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Single-Bundle versus Double-Bundle Posterior Cruciate Ligament Reconstruction: A Meta-Analysis of Randomized Controlled Trials

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Purpose: This meta-analysis evaluated the benefits of single-bundle (SB) and double-bundle (DB) surgical techniques for posterior cruciate ligament reconstruction (PCLR) in terms of clinical outcomes.

Methods: Five electronic databases were searched for relevant articles published until September 2016. Clinical outcomes of both techniques were evaluated using Lysholm knee function scores, Tegner activity scores, side-to-side differences, and International Knee Documentation Committee (IKDC) objective grades. The results are presented as a risk ratio (RR) for binary outcomes and a weighted mean difference (WMD) for continuous outcomes with a 95% confidence interval (CI).

Results: Four randomized controlled trials (RCTs) were included. There were no significant differences in the Lysholm knee function scores (WMD=1.63; 95% CI, 0.00 to 3.27; I^2=0%), Tegner activity scores (WMD=0.17; 95% CI, –0.08 to 0.43; I^2=20%), side-to-side differences (WMD=–0.97; 95% CI, –2.41 to 0.47; I^2=78%), and IKDC objective grades (RR=1.18; 95% CI, 1.00 to 1.39; I^2=0%) at the final follow-up.

Conclusions: The present study demonstrates that both SB and DB techniques for PCLR are comparable in terms of restoration of knee stability and improvement of knee function. However, it is still unclear which technique yields better clinical outcomes. To verify and further corroborate our results, more larger-scale, high-quality RCTs are encouraged.

Keywords: **Knee, Posterior cruciate ligament, Reconstruction, Arthroscopy, Meta-analysis**

Introduction

Posterior cruciate ligament (PCL) injuries comprise 3% to 38% of all acute knee injuries[1]. As the incidences of PCL injuries increase, various treatment techniques for posterior cruciate ligament reconstruction (PCLR) have been developed over the past several years. However, controversy regarding surgical techniques for PCLR still remains.

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The PCL is the strongest ligament and acts as a primary restraint of posterior tibial translation in the knee joint. It consists of an anterolateral (AL) bundle and a posteromedial (PM) bundle. Because of the anatomical structure of the PCL, surgical techniques related to bundle type reconstruction have been the subject of debate among surgeons. Previously, the AL bundle was considered to be associated with linear stiffness and ultimate loading compared with the PM bundle[2,3]; thus, the focus was mainly on reconstruction of the anatomy of the AL bundle. However, early studies showed its limited efficacy, such as persistent postoperative instability, particularly residual posterior laxity in full extension. Although posterior stability is restored in the flexed knee, because the PM bundle is taut in knee extension, laxity remains in knee extension[4]. Therefore, some authors have suggested that double-bundle (DB) PCLR is superior to single-bundle (SB) PCLR in terms of restoration of posterior laxity of the knee[5]. Hou et al.[6] reported that the results of their study showed that both SB and DB PCLR techniques produced comparable clinical results; thus, the DB PCLR was not recommended as the preferred surgical procedure because it requires a longer recovery time and involves more trauma. However, other authors reported that although single AL bundle reconstruction best restored the normal PCL force profiles, laxity was greater than normal in low knee flexion angles. For these reasons, they suggested that additional reconstruction of the PM bundle would reduce laxity in low flexion angles, and DB PCLR would more closely restore the kinematics of the intact knee than SB PCLR[7-9].

The primary goal of surgical interventions for PCL injuries is to restore normal knee stability. Several studies have demonstrated the superiority of DB PCLR to SB PCLR for restoration of anteroposterior (AP) stability and rotatory stability; conversely, others[10-12] showed no significant difference in knee stability between the two procedures. The purpose of the present study is to perform a meta-analysis to compare the clinical outcomes of PCLRs using the SB and DB techniques under the hypothesis that the two techniques would not be significantly different in all outcome measures. There is only one previous meta-analysis that addresses the same topic we would like to discuss in this study; however, it only included retrospective studies and only 2 randomized controlled trials (RCTs), and parameters, such as side-to-side differences or International Knee Documentation Committee (IKDC) objective grades, were not evaluated in the study. In this study, we did not include retrospective studies to minimize bias and used 4 RCTs to compensate for weaknesses of the previous meta-analysis.

