial portal, Transtibial)	Graft type	Graft source
		SB	DB	Gender		Age				
				M	F					
Adachi 2004 [15]	32 months	55	53	65	43	SB; 29.5 (Range; 14–49), DB; 29.2 (Range; 14–47)	1998–2000	NR	Autograft	Semitendinosus in SB, Semitendinosus and Gracilis in DB
Adravanti 2016 [16]	6 years	30	30	34	26	SB; 28.3 (±6.2), DB; 26.4 (±8.5)	2008–2009	Transtibial in SB, Outside-in for posterolateral tunnel and transtibial for anteromedial tunnel in DB	Autograft	Semitendinosus and Gracilis
Aga 2018 [17]	2 years	62	54	88	28	SB; 27.1 (±5.5), DB; 27.4 (±6.3)	2010–2015	Accessory anteromedial portal	Autograft	Semitendinosus and Gracilis
Aglietti 2010 [43]	2 years	35	35	53	17	SB; 28 (Range; 16–40), DB; 28 (Range; 16–40)	NR	Outside-in for SB and DB	Autograft	Semitendinosus and Gracilis
Ahldén 2013/Karikis 2016 [38, 39]	5 years	50	53	70	33	Median (Range): SB; 25 (18–52), DB; 29 (18–52)	2008–2009	Anteromedial and anterolateral portals for SB and DB	Autograft	Semitendinosus and Gracilis
Araki 2010 [36]	1 year	10	10	10	10	SB; 24.7 (±11.8), DB; 25.2 (±12.1)	NR	Accessory anteromedial portal for SB and posterolateral tunnel in DB, Transtibial for anteromedial tunnel in DB	Autograft	Semitendinosus and Gracilis
Beyaz 2017 [18]	8 years	16	15	31	0	SB; 31.06 (±5.48), DB; 33.53 (±5.47)	2007–2008	Anteromedial portal	Autograft	Semitendinosus and Gracilis
Claes 2011 [19]	6 months	8	8	10	6	SB; 34.7 (±13.2), DB; 30.6 (±9.6)	NR	Anterolateral portal	Autograft	Semitendinosus and Gracilis
Devgan 2016 [37]	SB; 34.8 months, DB; 36.2 months	30	30	58	2	SB; 23.73 (±5.82), DB; 25 (±7.45)	2009–2012	Anteromedial portal for SB and DB	Autograft	Semitendinosus and Gracilis
Gobbi 2012 [20]	46.2 months	30	30	33	27	SB; 31.9 (±1.92), DB; 28.9 (±1.89)	2004–2007	Anteromedial portal in SB, Outside in used in DB	Autograft	Semitendinosus
Hussein 2012 [21]	51 months	78	131	126	83	SB; 34.2 (Range; 16–63), DB; 32.3 (Range; 16–74)	2005–2007	Accessory anteromedial portal	Autograft	Semitendinosus and Gracilis

Table 1 (continued)

Study name	Mean follow-up	Number of patients at baseline		Demographic data			Year data collected	Reconstruction technique (i.e., All-inside, Outside- in, Accessory anteromedial portal, Transtibial)	Graft type	Graft source
		SB	DB	Gender		Age				
				M	F					
Ibrahim 2009 [41]	29 months	50	48	98	0	Mean age for all; 28 years	NR	Transtibial for SB, Antromedial portal for DB	Autograft	Semitendinosus and Gracilis
Järvelä 2007 (1st)/ Suomalainen 2011 [46, 47]	2 years	78	75	110	43	SB; 32 (±10), DB; 32 (±10)	2003–2008	Anteromedial portal for SB and DB	Autograft	Semitendinosus and Gracilis
Järvelä 2008 (2nd)/ Suomalainen 2012 [48, 49]	5 years	30	30	42	18	SB; 30 (±8), DB; 34 (±10)	2003–2005	Anteromedial portal for SB and anteromedial tunnel in DB, Accessory anteromedial portal for posterolateral tunnel in DB	Autograft	Semitendinosus and Gracilis
Kang 2015 [22]	SB; 31 months, DB; 33 months	43	41	41	43	SB; 30 (±5), DB; 28 (±5)	2010–2011	Anteromedial portal	Allograft	Bone-patellar tendon-bone in SB, Tibialis anterior tendon in DB
Koga 2015 [23]	69 months	25	28	23	30	SB; 24 (Range; 14–44), DB; 25 (Range 14–49)	2002–2004	Anteromedial portal in SB, Transtibial in DB	Autograft	Quadrupled Semitendinosus in SB, Doubled Semitendinosus in DB
Komzák 2018 [24]	27 months	20	20	23	17	Mean age for all; 27.5 (Range; 17–42)	2011–2012	NR	Autograft	Hamstring tendon (not specified)
Liu 2016 [12]	80 months	40	40	66	14	SB; 29.7 (Range; 17–47), DB; 25.6 (16–45)	2007–2008	Accessory anteromedial portal for SB and DB	Autograft	Semitendinosus and Gracilis
Mayr 2016/ 2018 [9, 25]	5 years	28	34	33	29	SB; 39 (±10), DB; 37.8 (±9.9)	2009–2010 and 2014–2015	Anteromedial portal	Autograft	Semitendinosus and Gracilis
Mohtadi 2019 [11]	5 years	110	110	120	100	SB; 28.5 (±9.9), DB; 28.3 (±9.8)	2007–2010	Transtibial for SB, Anteromedial portal for DB	Autograft	Semitendinosus and Gracilis
Morey 2015 [35]	4 years	20	20	39	1	SB; 28.3 (±6.08), DB; 26.4 (±5.93)	2009–2010	Anteromedial portal for SB and anteromedial tunnel in DB, Accessory anteromedial portal for posterolateral tunnel in DB	Autograft	Semitendinosus and Gracilis

Table 1 (continued)

Study name	Mean follow-up	Number of patients at baseline		Demographic data			Year data collected	Reconstruction technique (i.e., All-inside, Outside- in, Accessory anteromedial portal, Transtibial)	Graft type	Graft source
		SB	DB	Gender		Age				
				M	F					
Muneta 2007 [40]	25 months	34	34	34	34	SB; 23.4 (Range; 14–44), DB; 24 (Range; 14–49)	2002–2004	Antromedial portal for SB and DB	Autograft	Semitendinosus
Núñez 2012 [26]	2 years	23	29	44	8	SB; 30.6 (±7.9), DB; 30.8 (±8.3)	Jan 2008 -Nov 2008	Transtibial in SB, Accessory ateromedial portal in DB	Autograft	Semitendinosus and Gracilis
Sagar 2019 [10]	5 years	30	30	58	2	SB; 26.9, DB; 28.2	2012–2013	Accessory anteromedial portal for SB and posterolateral tunnel in DB, Transtibial for anteromedial tunnel in DB	Autograft	Semitendinosus
Sasaki 2016 [27]	2 years	69	67	65	71	SB; 27 (±11.9), DB; 28.2 (±12.6)	2007–2009	Transtibial, Anteromedial, or Outside-in techniques	Autograft	Bone-patellar tendon-bone in SB, Semitendinosus and Gracilis tendons in DB
Siebold 2008 [28]	19 months	35	35	63	7	SB; 29 (Range; 17–42), DB; 28 (Range; 17–45)	2004–2005	Transtibial	Autograft	Semitendinosus and Gracilis
Song 2013 [29]	SB; 5.3 years, DB; 5.7 years	60	52	82	30	SB; 30.3 (Range; 17–50), DB; 35.5 (Range; 19–58)	2004–2007	Anteriomedial portal for SB and DB	Allograft	Tibialis anterior
Streich 2008 [30]	2 years	25	24	49	0	SB; 29.2 (±6.3), DB; 30 (±6.5)	2004–2005	Transtibial for SB and DB	Autograft	Quadrupled Semitendinosus in SB, Doubled Semitendinosus in DB
Sun 2015 [31]	3 years	142	154	207	89	SB; 28.2 (Range; 19–52), DB; 27.5 (Range; 19–52)	2000–2005	Anteromedial portal for SB and DB	Allograft in SB, autograft in DB	Tibialis anterior in SB, Semitendinosus and Gracilis tendone in DB
Ventura 2013 [32]	2 years	40	40	51	29	SB; 28.8 (±5.8), DB; 28.4 (±8.6)	2008–2010	Transtibial for SB and DB	Autograft	Semitendinosus and Gracilis