Methods

1. Study Selection

To identify relevant studies, we searched MEDLINE, EMBASE, the Cochrane Central Register of Controlled Trials, Web of Science, and Scopus databases using the controlled vocabulary and free text words described in Appendix 1. We attempted to identify all relevant studies regardless of language, publication type (journal articles, posters, conference articles, instructional course lectures, etc.), journal title, and publication date. The search was completed in September 2016 and included reference lists of the studies and any review articles identified.

2. Eligibility Criteria

Studies were included if 1) the subjects were patients who underwent PCLR using an SB or DB technique, 2) clinical outcomes of SB and DB PCLRs were compared, and 3) clinical outcomes were evaluated with a more than 24 months of follow-up, and 4) the study design was RCT. Non-RCTs, studies that did not compare the effects of surgical techniques, single-arm studies that only described femoral side reconstruction or tibial side reconstruction using an either SB or DB technique, studies that recommended surgical treatment for PCL injuries, *in vitro* studies, and animal studies were not included in the present study. Ultimately, 4 RCTs were included in this study, which focused on isolated PCL injury patients on whom either SB or DB PCLR was performed. Regarding posterolateral complex (PLC) injuries, Apsingi et al.[13] suggested that isolated PCLR would not be sufficient to restore normal rotational laxity in the PCL/PLC-injured knee. Therefore, studies in which isolated PCL reconstructions were performed in the presence of a PLC injury were excluded.

3. Data Collection and Analysis

Two authors (DYL and YJP) independently assessed the titles or abstracts of studies identified by the search strategy, and then full texts were assessed for final inclusion. Uncertainty about inclusions was resolved through discussion and consensus. Eligible data were independently abstracted into predefined forms by the authors and checked for accuracy. We collected information on study characteristics (authors, journal, study design, publication year, and sample size), patient demographic data (sex, age, surgical technique, number of subjects in each group, graft used for reconstruction, and follow-up time) (Table 1), and the results of clinical outcomes including Lysholm knee function scores, Tegner activity scores, side-to side differences, and IKDC objective grades (Table 2). In each study, the IKDC objective grades were reported using four categories (normal, nearly normal, abnormal, and severely abnormal). For the convenience of calculation, we classified the IKDC objective grades into normal or abnormal. “Normal” included normal and nearly normal; “abnormal” included abnormal and severely abnormal. Based on tables and result data of 4 RCTs, the number of subjects or the means and standard deviations of demographic data and comparison of clinical outcomes between groups were investigated according to Cochrane Collaboration guidelines.

4. Assessment of Methodological Quality

Two authors (DYL and YJP) independently assessed the methodological quality of each RCT. Specifically, the risk of bias in each study was assessed using the Jadad quality assessment scale. The maximum score is 5 in the Jadad scale, which consists of randomization (2), blinding (2), and an account of all patients (1)[14]. Any disagreements between the authors were resolved through discussion or review by the third author. We did not evaluate

Table 1. Characteristics of the Included Studies

Study	Journal	Study design	Year	Technique (sample size)	Surgical technique	Age (yr)	Sex (M:F)	Graft	Follow-up time (mo)
Wang et al.[15]	*Injury*	RCT	2004	SB (19)	TT	29.4±13.6	14:5	SemiT+gracilis	41±13
				DB (16)	TT	28.2±10.4	12:4	SemiT+gracilis	28.2±4.2
Yoon et al.[16]	*American Journal of Sport Medicine*	RCT	2010	SB (25)	TT	28.5 (17–47)	20:5	Achilles tendon	31 (24–42)
				DB (28)	TT	27.4 (18–46)	25:3	Achilles tendon	33 (24–43)
Li et al.[17]	*Arthroscopy*	RCT	2014	SB (22)	TT	25.1±2.6	15:7	TA tendon	28.7±3.0
				DB (24)	TT	23.5±5.2	18:6	TA tendon	30.4±5.1
Hou et al.[6]	*Chinese Journal of Tissue Engineering Research*	RCT	2015	SB (41)	TT	27.7±8.3	20:21	NP	24
				DB (40)	TT	26.7±10.7	18:22	NP	24

Values are presented as mean±standard deviation (range).
RCT: randomized controlled trial, SB: single-bundle, DB: double-bundle, TT: transtibial, SemiT: semitendinosus, TA: tibialis anterior, NP: not provided.

Table 2. Comparison of Clinical Outcomes between Groups in Included Studies

Study	Group (no.)	Lysholm knee function score	Tegner activity score	Side-to-side difference (mm)	IKDC objective grade[a] (normal/abnormal)
Wang et al.[15]	SB (19)	88±10	4.5±1.7	2.3±1.4	11/8
	DB (16)	89±9	5.2±1.6	3.1±3.0	13/3
Yoon et al.[16]	SB (25)	89 (71–99)	6 (4–7)	4.5±2.3	18/7
	DB (28)	91 (76–100)	6 (4–7)	3.1±2.4	24/4
Li et al.[17]	SB (22)	88.0±4.2	6.2±0.9	4.1±1.3	18/4
	DB (24)	89.8±3.8	6.8±1.2	2.2±1.3	22/2
Hou et al.[6]	SB (41)	85.3±8.3	4.2±0.6	NP	NP
	DB (40)	86.4±7.6	4.3±0.6	NP	NP

Values are presented as mean±standard deviation (range).
IKDC: International Knee Documentation Committee, SB: single-bundle, DB: double-bundle, NP: not provided.
[a]IKDC objective grades A and B were regarded as normal and C and D as abnormal.

publication bias because of the low statistical power as the number of included studies was less than 10.

5. Statistical Analysis

The main purpose of this review was to evaluate the clinical outcomes after PCLRs using SB and DB techniques. These outcomes were evaluated by using knee scoring systems and by examining knee stability in each clinical study. To evaluate the reconstructed knees, we calculated the risk ratio (RR) or the weighted mean difference (WMD) of each result of the SB and DB PCLRs, and we also analyzed the differences in the outcome parameters between the groups. RevMan ver. 5.3 (The Nordic Cochrane Centre, Copenhagen, Denmark) was used to estimate the overall pooled effect size for each outcome. A meta-analysis of the included studies was done using a random-effects model. For continuous outcomes, we conducted WMD analysis using the inverse variance method. For binary outcomes, we calculated the RR between groups using the Mantel-Haenszel method. Statistical heterogeneity among the studies was assessed using I-squared (I^2), with values of 25%, 50%, and 75% considered low, moderate, and high, respectively, and Cochrane Q statistic (chi-square test) for heterogeneity. A p-value <0.10 was defined as significant heterogeneity.

Results

1. Identification of Studies

A total of 5,640 relevant articles were initially identified. Of these, 2,310 were duplicated in the databases. After screening of the remaining 3,330 articles using titles and abstracts, all but 6 were excluded because they were irrelevant to the purpose of the present study. A thorough full-text review of the 6 articles resulted in exclusion of 2 lacking vital data, such as clinical outcomes or randomization. The majority of the excluded articles were not RCTs, inappropriate for comparison due to surgical techniques used for PCLR, evaluated patients who underwent conservative treatment for PCL injuries, introduced other surgical techniques, such as transtibial (TT) or tibial inlay (TI) technique for PCLR, or *in vitro* or animal studies. Four articles were included for data extraction and meta-analysis (Fig. 1)[6,15-17]. Detailed data on surgical techniques (TT or TI), bundle types (SB or DB), and graft types of the 4 RCTs are described in Table 1.

2. Quality of the Included Studies

To evaluate the methodological quality, the Jadad quality assessment scale was used. The Jadad scale score of the included RCTs was ≥2 points (range, 2 to 4 points). These results indicated a low risk of bias of the included RCTs with the exception of one study[2] which had a Jadad scale score of 2.

3. Lysholm Knee Function Score

All four studies (100%) reported the Lysholm knee function scores of the SB and DB groups. Of the total 215 patients, 108 patients were in the DB group and 107 patients were in the SB group. There were no significant differences in the Lysholm knee function scores between the SB and DB groups (WMD=1.63; 95% CI, 0.00 to 3.27; I^2=0%) (Fig. 2).