Table 1 (continued)

Study name	Mean follow-up	Number of patients at baseline		Demographic data			Year data collected	Reconstruction technique (i.e., All-inside, Outside- in, Accessory anteromedial portal, Transtibial)	Graft type	Graft source
		SB	DB	Gender		Age				
				M	F					
Wang 2009 [42]	SB; 14.4 months, DB; 17.7 months	32	32	49	15	SB; 23.6 (±5.2), DB; 27.3 (±10)	2005–2006	Transtibial for SB, Accessory anteromedial portal for anteromedial tunnel of DB, Anteromedial portal for posterolateral tunnel of DB	Autograft	Semitendinosus and Gracilis
Xu 2013 [33]	16.3 months	32	34	49	17	SB; 33.3 (±12.8), DB; 30.2 (±7.7)	2009–2010	Accessory anteromedial portal for SB and DB	Autograft	Semitendinosus and Gracilis
Yagi 2007/Fujita 2011 [44, 45]	SB; 33.7 months, DB; 31.9 months	20	20	13	27	SB; 22.3 (±7.8), DB; 22.9 (±7.9)	NR	Transtibial for SB and anteromedial tunnel in DB, Accessory anteromedial portal for posterolateral tunnel in DB	Autograft	Semitendinosus and Gracilis
Zhang 2019 [34]	25.1 months	78	78	97	59	SB; 27.6 (±7.3), DB; 25.9 (±5.2)	2009–2014	Anteromedial portal for SB and DB	Autograft	Semitendinosus and Gracilis

Table 2 Risk of bias assessment of the included studies

Study	Randomization	Deviations from the intended intervention	Missing outcomes data	Measurement of the outcome	Selection of the reported results	Overall risk of bias
Adachi 2003 [15]	?	?	⊖	⊖	⊖	?
Adravanti 2016 [16]	?	?	⊖	⊖	⊖	?
Aga 2018 [17]	⊖	?	⊖	⊖	⊖	?
Aglietti 2010 [43]	⊖	⊖	⊖	⊖	⊖	⊖
Ahldén 2013 Karikis 2016 [38, 39]	⊖	⊕	⊖	⊖	⊖	⊕
Araki 2010 [36]	⊖	⊖	⊖	⊖	⊖	⊖
Beyaz 2017 [18]	⊖	?	⊖	⊖	⊖	?
Claes 2011 [19]	?	⊕	⊖	⊖	⊖	⊕
Devgan 2016 [37]	⊕	⊖	⊖	⊖	⊖	⊕
Gobbi 2011 [20]	⊖	⊖	⊖	⊖	⊖	⊖
Hussein 2012 [21]	⊖	?	⊖	⊖	⊖	?
Ibrahim 2009 [41]	⊖	?	⊖	⊖	⊖	?
Järvelä 2007 (1st)/Suomalainen 2011 [46, 47]	⊖	?	⊖	⊖	⊖	?
Järvelä 2008 (2nd)/Suomalainen 2012 [48, 49]	⊖	⊕	⊖	⊖	⊖	⊕
Kang 2015 [22]	⊖	⊖	⊖	?	⊖	?
Koga 2015 [23]	⊕	⊕	?	⊖	⊖	⊕
Komzák 2018 [24]	⊖	⊖	⊖	⊖	⊖	⊖
Liu 2016 [12]	⊖	?	⊖	⊖	⊖	?
Mayr 2016/2018 [9, 25]	⊖	?	⊖	⊖	⊖	?
Mohtadi 2019 [11]	⊖	⊖	⊖	⊖	⊖	⊖
Morey 2015 [35]	⊖	⊕	⊖	⊖	⊖	⊕
Muneta 2007 [40]	⊕	⊕	⊖	⊖	⊖	⊕
Nunez 2012 [26]	⊖	?	⊖	⊖	⊖	?
Sagar 2019 [10]	⊖	?	⊖	⊖	⊖	?
Sasaki 2016 [27]	⊖	?	⊖	⊖	⊖	?
Siebold 2008 [28]	⊖	⊖	⊖	⊖	⊖	⊖
Song 2013 [29]	⊕	?	⊖	⊖	⊖	⊕
Streich 2008 [30]	?	?	⊖	⊖	⊖	?
Sun 2014 [31]	⊖	?	⊖	⊖	⊖	?
Ventura 2013 [32]	⊖	⊖	⊖	⊖	⊖	⊖
Wang 2009 [42]	?	⊖	⊖	⊖	⊖	?
Xu 2013 [33]	⊖	⊕	⊖	⊖	⊖	⊕
Yagi 2007 /Fujita 2011 [44, 45]	⊕	?	⊖	⊖	⊖	⊕
Zhang 2019 [34]	⊖	?	⊖	⊖	⊖	?

⊕: High Risk, ⊖: Low Risk, ?: Some Concerns

Return to Pre-injury Sport Activity

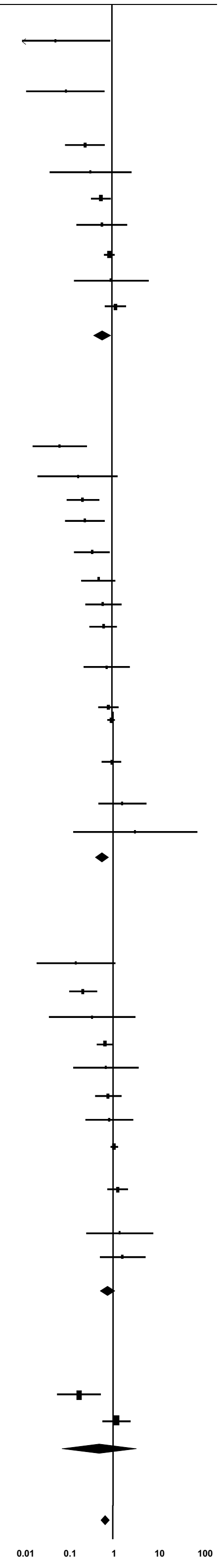
Five studies reported on Return to pre-injury sports activity [11, 12, 17, 40, 43]. Both groups showed similar rate in terms of return to pre-injury sports activity (RR = 1.09, 95% CI 0.93 to 1.26, $P = 0.26$; $I^2 = 1\%$) (Supplementary Fig. H).