4. Tegner Activity Score

All four studies (100%) reported the Tegner activity scores in

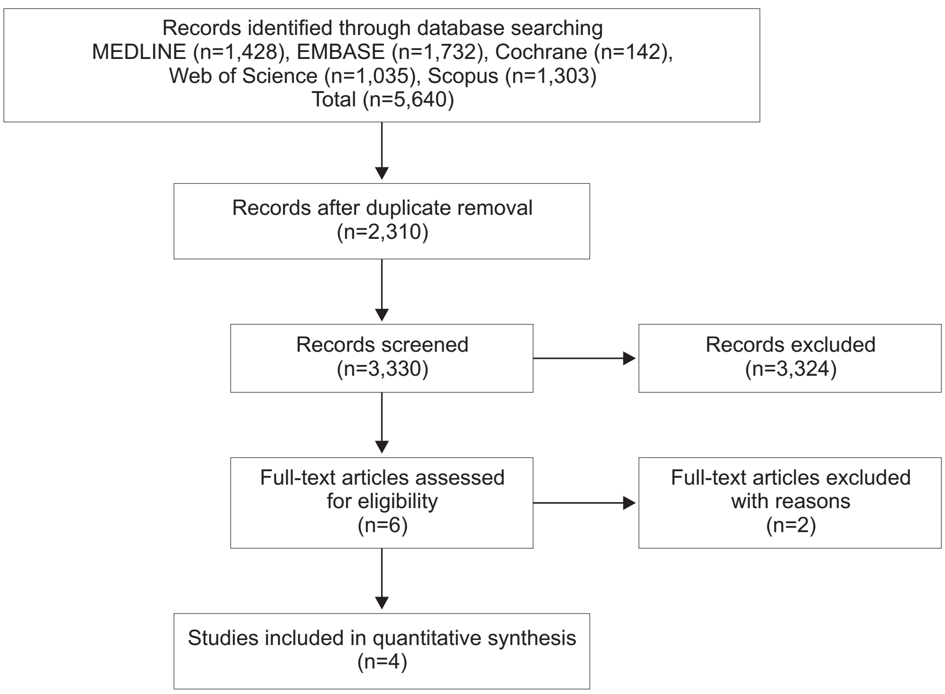

Fig. 1. PRISMA (Preferred Reporting Items of Systematic Reviews and Meta-Analyses) flow diagram.

	DB			SB				Mean difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Li et al.[17]	89.8	3.8	24	88	4.2	22	49.6%	1.80 [−0.52, 4.12]
Wang et al.[15]	89	9	16	88	10	19	6.7%	1.00 [−5.30, 7.30]
Yoon et al.[16]	91	6	28	89	7	25	21.4%	2.00 [−1.53, 5.53]
Hou et al.[6]	86.4	7.6	40	85.3	8.3	41	22.3%	1.10 [−2.36, 4.56]
Total (95% CI)			**108**			**107**	**100.0%**	**1.63 [−0.00, 3.27]**

Heterogeneity: Tau^2=0.00, Chi^2=0.19, df=3 (p=0.98); I^2=0%
Test for overall effect: Z=1.96 (p=0.05)

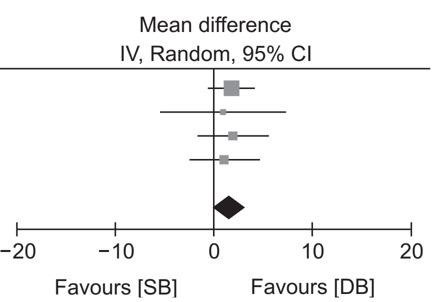

Fig. 2. Forest plot of Lysholm knee function scores (points) in both techniques. DB: double-bundle, SB: single-bundle, SD: standard deviation, CI: confidence interval.

the SB and DB groups. Of the total 215 patients, 108 patients were in the DB group and 107 patients were in the SB group. There were no significant differences in the Tegner activity scores between the SB and DB groups (WMD=0.17; 95% CI, –0.08 to 0.43; I^2=20%) (Fig. 3).

5. Side-to-Side Difference

Among the 4 studies, 3 studies (75%) reported on the side-to-side differences of the SB and DB groups. Of the total 134 patients, 68 patients were in the DB group and 66 patients were in the SB group. There were no significant differences in side-to-side difference between the SB and DB groups (WMD=–0.97; 95% CI, –2.41 to 0.47; I^2=78%) (Fig. 4).

6. IKDC Objective Grade

Among the 4 studies, 3 studies (75%) reported on IKDC objective grades in SB and DB groups. Of the total 134 patients, 68 patients were in the DB group and 66 patients were in the SB group. There were no significant differences in the IKDC objective grade between the SB and DB groups (RR=1.18; 95% CI, 1.00 to 1.39; I^2=0%) (Fig. 5).

Discussion

There are several controversial issues in the surgical treatment of PCL tears. In the present study, we reviewed RCTs comparing outcomes of SB PCLR versus DB PCLR. Although there is a previous meta-analysis on this topic[18], it only included 2 RCTs that

	DB			SB				Mean difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Li et al.[17]	6.8	1.2	24	6.2	0.9	22	14.7%	0.60 [−0.01, 1.21]
Wang et al.[15]	5.2	1.6	16	4.5	1.7	19	5.0%	0.70 [−0.39, 1.79]
Yoon et al.[16]	6	0.75	28	6	0.75	25	28.9%	0.00 [−0.40, 0.40]
Hou et al.[6]	4.3	0.6	40	4.2	0.6	41	51.4%	0.10 [−0.16, 0.36]
Total (95% CI)			**108**			**107**	**100.0%**	**0.17 [−0.08, 0.43]**

Heterogeneity: Tau^2=0.01, Chi^2=3.73, df=3 (p=0.29); I^2=20%
Test for overall effect: Z=1.37 (p=0.17)

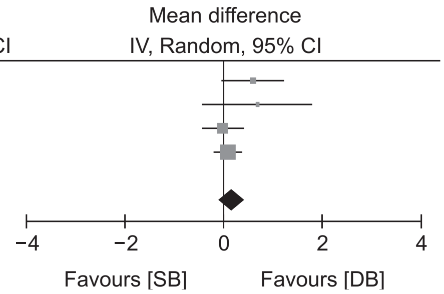

Fig. 3. Forest plot of Tegner activity scores (points) in both techniques. DB: double-bundle, SB: single-bundle, SD: standard deviation, CI: confidence interval.

	DB			SB				Mean difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Li et al.[17]	2.2	1.3	24	4.1	1.3	22	39.0%	−1.90 [−2.65, −1.15]
Wang et al.[15]	3.1	3	16	2.3	1.4	19	28.4%	0.80 [−0.80, 2.40]
Yoon et al.[16]	3.1	2.4	28	4.5	2.3	25	32.6%	−1.40 [−2.67, −0.13]
Total (95% CI)			**68**			**66**	**100.0%**	**−0.97 [−2.41, 0.47]**

Heterogeneity: Tau^2=1.24, Chi^2=8.97, df=2 (p=0.01); I^2=78%
Test for overall effect: Z=1.32 (p=0.19)

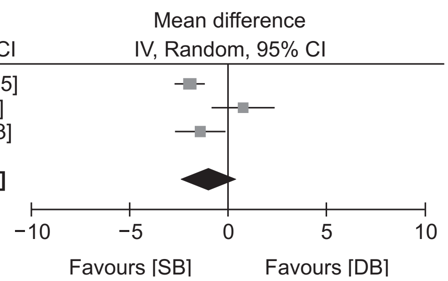

Fig. 4. Forest plot of side-to-side differences (mm) in both techniques. DB: double-bundle, SB: single-bundle, SD: standard deviation, CI: confidence interval.

	DB		SB			Risk ratio
Study or Subgroup	Events	Total	Events	Total	Weight	M-H, Random, 95% CI
Li et al.[17]	22	24	18	22	52.4%	1.12 [0.89, 1.41]
Wang et al.[15]	13	16	11	19	13.8%	1.40 [0.89, 2.20]
Yoon et al.[16]	24	28	18	25	33.8%	1.19 [0.89, 1.59]
Total (95% CI)		**68**		**66**	**100.0%**	**1.18 [1.00, 1.39]**
Total events	59		47			

Heterogeneity: Tau^2=0.00, Chi^2=0.84, df=2 (p=0.33); I^2=0%
Test for overall effect: Z=1.94 (p=0.05)