Discussion

This comprehensive systematic review and meta-analysis based on the highest level of evidence obtained from RCTs compared the short-term, mid-term, and long-term outcomes of anatomical SB and anatomical DB ACL reconstruction

Fig. 2 Pivot shift test at different time points (SB vs DB)

Study	DB (n/N)	SB (n/N)	Weight (%)	Risk Ratio, Random, 95% CI
1 year follow up				
Järvelä 2007 (1st)/ Suomalainen 2011	1/30	9/25	4.07	0.09 [0.01, 0.68]
Järvelä 2008 (2nd)/ Suomalainen 2012	0/22	9/23	2.25	0.05 [0.00, 0.89]
Ventura 2013	4/40	16/40	11.29	0.25 [0.09, 0.68]
Araki 2010	1/10	3/10	3.78	0.33 [0.04, 2.68]
Sun 2015	21/154	34/142	20.69	0.57 [0.34, 0.93]
Yagi 2007/ Fujita 2011	3/20	5/20	8.12	0.60 [0.16, 2.18]
Mohtadi 2019	49/102	60/106	25.58	0.84 [0.65, 1.10]
Xu 2013	2/34	2/32	4.43	0.94 [0.14, 6.29]
Aga 2018	18/50	18/60	19.79	1.20 [0.70, 2.04]
Subtotal	99/462	156/458	100	0.59 [0.38, 0.91]
Heterogeneity $Tau^2 = 0.17$; $Chi^2 = 17.96$, df = 8 (P = 0.02); $I^2 = 55.46\%$				
Test for overall effect Z = -2.37 (P = 0.01)				
2 years follow up				
Ibrahim 2009	2/50	28/48	4.28	0.06 [0.38, 0.91]
Streich 2008	1/24	6/25	2.32	0.17 [0.02, 1.33]
Zhang 2019	6/78	27/78	7.84	0.22 [0.09, 0.50]
Ventura 2013	4/40	16/40	6.42	0.25 [0.09, 0.68]
Muneta 2007	5/34	14/34	7.19	0.35 [0.14, 0.88]
Aglietti 2010	6/35	12/35	7.55	0.50 [0.21, 1.18]
Kang 2015	6/41	10/43	7.08	0.62 [0.25, 1.57]
Ahlde n 2013/ Karikis 2016	10/50	15/48	9.09	0.64 [0.31, 1.28]
Järvelä 2007 (1st)/ Suomalainen 2011	4/22	5/21	5.33	0.76 [0.23, 2.46]
Aga 2018	18/52	25/61	11.38	0.84 [0.52, 1.36]
Mohtadi 2019	69/107	76/104	14.14	0.00 [0.73, 1.05]
Järvelä 2007 (1st)/ Suomalainen 2011	20/61	22/60	11.27	0.89 [0.54, 1.45]
Sasaki 2016	6/67	4/69	5.06	1.54 [0.45, 5.23]
Siebold 2008	1/35	0/35	1.06	3.00 [0.12, 71.21]
Subtotal	158/696	260/701	100	0.55 [0.39, 0.77]
Heterogeneity $Tau^2 = 0.20$; $Chi^2 = 36.08$, df = 13(P<0.001); $I^2 = 63.96\%$				
Test for overall effect Z = -3.42 (P<0.001)				
3-5 years follow up				
Morey 2015	1/20	7/20	2.94	0.14 [0.01, 1.05]
Hussein 2012	9/131	26/78	11.66	0.20 [0.10, 0.41]
Sagar 2019	1/30	3/30	2.48	0.33 [0.03, 3.02]
Sun 2015	29/154	42/142	16.06	0.63 [0.42, 0.96]
Yagi 2007/ Fujita 2011	2/18	3/18	3.98	0.66 [0.12, 3.52]
Song 2013	12/65	16/65	12.22	0.75 [0.38, 1.45]
Gobbi 2012	4/30	5/30	6.39	0.80 [0.23, 2.69]
Mohtadi 2019	73/103	70/99	19.20	1.00 [0.84, 1.19]
Järvelä 2008 (2nd)/ Suomalainen 2012	13/20	11/21	14.42	1.24 [0.73, 2.08]
Mayr 2016/ 2018	3/28	2/25	3.83	1.33 [0.24, 7.37]
Ahlde n 2013/ Karikis 2016	7/46	4/41	6.83	1.56 [0.49, 4.94]
Subtotal	154/645	189/569	100	0.71 [0.49, 1.03]
Heterogeneity $Tau^2 = 0.17$; $Chi^2 = 27.85$, df = 10 (P = 0.002); $I^2 = 64.10\%$				
Test for overall effect Z = -1.76 (P = 0.07)				
>5 years follow up				
Koga 2015	3/28	16/25	47.49	0.16 [0.05, 0.50]
Liu 2016	11/32	10/34	52.51	1.16 [0.57, 2.37]
Subtotal	14/60	26/59	100	0.46 [0.06, 3.11]
Heterogeneity $Tau^2 = 1.66$; $Chi^2 = 8.38$, df = 1 (P < 0.001); $I^2 = 88.07\%$				
Test for overall effect Z = -0.79 (P = 0.42)				
Total	425/1863	631/1787		0.61 [0.49, 0.75]
Heterogeneity $Tau^2 = 0.14$; $Chi^2 = 93.32$, df = 35 (P < 0.001); $I^2 = 62.49\%$				
Test for overall effect Z = -4.46 (P < 0.001)				