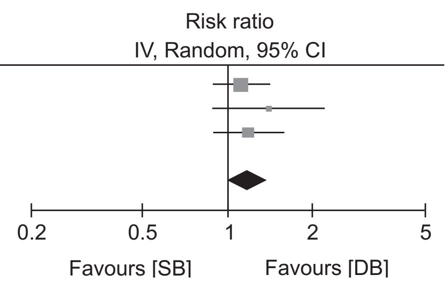

Fig. 5. Forest plot of International Knee Documentation Committee objective grades in both techniques. DB: double-bundle, SB: single-bundle, SD: standard deviation, CI: confidence interval.

assessed clinical parameters, such as the Lysholm knee function score and the Tegner activity score. Furthermore, the previous meta-analysis included all peer-reviewed studies published until April 2014. Thus, for more in-depth, evidence-based comparison of SB PCLR versus DB PCLR, we conducted a meta-analysis on this topic. Ultimately, 4 RCTs, including the recent study, were evaluated. The subjects included in the 4 RCTs did not have combined injuries to the anterior cruciate ligament and PLC. According to previous reports, the presence of a PLC injury would not be fully compensated by isolated PCLR for restoration of normal knee stability, so patients with PCL and PLC injuries were considered inappropriate to be included for analysis. In addition to Lysholm knee function scores and the Tegner activity scores, the present study included other clinical parameters such as side-to-side differences and the IKDC objective grades. Contrary to previous studies, our analysis showed no evidence of the superiority of DB PCLR in clinical outcomes assessed by the Lysholm knee function scores, Tegner activity scores, side-to-side differences, and IKDC objective grades. Thus, the results of this meta-analysis support our hypothesis that the two techniques would not show significant differences in all outcome measures.

In previous studies, many authors reported that DB PCLR would be more beneficial in restoring the intact knee function[9,19-21]. However, such studies were confined to *in vitro* studies, and there are no clinical studies demonstrating that DB PCLR is superior to SB PCLR. In addition, DB PCLR is not recommended as the preferred surgical procedure due to the longer operation time, technical difficulty, and larger trauma. Thus, based on clinical trials, the superiority between the two techniques in terms of clinical improvement remains inconclusive.

Despite the recent increase in research on the PCL, we observed there were still insufficient data on surgical techniques for PCLR in our previous study[22]. One of the key controversies surrounding the surgical techniques of PCLR is whether DB PCLR provides superior outcomes compared to SB PCLR. In several biomechanical studies, Race and Amis[20], Harner et al.[9], and Markolf et al.[7] showed statistically significant improvement in AP stability following DB PCLR compared to SB PCLR. Among the studies included in this meta-analysis, however, Wang et al.[15] reported that the significance in differences between SB PCLR versus DB PCLR was unclear and concluded that further large-scale studies are needed to examine long-term results. On the other hand, both Li et al.[17] and Yoon et al.[16] demonstrated that DB PCLR showed better results in posterior knee stability and IKDC objective grades. However, although posterior knee stability and IKDC objective grades were statistically significantly improved after DB PCLR in the two studies, it is inconclusive whether DB PCLR is definitely superior to SB PCLR in terms of clinical and functional improvement because there was no significant difference in the subjective scores such as Lysholm knee function scores and Tegner activity scores. Hou et al.[6] reported that the Lysholm knee function scores and Tegner activity scores both increased significantly in both DB and SB PCLR groups showing no statistically significant intergroup difference. Unlike other authors, however, Hou et al.[6] did not recommend DB PCLR as the preferred surgical procedure because of the longer operation time and increased trauma. Despite the discrepancies among studies, clinical outcome scores, such as the Lysholm knee function scores, the Tegner activity scores, side-to-side differences, and IKDC objective grades, were not significantly different between the SB and DB techniques in this meta-analysis. Although the improvement of Lysholm knee function score and IKDC objective score were more closely associated with DB PCLR since the p-value was 0.05, the CI of Lysholm knee function score includes 0 and that of IKDC objective score includes 1, failing to convey statistical significance. Therefore, it is controversial to conclude that DB PCLR would result in better clinical outcomes. In addition, although some authors advocated DB PCLR for achieving knee stability in several biomechanical studies, there was no published clinical evidence demonstrating the superiority of DB PCLR. This finding corresponds to the results of our study and further supports the outcomes of previous studies as well. To obtain more reliable evidence, further studies conducted in the environment where various independent factors that can impact the outcomes of PCLR are controlled are needed.

The clinical studies included in this meta-analysis compared clinical outcomes of SB and DB techniques for PCL injuries. According to the Jadad quality assessment scale, all clinical studies scored ≥2 points. Three or more points indicate a low risk of bias and thus a high quality study. Although one study[6] was of low quality based on the Jadad scale (2 points), it demonstrated that the cohort was divided randomly and the fate of all patients in the trial was well described. Thus, we determined that it was appropriate to be included in the analysis in addition to the other studies considered eligible for the meta-analysis according to the Jadad scale score. Furthermore, screening and data extraction were done by two independent, blind reviewers in the present study. Although several recent systematic reviews focused on SB and DB PCLRs, only one meta-analysis of clinical studies on this topic was reported. As mentioned previously, the study evaluated only two clinical parameters using 2 RCTs and included 8 retrospective cohort studies, increasing the risk of bias. Furthermore, the previous study's outcomes were evaluated at 12 months after surgery, whereas we evaluated clinical outcomes 24 months after surgery in this study. All of these are strengths of our study compared to the previous meta-analysis.

Despite its strengths, there are some limitations to the present study. First, a relatively small number of studies were included in this meta-analysis. The number of previously published RCTs related to the study topic was insufficient for accurate analysis. However, all clinical studies included in this meta-analysis were RCTs that had a low risk of bias. Although the number itself was small, we believed that the results of each study carry valuable clinical significance and therefore included in the analysis. Second, technical factors of surgery that may affect the outcomes following PCLR should have been controlled. However, it was practically difficult to take into account all those factors associated with SB or DB techniques as well as those associated with the TT or TI technique, open or arthroscopic surgery, the presence of remnant fibers, tensioning protocol, graft type, and fixation devices. Various factors could cause heterogeneity in this study. So, in an attempt to minimize the risk of bias, we included comparative studies conducted under the same protocol and used a random-effect model. Third, we did not assess the postoperative complications of PCLR. Fourth, we also did not evaluate the status of the remnant fibers in each study. In a previous study, remnant-preserving PCLR was associated with favorable clinical outcomes after PCLR[23,24]. Thus, these discrepancies should be controlled in future studies.

In conclusion, the present study demonstrates that both techniques for PCLR are associated with restoration of knee stability and improved knee function. However, which technique yields better improvement in clinical outcomes remains unclear. To verify and further corroborate our results, more larger-scale, high-quality RCTs are encouraged.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

References

1. Fanelli GC, Edson CJ. Posterior cruciate ligament injuries in trauma patients: part II. Arthroscopy. 1995;11:526-9.
2. Amis AA, Gupte CM, Bull AM, Edwards A. Anatomy of the posterior cruciate ligament and the meniscofemoral ligaments. Knee Surg Sports Traumatol Arthrosc. 2006;14:257-63.
3. Mauro CS, Sekiya JK, Stabile KJ, Haemmerle MJ, Harner CD. Double-bundle PCL and posterolateral corner reconstruction components are codominant. Clin Orthop Relat Res. 2008;466:2247-54.
4. Baker CL Jr, Norwood LA, Hughston JC. Acute combined posterior cruciate and posterolateral instability of the knee. Am J Sports Med. 1984;12:204-8.
5. Covey DC, Sapega AA, Sherman GM. Testing for isometry during reconstruction of the posterior cruciate ligament: anatomic and biomechanical considerations. Am J Sports Med. 1996;24:740-6.
6. Hou JH, Wu GY, Wang XS, Zhang YD. Single- and double-bundle posterior cruciate ligament reconstruction under arthroscopy: a prospective cohort study. Chin J Tissue Eng Res. 2015;19:3271-5.
7. Markolf KL, Feeley BT, Jackson SR, McAllister DR. Biomechanical studies of double-bundle posterior cruciate ligament reconstructions. J Bone Joint Surg Am. 2006;88:1788-94.
8. Markolf KL, Jackson SR, McAllister DR. Single- versus double-bundle posterior cruciate ligament reconstruction: effects of femoral tunnel separation. Am J Sports Med. 2010;38:1141-6.
9. Harner CD, Janaushek MA, Kanamori A, Yagi M, Vogrin TM, Woo SL. Biomechanical analysis of a double-bundle posterior cruciate ligament reconstruction. Am J Sports Med. 2000;28:144-51.
10. Whiddon DR, Zehms CT, Miller MD, Quinby JS, Montgomery SL, Sekiya JK. Double compared with single-bundle open inlay posterior cruciate ligament reconstruction in a cadaver model. J Bone Joint Surg Am. 2008;90:1820-9.
11. Bergfeld JA, Graham SM, Parker RD, Valdevit AD, Kambic HE. A biomechanical comparison of posterior cruciate ligament reconstructions using single- and double-bundle tibial inlay techniques. Am J Sports Med. 2005;33:976-81.
12. Apsingi S, Nguyen T, Bull AM, Unwin A, Deehan DJ, Amis AA. Control of laxity in knees with combined posterior cruciate ligament and posterolateral corner deficiency: comparison of single-bundle versus double-bundle posterior cruciate ligament reconstruction combined with modified Larson posterolateral corner reconstruction. Am J Sports Med. 2008;36:487-94.
13. Apsingi S, Nguyen T, Bull AM, Unwin A, Deehan DJ, Amis AA. The role of PCL reconstruction in knees with combined PCL and posterolateral corner deficiency. Knee Surg Sports