Study	DB (n/N)	SB (n/N)	Weight (%)	Risk Ratio, Random, 95% CI
1 year follow up				
Ventura 2013	1/40	2/40	1.91	0.50 [0.04, 5.29]
Yagi 2007/ Fujita 2011	3/20	5/20	6.39	0.60 [0.16, 2.18]
Araki 2010	-	-	0.73	1.00 [0.02, 46.07]
Aga 2018	32/60	31/61	90.97	1.04 [0.74, 1.47]
Subtotal	36/120	38/121	100	0.99 [0.72, 1.47]
Heterogeneity $Tau^2 = 0.00$; $Chi^2 = 1.01$, df = 3 (P = 0.79); $I^2 = 51.63\%$				
Test for overall effect Z = -0.01 (P = 0.99)				
2 years follow up				
Muneta 2007	1/34	7/34	2.34	0.14 [0.01, 1.09]
Ibrahim 2009	5/50	17/48	9.65	0.28 [0.11, 1.09]
Aglietti 2010	1/35	3/35	2.01	0.33 [0.03, 3.05]
Ventura 2013	1/40	2/40	1.77	0.50 [0.04, 5.29]
Zhang 2019	17/78	34/78	21.94	0.50 [0.30, 0.81]
Aga 2018	23/52	36/61	28.15	0.74 [0.51, 1.08]
Kang 2015	6/41	7/43	8.33	0.89 [0.33, 2.45]
Ahlde n 2013/ Karikis 2016	23/50	24/48	25.80	0.92 [0.60, 1.39]
Subtotal	77/380	130/387	100	0.62 [0.45, 0.86]
Heterogeneity $Tau^2 = 0.06$; $Chi^2 = 10.38$, df = 7 (P = 0.16); $I^2 = 32.59\%$				
Test for overall effect Z = -2.84 (P <0.001)				
3-5 years follow up				
Morey 2015	2/20	10/20	18.49	0.20 [0.05, 0.80]
Song 2013	10/65	13/65	33.04	0.76 [0.36, 1.62]
Ahlde n 2013/ Karikis 2016	25/45	18/36	42.56	1.11 [0.73, 1.68]
Mayr 2016/ 2018	3/28	0/25	5.91	6.27 [0.34, 115.84]
Subtotal	40/158	41/146	100	0.79 [0.37, 1.69]
Heterogeneity $Tau^2 = 0.30$; $Chi^2 = 7.30$, df = 1 (P = 0.06); $I^2 = 58.94\%$				
Test for overall effect Z = -0.59 (P = 0.54)				
>5 years follow up				
Koga 2015	2/28	7/25	87.42	0.25 [0.05, 1.11]
Liu 2016	-	-	12.58	1.06 [0.02, 51.88]
Subtotal	2/28	7/25		0.30 [0.07, 1.21]
Heterogeneity Tau2 = 0.00; Chi2 = 0.45, df = 1 (P = 0.50); I2 = 0%				
Test for overall effect Z = -1.61 (P = 0.09)				
Total	155/686	216/679		0.77 [0.62, 0.95]
Heterogeneity $Tau^2 = 0.07$; $Chi^2 = 25.82$, df = 17 (P = 0.07); $I^2 = 34.16\%$				
Test for overall effect Z = -2.36 (P = 0.01)				

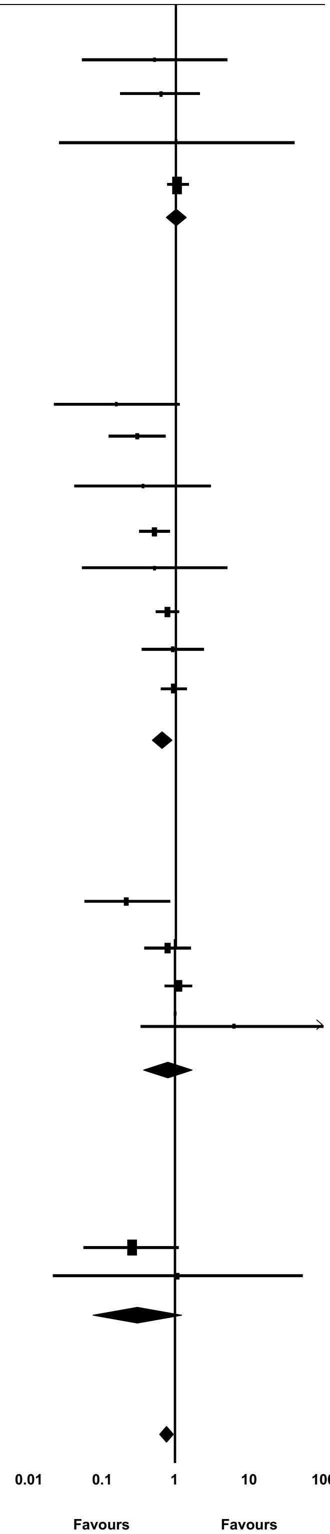


Fig. 3 Lachman test at different time points (SB vs DB)

Fig. 4 KT-1000/2000 arthrometer at different time points (SB vs DB)

Study	DB Total	SB Total	Weight (%)	Std. Mean Difference IV, Random, 95% CI
1 year follow up				
Ventura 2013	40	40	12.91	-0.66 [-1.11, -0.21]
Araki 2010	10	10	7.13	-0.62 [-1.52, 0.27]
Aglietti 2010	35	35	12.45	-0.62 [-1.10, -0.14]
Yagi 2007/ Fujita 2011	20	20	10.28	-0.42 [-1.05, 0.20]
Cleas 2011	8	8	6.35	-0.31 [-1.29, 0.67]
Järvelä 2008 (2nd)/ Suomalainen 2012	30	30	12.05	-0.04 [-0.55, 0.46]
Wang 2009	32	32	12.28	0.18 [-0.30, 0.67]
Xu 2013	34	32	12.35	0.35 [-0.13, 0.83]
Aga 2018	54	62	14.20	0.36 [-0.008, 0.72]
Subtotal	263	269	100	-0.16 [-0.47, 0.15]
Heterogeneity Tau^2 = 0.14; Chi^2 = 23.76, df = 8 (P = 0.003); I^2 = 66.33%				
Test for overall effect Z = -1.01 (P = 0.31)				
2 years follow up				
Aglietti 2010	35	35	7.06	-0.74 [-1.22, -0.25]
Ventura 2013	40	40	7.48	-0.72 [-1.17, -0.27]
Muneta 2007	34	34	6.98	-0.71 [-1.20, -0.22]
Siebold 2008	35	35	7.16	-0.51 [-0.99, -0.04]
Zhang 2019	78	78	9.43	-0.42 [-0.74, -0.11]
Järvelä 2008 (2nd)/ Suomalainen 2012	30	30	6.74	-0.35 [-0.86, 0.15]
Aga 2018	54	62	8.71	-0.21 [-0.57, 0.15]
Komzak 2018	20	20	5.51	-0.07 [-0.69, 0.54]
Järvelä 2007 (1st)/ Suomalainen 2011	75	78	9.44	0.00 [-0.31, 0.31]
Kang 2015	41	43	7.82	0.06 [-0.36, 0.49]
Streich 2008	24	25	6.14	0.09 [-0.46, 0.65]
Sasaki 2016	67	69	9.14	0.20 [-0.13, 0.53]
Ahlde n 2013/ Karikis 2016	53	50	8.39	0.22 [-0.16, 0.61]
Subtotal	586	599	100	-0.23 [-0.42, -0.03]
Heterogeneity Tau^2 = 0.07; Chi^2 = 32.46, df = 12 (P <0.001); I^2 = 63.03%				
Test for overall effect Z = -2.35 (P = 0.01)				
3-5 years follow up				
Yagi 2007/ Fujita 2011	20	20	11.20	-0.53 [-1.16, 0.10]
Hussein 2012	131	78	29.36	-0.46 [-0.74, -0.17]
Järvelä 2008 (2nd)/ Suomalainen 2012	30	30	15.41	-0.20 [-0.71, 0.30]
Ahlde n 2013/ Karikis 2016	53	50	21.72	0.00 [-0.38, 0.38]
Adachi 2004	53	55	22.31	0.04 [-0.33, 0.41]
Subtotal	287	233	100	-0.21 [-0.45, 0.02]
Heterogeneity Tau^2 = 0.03; Chi^2 = 6.78, df = 4 (P = 0.14); I^2 = 41.07%				
Test for overall effect Z = -1.78 (P = 0.07)				
>5 years follow up				
Koga 2015	28	25	31.98	-0.96 [-1.53, -0.39]
Liu 2016	32	34	34.33	0.03 [-0.45, 0.51]
Adravanti 2016	30	30	33.69	0.14 [-0.36, 0.64]
Subtotal	90	89	100	-0.25 [-0.90, 0.40]
Heterogeneity Tau^2 = 0.26; Chi^2 = 9.52, df = 2 (P <0.001); I^2 = 78.99%				
Test for overall effect Z = -0.74 (P = 0.45)				
Total	1226	1190		-0.21 [-0.34, -0.08]
Heterogeneity Tau^2 = 0.08; Chi^2 = 73.84, df = 29 (P <0.001); I^2 = 60.72%				
Test for overall effect Z = -3.18 (P <0.001)				

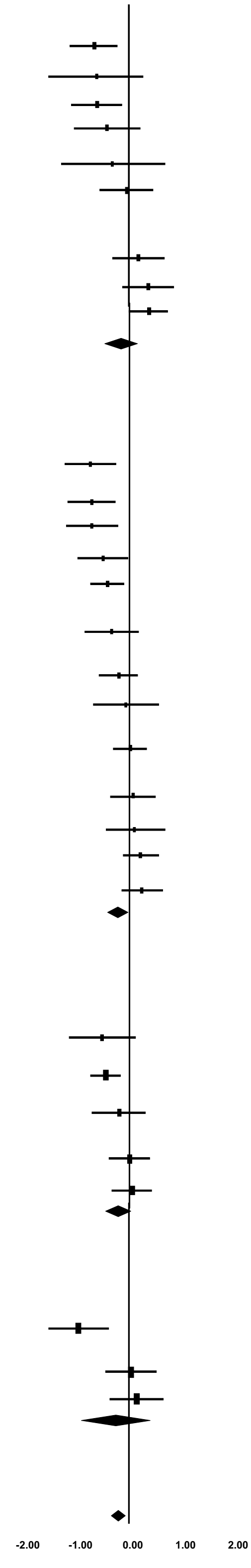
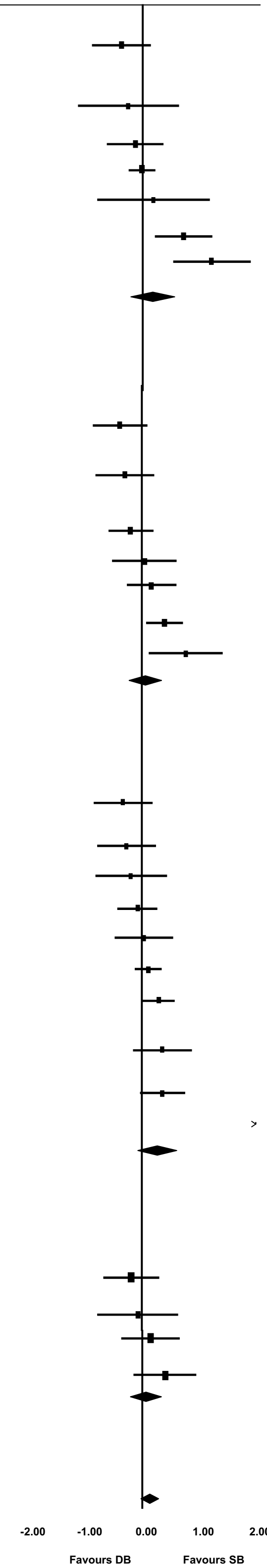


Fig. 5 Lysholm score at different time points (SB vs DB)

Study	DB Total	SB Total	Weight (%)	Std. Mean Difference IV, Random, 95% CI
1 year follow up				
Järvelä 2008 (2nd)/ Suomalainen 2012	30	30	15.70	-0.37 [-0.89, 0.13]
Araki 2010	10	10	10.17	-0.25 [-1.13, 0.62]
Wang 2009	32	32	16.04	-0.13 [-0.63, 0.35]
Sun 2015	154	142	20.15	-0.02 [-0.24, 0.20]
Cleas 2011	8	8	9.00	0.19 [-0.79, 1.17]
Xu 2013	34	32	15.91	0.71 [0.22, 1.21]
Komzak 2018	20	20	13.03	1.21 [0.53, 1.88]
Subtotal	288	274	100	0.17 [-0.20, 0.56]
Heterogeneity $Tau^2 = 0.17$; $Chi^2 = 22.33$, df = 6 (P <0.001); $I^2 = 73.13\%$				
Test for overall effect Z = 0.90 (P = 0.36)				
2 years follow up				
Siebold 2008	35	35	14.18	-0.39 [-0.86, 0.08]
Järvelä 2008 (2nd)/ Suomalainen 2012	30	30	13.36	-0.30 [-0.81, 0.20]
Ahlde n 2013/ Karikis 2016	53	50	16.25	-0.20 [-0.58, 0.18]
Streich 2008	24	25	12.27	0.04 [-0.51, 0.60]
Kang 2015	41	43	15.23	0.16 [-0.26, 0.59]
Zhang 2019	78	78	18.02	0.40 [0.08, 0.71]
Komzak 2018	20	20	10.69	0.76 [0.12, 1.40]
Subtotal	281	281	100	0.05 [-0.23, 0.34]
Heterogeneity $Tau^2 = 0.09$; $Chi^2 = 16.55$, df = 6 (P = 0.01); $I^2 = 63.76\%$				
Test for overall effect Z = 0.38 (P = 0.70)				
3-5 years follow up				
Devgan 2016	30	30	9.88	-0.33 [-0.84, 0.17]
Gobbi 2012	30	30	9.89	-0.27 [-0.78, 0.23]
Yagi 2007/ Fujita 2011	20	20	8.93	-0.19 [-0.81, 0.42]
Song 2013	65	65	11.22	-0.08 [-0.42, 0.26]
Sagar 2019	30	30	9.91	0.02 [-0.48, 0.53]
Sun 2015	154	142	11.98	0.11 [-0.11, 0.33]
Hussein 2012	131	78	11.65	0.29 [0.01, 0.57]
Järvelä 2008 (2nd)/ Suomalainen 2012	30	30	9.87	0.35 [-0.15, 0.86]
Ahlde n 2013/ Karikis 2016	53	50	10.87	0.35 [-0.03, 0.74]
Morey 2015	20	20	5.81	3.83 [2.78, 4.87]
Subtotal	563	495	100	0.26 [-0.08, 0.60]
Heterogeneity $Tau^2 = 0.24$; $Chi^2 = 59.86$, df = 9 (P <0.001); $I^2 = 84.96\%$				
Test for overall effect Z = 1.49 (P = 0.13)				
>5 years follow up				
Liu 2016	32	34	31.51	-0.19 [-0.67, 0.28]
Beyaz 2017	15	16	14.86	-0.07 [-0.77, 0.63]
Adravanti 2016	30	30	28.75	0.13 [-0.37, 0.64]
Koga 2015	28	25	24.88	0.39 [-0.14, 0.94]
Subtotal	105	105	100	0.06 [-0.20, 0.33]
Heterogeneity $Tau^2 = 0.00$; $Chi^2 = 2.77$, df = 3 (P = 0.42); $I^2 = 0\%$				
Test for overall effect Z = 0.46 (P = 0.64)				
Total	1237	1155		0.12 [-0.03, 0.27]
Heterogeneity $Tau^2 = 0.13$; $Chi^2 = 102.25$, df = 27 (P <0.001); $I^2 = 73.59\%$				
Test for overall effect Z = 1.52 (P = 0.12)				



techniques. The analysis suggests no significant difference between DB and SB techniques in mid-term and long-term follow-up with regard to knee stability and functional outcomes. The analysis also suggests that graft failure and return to pre-injury sports activity rates to be similar in both groups.