Traumatol Arthrosc. 2008;16:104-11.
14. Jadad AR, Moore RA, Carroll D, Jenkinson C, Reynolds DJ, Gavaghan DJ, McQuay HJ. Assessing the quality of reports of randomized clinical trials: is blinding necessary? Control Clin Trials. 1996;17:1-12.
15. Wang CJ, Weng LH, Hsu CC, Chan YS. Arthroscopic single- versus double-bundle posterior cruciate ligament reconstructions using hamstring autograft. Injury. 2004;35:1293-9.
16. Yoon KH, Bae DK, Song SJ, Cho HJ, Lee JH. A prospective randomized study comparing arthroscopic single-bundle and double-bundle posterior cruciate ligament reconstructions preserving remnant fibers. Am J Sports Med. 2011;39:474-80.
17. Li Y, Li J, Wang J, Gao S, Zhang Y. Comparison of single-bundle and double-bundle isolated posterior cruciate ligament reconstruction with allograft: a prospective, randomized study. Arthroscopy. 2014;30:695-700.
18. Zhao JX, Zhang LH, Mao Z, Zhang LC, Zhao Z, Su XY, Zhang LN, Gao Y, Sun Y, Tang PF. Outcome of posterior cruciate ligament reconstruction using the single- versus double bundle technique: a meta-analysis. J Int Med Res. 2015;43:149-60.
19. Mannor DA, Shearn JT, Grood ES, Noyes FR, Levy MS. Two-bundle posterior cruciate ligament reconstruction. An in vitro analysis of graft placement and tension. Am J Sports Med. 2000;28:833-45.
20. Race A, Amis AA. PCL reconstruction. In vitro biomechanical comparison of 'isometric' versus single and double-bundled 'anatomic' grafts. J Bone Joint Surg Br. 1998;80:173-9.
21. Shearn JT, Grood ES, Noyes FR, Levy MS. Two-bundle posterior cruciate ligament reconstruction: how bundle tension depends on femoral placement. J Bone Joint Surg Am. 2004;86:1262-70.
22. Lee DY, Kim DH, Park JS, Nam DC, Cho SH, Jeong JH, Hwang SC. Systematic review of cadaveric studies on anatomic posterior cruciate ligament reconstruction: the landmarks in anatomic posterior cruciate ligament reconstruction. Knee Surg Relat Res. 2014;26:191-8.
23. Lee SH, Jung YB, Lee HJ, Jung HJ, Kim SH. Remnant preservation is helpful to obtain good clinical results in posterior cruciate ligament reconstruction: comparison of clinical results of three techniques. Clin Orthop Surg. 2013;5:278-86.
24. Song JG, Kim HJ, Han JH, Bhandare NN, Shetty GM, Kang SB, Song YW, Nha KW. Clinical outcome of posterior cruciate ligament reconstruction with and without remnant preservation. Arthroscopy. 2015;31:1796-806.