Mascarenhas et al. in a systematic review showed that DB was better in terms of knee stability outcomes and functional outcomes compared to SB technique [50]. Similarly, few more recent reviews found better knee stability and functional outcomes associated with DB in the mid-term follow-up. However, participants who received DB or SB reported similar outcomes in the long-term follow-up [7, 8, 51].

Pivot shift test, Lachman test, and KT-1000/2000 knee arthrometer assess the efficacy of ACL reconstruction in restoring the biomechanical function of the knee. Our review showed a substantial improvement in rotational stability measured by pivot shift test, anterior stability measured by Lachman test and KT-1000/2000 knee arthrometer in favor of DB at short term, yet no difference was noted at mid-term and long-term follow-up. Similarly, a recent biomechanical systematic review found that DB was associated with better restoration of anterior knee stability compared to SB ACL reconstruction technique. However, the review found no difference between the two groups in terms of rotational stability [52].

Many reviews reported about graft failure rate which was consistently similar between DB and SB at short-term, mid-term, and long-term follow-up [7, 8, 51]. However, a recent RCT with 10 years follow-up revealed that DB has significantly less graft failure rate compared to SB [53]. Only one systematic review reported about return to pre-injury sports activity which was significantly better in favor of DB technique [54].

Knee Osteoarthritis (OA) progression is one of the most unfavorable complications following ACL injury and perhaps ACL reconstruction. DB was associated with a significant delay with respect to OA progression compared to SB at the mid-term follow-up [51]. However, both surgical techniques found to carry similar risk of developing knee OA at the long-term follow-up [8, 53]. This suggests that SB ACL reconstruction is associated with earlier clinical or radiological manifestations of OA compared to the DB technique, yet the rate of OA progression becomes similar at the long-term follow-up.

Our review provided a relatively large sample size obtained from well-conducted RCTs comparing the clinical outcomes of anatomical DB and SB ACL reconstruction. Furthermore, our review provided short-term, mid-term, and long-term follow-up data for the most commonly assessed knee stability and functional outcomes.

We acknowledge that our review has some limitations. First, we did not assess the risk of developing OA following ACL reconstruction through DB or SB due to the paucity of RCTs reporting this outcome. Second, few of the included RCTs were able to provide long-term follow-up data. So, caution should be taken when interpreting these results. Third, diversity in the graft type, fixation device, and method of femoral drilling across the enrolled papers was an inherent limitation of this systematic review.

Conclusion

Anatomical DB ACL reconstruction technique was superior and showed significantly better results than anatomical SB in terms of overall pivot shift test, Lachman test, and KT 1000/2000 arthrometer. No difference was found between the two surgical techniques in overall Lysholm score, Tegner score, IKDC subjective score, IKDC objective scale, graft failure rate, and return to pre-injury sports activity. DB and SB reconstruction techniques showed similar outcomes in the mid-term and long-term follow-up. Further RCTs are warranted comparing the risk of OA progression between the two surgical techniques in the long-term follow-up.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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

Informed consent For this type of study informed consent is not required.

References

1. Joseph, A. M., Collins, C. L., Henke, N. M., Yard, E. E., Fields, S. K., & Comstock, R. D. (2013). A multisport epidemiologic comparison of anterior cruciate ligament injuries in high school athletics. *Journal of Athletic Training, 48*(6), 810–817.
2. Beynnon, B. D., Johnson, R. J., Abate, J. A., Fleming, B. C., & Nichols, C. E. (2005). Treatment of anterior cruciate ligament injuries, part I. *The American Journal of Sports Medicine, 33*(10), 1579–1602.
3. Beynnon, B. D., Johnson, R. J., Abate, J. A., Fleming, B. C., & Nichols, C. E. (2005). Treatment of anterior cruciate ligament injuries, part 2. *The American Journal of Sports Medicine, 33*(11), 1751–1767.
4. Xu, M., Gao, S., Zeng, C., Han, R., Sun, J., Li, H., Xiong, Y., & Lei, G. (2013). Outcomes of anterior cruciate ligament reconstruction using single-bundle versus double-bundle technique: meta-analysis of 19 randomized controlled trRials. *Arthroscopy: The Journal of Arthroscopic & Related Surgery, 29*(2), 357–365.

5. Li, Y. L., Ning, G. Z., Wu, Q., Wu, Q. L., Li, Y., Hao, Y., & Feng, S. Q. (2014). Single-bundle or double-bundle for anterior cruciate ligament reconstruction: A meta-analysis. *The Knee, 21*(1), 28–37.
6. Li, X., Xu, C. P., Song, J. Q., Jiang, N., & Yu, B. (2013). Single-bundle versus double-bundle anterior cruciate ligament reconstruction: An up-to-date meta-analysis. *International Orthopaedics, 37*(2), 213–226.
7. Kong, L., Liu, Z., Meng, F., & Shen, Y. (2017). Single-bundle versus double-bundle anterior cruciate ligament reconstruction: A systematic review and meta-analysis. *International Journal of Clinical and Experimental Medicine, 10*(1), 1–5.
8. Chen, H., Chen, B., Tie, K., Fu, Z., & Chen, L. (2018). Single-bundle versus double-bundle autologous anterior cruciate ligament reconstruction: A meta-analysis of randomized controlled trials at 5-year minimum follow-up. *Journal of Orthopaedic Surgery and Research, 13*(1), 50.
9. Mayr, H. O., Bruder, S., Hube, R., Bernstein, A., Suedkamp, N. P., & Stoehr, A. (2018). Single-bundle versus double-bundle anterior cruciate ligament reconstruction—5-year results. *Arthroscopy: The Journal of Arthroscopic and Related Surgery, 34*(9), 2647–2653.
10. Sagar, J. V. (2019). A 5 year prospective double blind comparative study of ACL reconstruction using hamstring single bundle vs double bundle graft. *International Journal of Orthopaedics, 5*(4), 683–688.
11. Mohtadi, N. G., & Chan, D. S. (2019). A randomized clinical trial comparing Patellar tendon, hamstring tendon, and Double-Bundle ACL reconstructions: Patient-reported and clinical outcomes at 5-year follow-up. *JBJS, 101*(11), 949–960.
12. Liu, Y., Cui, G., Yan, H., Yang, Y., & Ao, Y. (2016). Comparison between single-and double-bundle anterior cruciate ligament reconstruction with 6-to 8-stranded hamstring autograft: A prospective, randomized clinical trial. *The American Journal of Sports Medicine, 44*(9), 2314–2322.
13. Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P., et al. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. *Annals of Internal Medicine, 151*, W-65-W-94.
14. Sterne, J. A. C., Savovic, J., Page, M. J., Elbers, R. G., Blencowe, N. S., Boutron, I., et al. (2019). RoB 2: A revised tool for assessing risk of bias in randomised trials. *BMJ, 366*, l4898.
15. Adachi, N., Ochi, M., Uchio, Y., Iwasa, J., Kuriwaka, M., & Ito, Y. (2004). Reconstruction of the anterior cruciate ligament: single-versus double-bundle multistranded hamstring tendons. *The Journal of Bone and Joint Surgery. British Volume, 86*(4), 515–520.
16. Adravanti, P., Dini, F., de Girolamo, L., Cattani, M., & Rosa, M. A. (2017). Single-bundle versus double-bundle anterior cruciate ligament reconstruction: A prospective randomized controlled trial with 6-year follow-up. *The Journal of Knee Surgery, 30*(09), 898–904.
17. Aga, C., Risberg, M. A., Fagerland, M. W., Johansen, S., Trøan, I., Heir, S., & Engebretsen, L. (2018). No difference in the KOOS quality of life subscore between anatomic double-bundle and anatomic single-bundle anterior cruciate ligament reconstruction of the knee: A prospective randomized controlled trial with 2 years' follow-up. *The American Journal of Sports Medicine, 46*(10), 2341–2354.
18. Beyaz, S., Güler, Ü. Ö., Demir, Ş., Yüksel, S., Çınar, B. M., Özkoç, G., & Akpınar, S. (2017). Tunnel widening after single-versus double-bundle anterior cruciate ligament reconstruction: A randomized 8-year follow-up study. *Archives of Orthopaedic and Trauma Surgery, 137*(11), 1547–1555.
19. Claes, S., Neven, E., Callewaert, B., Desloovere, K., & Bellemans, J. (2011). Tibial rotation in single-and double-bundle ACL reconstruction: A kinematic 3-D in vivo analysis. *Knee Surgery, Sports Traumatology, Arthroscopy, 19*(1), 115–121.
20. Gobbi, A., Mahajan, V., Karnatzikos, G., & Nakamura, N. (2012). Single-versus double-bundle ACL reconstruction: is there any difference in stability and function at 3-year followup? *Clinical Orthopaedics and Related Research®, 470*(3), 824–834.
21. Hussein, M., van Eck, C. F., Cretnik, A., Dinevski, D., & Fu, F. H. (2012). Prospective randomized clinical evaluation of conventional single-bundle, anatomic single-bundle, and anatomic double-bundle anterior cruciate ligament reconstruction: 281 cases with 3-to 5-year follow-up. *The American Journal of Sports Medicine, 40*(3), 512–520.
22. Kang, H. J., Wang, X. J., Wu, C. J., Cao, J. H., & Zheng, Z. M. (2015). Single-bundle modified patellar tendon versus double-bundle tibialis anterior allograft ACL reconstruction: A prospective randomized study. *Knee Surgery, Sports Traumatology, Arthroscopy, 23*(8), 2244–2249.
23. Koga, H., Muneta, T., Yagishita, K., Watanabe, T., Mochizuki, T., Horie, M., Nakamura, T., Otabe, K., & Sekiya, I. (2015). Mid-to long-term results of single-bundle versus double-bundle anterior cruciate ligament reconstruction: randomized controlled trial. *Arthroscopy: The Journal of Arthroscopic & Related Surgery, 31*(1), 69–76.
24. Komzák, M., Hart, R., Feranec, M., Šmíd, P., & Kocová, R. (2018). In vivo knee rotational stability 2 years after double-bundle and anatomic single-bundle ACL reconstruction. *European Journal of Trauma and Emergency Surgery, 44*(1), 105–111.
25. Mayr, H. O., Benecke, P., Hoell, A., Schmitt-Sody, M., Bernstein, A., Suedkamp, N. P., & Stoehr, A. (2016). Single-bundle versus double-bundle anterior cruciate ligament reconstruction: a comparative 2-year follow-up. *Arthroscopy: The Journal of Arthroscopic & Related Surgery, 32*(1), 34–42.
26. Núñez, M., Sastre, S., Núñez, E., Lozano, L., Nicodemo, C., & Segur, J. M. (2012). Health-related quality of life and direct costs in patients with anterior cruciate ligament injury: single-bundle versus double-bundle reconstruction in a low-demand cohort—a randomized trial with 2 years of follow-up. *Arthroscopy: The Journal of Arthroscopic & Related Surgery, 28*(7), 929–935.
27. Sasaki, S., Tsuda, E., Hiraga, Y., Yamamoto, Y., Maeda, S., Sasaki, E., & Ishibashi, Y. (2016). Prospective randomized study of objective and subjective clinical results between double-bundle and single-bundle anterior cruciate ligament reconstruction. *The American Journal of Sports Medicine, 44*(4), 855–864.
28. Siebold, R., Dehler, C., & Ellert, T. (2008). Prospective randomized comparison of double-bundle versus single-bundle anterior cruciate ligament reconstruction. *Arthroscopy: The Journal of Arthroscopic & Related Surgery, 24*(2), 137–145.
29. Song, E. K., Seon, J. K., Yim, J. H., Woo, S. H., Seo, H. Y., & Lee, K. B. (2013). Progression of osteoarthritis after double-and single-bundle anterior cruciate ligament reconstruction. *The American journal of sports medicine, 41*(10), 2340–2346.
30. Streich, N. A., Friedrich, K., Gotterbarm, T., & Schmitt, H. (2008). Reconstruction of the ACL with a semitendinosus tendon graft: A prospective randomized single blinded comparison of double-bundle versus single-bundle technique in male athletes. *Knee Surgery, Sports Traumatology, Arthroscopy, 16*(3), 232–238.
31. Sun, R., Chen, B. C., Wang, F., Wang, X. F., & Chen, J. Q. (2015). Prospective randomized comparison of knee stability and joint degeneration for double-and single-bundle ACL reconstruction. *Knee Surgery, Sports Traumatology, Arthroscopy, 23*(4), 1171–1178.
32. Ventura, A., Iori, S., Legnani, C., Terzaghi, C., Borgo, E., & Albisetti, W. (2013). Single-bundle versus double-bundle anterior cruciate ligament reconstruction: assessment with vertical jump test. *Arthroscopy: The Journal of Arthroscopic & Related Surgery, 29*(7), 1201–1210.

33. Xu, Y., Ao, Y. F., Wang, J. Q., & Cui, G. Q. (2014). Prospective randomized comparison of anatomic single-and double-bundle anterior cruciate ligament reconstruction. *Knee Surgery, Sports Traumatology, Arthroscopy, 22*(2), 308–316.
34. Zhang, Q., Yang, Y., Li, J., Zhang, H., Fu, Y., & Wang, Y. (2019). Functional double-bundle anterior cruciate ligament reconstruction using hamstring tendon autografts with preserved insertions is an effective treatment for tibiofemoral instability. *Knee Surgery, Sports Traumatology, Arthroscopy, 27*(11), 3471–3480.
35. Morey, V. M., Nag, H. L., Chowdhury, B., Sankineani, S. R., & Naranje, S. M. (2015). A prospective comparative study of clinical and functional outcomes between anatomic double bundle and single bundle hamstring grafts for arthroscopic anterior cruciate ligament reconstruction. *International Journal of Surgery, 1*(21), 162–167.
36. Araki, D., Kuroda, R., Kubo, S., Fujita, N., Tei, K., Nishimoto, K., Hoshino, Y., Matsushita, T., Matsumoto, T., Nagamune, K., & Kurosaka, M. (2011). A prospective randomised study of anatomical single-bundle versus double-bundle anterior cruciate ligament reconstruction: Quantitative evaluation using an electromagnetic measurement system. *International Orthopaedics, 35*(3), 439–446.
37. Devgan, A., Rohilla, R., Singh, A., Tanwar, M., Devgan, R., & Siwach, K. (2016). A prospective study to evaluate the clinicoradiological outcomes of arthroscopic single bundle versus double bundle anterior cruciate ligament reconstruction. *Journal of clinical Orthopaedics and Trauma, 1*(7), 236–242.
38. Ahldén, M., Sernert, N., Karlsson, J., & Kartus, J. (2013). A prospective randomized study comparing double-and single-bundle techniques for anterior cruciate ligament reconstruction. *The American Journal of Sports Medicine, 41*(11), 2484–2491.
39. Karikis, I., Desai, N., Sernert, N., Rostgard-Christensen, L., & Kartus, J. (2016). Comparison of anatomic double-and single-bundle techniques for anterior cruciate ligament reconstruction using hamstring tendon autografts: A prospective randomized study with 5-year clinical and radiographic follow-up. *The American Journal of Sports Medicine, 44*(5), 1225–1236.
40. Muneta, T., Koga, H., Mochizuki, T., Ju, Y. J., Hara, K., Nimura, A., Yagishita, K., & Sekiya, I. (2007). A prospective randomized study of 4-strand semitendinosus tendon anterior cruciate ligament reconstruction comparing single-bundle and double-bundle techniques. *Arthroscopy: The Journal of Arthroscopic & Related Surgery, 23*(6), 618–628.
41. Ibrahim, S. A., Hamido, F., Al Misfer, A. K., Mahgoob, A., Ghafar, S. A., & Alhran, H. (2009). Anterior cruciate ligament reconstruction using autologous hamstring double bundle graft compared with single bundle procedures. *The Journal of Bone and Joint Surgery. British Volume, 91*(10), 1310–1315.
42. Wang, J. Q., Ao, Y. F., Yu, C. L., Ping, L. I., Yan, X. U., & Chen, L. X. (2009). Clinical evaluation of double-bundle anterior cruciate ligament reconstruction procedure using hamstring tendon grafts: A prospective, randomized and controlled study. *Chinese Medical Journal, 122*(6), 706–711.
43. Aglietti, P., Giron, F., Losco, M., Cuomo, P., Ciardullo, A., & Mondanelli, N. (2010). Comparison between single-and double-bundle anterior cruciate ligament reconstruction: A prospective, randomized, single-blinded clinical trial. *The American Journal of Sports Medicine, 38*(1), 25–34.
44. Yagi, M., Kuroda, R., Nagamune, K., Yoshiya, S., & Kurosaka, M. (2007). Double-bundle ACL reconstruction can improve rotational stability. *Clinical Orthopaedics and Related Research®, 454*, 100–107.
45. Fujita, N., Kuroda, R., Matsumoto, T., Yamaguchi, M., Yagi, M., Matsumoto, A., Kubo, S., Matsushita, T., Hoshino, Y., Nishimoto, K., & Araki, D. (2011). Comparison of the clinical outcome of double-bundle, anteromedial single-bundle, and posterolateral single-bundle anterior cruciate ligament reconstruction using hamstring tendon graft with minimum 2-year follow-up. *Arthroscopy: The Journal of Arthroscopic & Related Surgery, 27*(7), 906–913.
46. Järvelä, T. (2007). Double-bundle versus single-bundle anterior cruciate ligament reconstruction: A prospective, randomize clinical study. *Knee Surgery, Sports Traumatology, Arthroscopy, 15*(5), 500–507.
47. Suomalainen, P., Moisala, A. S., Paakkala, A., Kannus, P., & Järvelä, T. (2011). Double-bundle versus single-bundle anterior cruciate ligament reconstruction: Randomized clinical and magnetic resonance imaging study with 2-year follow-up. *The American Journal of Sports Medicine, 39*(8), 1615–1623.
48. Järvelä, T., Moisala, A. S., Sihvonen, R., Järvelä, S., Kannus, P., & Järvinen, M. (2008). Double-bundle anterior cruciate ligament reconstruction using hamstring autografts and bioabsorbable interference screw fixation: Prospective, randomized, clinical study with 2-year results. *The American Journal of Sports Medicine, 36*(2), 290–297.
49. Suomalainen, P., Järvelä, T., Paakkala, A., Kannus, P., & Järvinen, M. (2012). Double-bundle versus single-bundle anterior cruciate ligament reconstruction: A prospective randomized study with 5-year results. *The American Journal of Sports Medicine, 40*(7), 1511–1518.
50. Mascarenhas, R., Cvetanovich, G. L., Sayegh, E. T., Verma, N. N., Cole, B. J., Bush-Joseph, C., & Bach, B. R., Jr. (2015). Does double-bundle anterior cruciate ligament reconstruction improve postoperative knee stability compared with single-bundle techniques? A systematic review of overlapping meta-analyses. *Arthroscopy: The Journal of Arthroscopic & Related Surgery, 31*(6), 1185–1196.
51. Chen, G., & Wang, S. (2015). Comparison of single-bundle versus double-bundle anterior cruciate ligament reconstruction after a minimum of 3-year follow-up: A meta-analysis of randomized controlled trials. *International Journal of Clinical and Experimental Medicine, 8*(9), 14604.
52. Oh, J. Y., Kim, K. T., Park, Y. J., Won, H. C., Yoo, J. I., Moon, D. K., Cho, S. H., & Hwang, S. C. (2020). Biomechanical comparison of single-bundle versus double-bundle anterior cruciate ligament reconstruction: A meta-analysis. *Knee Surgery & Related Research, 32*(1), 1–1.
53. Järvelä, S., Kiekara, T., Suomalainen, P., & Järvelä, T. (2017). Double-bundle versus single-bundle anterior cruciate ligament reconstruction: A prospective randomized study with 10-year results. *The American Journal of Sports Medicine, 45*(11), 2578–2585.
54. Tiamklang, T., Sumanont, S., Foocharoen, T., & Laopaiboon, M. (2012). Double-bundle versus single-bundle reconstruction for anterior cruciate ligament rupture in adults. *Cochrane Database of Systematic Reviews*, *11*(11), CD008413. https://doi.org/10.1002/14651858.CD008413.pub2.