Meta-analysis

Single-Bundle and Double-Bundle Posterior Cruciate Ligament Reconstructions: A Systematic Review and Meta-analysis of 441 Patients at a Minimum 2 Years' Follow-up

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Purpose: To perform a systematic review on the techniques and a meta-analysis on the functional and objective outcomes after single-bundle (SB) versus double-bundle (DB) posterior cruciate ligament (PCL) reconstructions. **Methods:** A systematic review of the techniques, as well as functional and objective outcomes of clinical studies comparing SB versus DB PCL reconstruction with a mean follow-up of at least 24 months and minimum level of evidence of III were performed. After review of the literature, a quality analysis of the studies (Detsky score) and a meta-analysis comparing raw mean differences in data between SB and DB PCL groups were performed. Clinical outcome measures included in the meta-analysis were functional outcomes (Lysholm, Tegner, and objective International Knee Documentation Committee [IKDC] scores) and objective measurements (arthrometer and stress radiographs). **Results:** The systematic search identified 11 studies (441 patients). Three studies were prospective randomized controlled trials and the other 8 studies were case-control studies. Two hundred thirty-two patients were treated with SB PCL reconstruction, whereas 209 were treated with DB PCL reconstruction. Only 4 studies satisfied the threshold for a satisfactory level of methodologic quality (>75%). There were no significant differences between SB and DB PCL reconstructions in postoperative Lysholm ($P = .6$, 95% confidence interval [CI], −0.98, 2.18) or Tegner scores ($P = .37$, 95% CI, −0.19, 0.92). DB PCL reconstruction provided significantly better objective posterior tibial translation stability than the SB technique using the Telos technique at 90° ($P = -.58$, 95% CI, −1.06, −0.10). **Conclusions:** Improved patient-reported outcomes and knee stability were achieved with both SB and DB PCL reconstruction surgery. DB PCL reconstruction provided significantly improved objective posterior tibial stability and objective IKDC scores when compared with SB PCL reconstruction in randomized clinical trials. No significant difference was found for the other patient-reported outcomes. **Level of Evidence:** Level III, systematic review and meta-analysis of Level II and III studies.

The understanding of the diagnosis and treatment options for posterior cruciate ligament (PCL) injuries has rapidly evolved in recent years, leading to advancements in surgical techniques and improved clinical outcomes. Historically, good to excellent outcomes were initially reported after nonoperative treatment of isolated PCL tears[1,2]; however, recent studies have shown declining clinical outcome scores and early osteoarthritis after complete isolated and combined PCL injuries treated nonoperatively.[3-5] These findings have prompted

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The investigation was performed at the Steadman Philippon Research Institute, Vail, Colorado.

The authors report the following potential conflicts of interest or sources of funding: R.F.L. is a consultant for and receives royalties from Arthrex, Ossur, and Smith & Nephew; institution provided support by Arthrex, Ossur, Siemens, and Smith & Nephew; receives grants from Health East, Norway, and a National Institutes of Health R-13 grant for biologics; patents (planned, pending, or issued) for Ossur and Smith & Nephew; royalties from Arthrex, Ossur, and Smith & Nephew. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

Received February 13, 2017; accepted June 28, 2017.

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0749-8063/17172/$36.00
http://dx.doi.org/10.1016/j.arthro.2017.06.049

surgeons to consider early operative intervention in symptomatic grade III (complete) tears.[6]

The PCL is composed of 2 main bundles, a larger anterolateral (ALB) and a smaller posteromedial bundle (PMB),[7-9] and functions as the primary restraint to posterior tibial translation of the knee.[10] Near-normal knee kinematics have been reported when the ALB is preserved and the PMB is sectioned, and therefore these data initially suggested that the ALB should be the focus of traditional single-bundle (SB) reconstruction.[11,12] However, Kennedy et al.[13] found similar results when the ALB was sectioned and the PMB was left intact, validating that both bundles have a codominant relationship and biomechanically showing that both bundles should be reconstructed. Recent biomechanical studies have revealed that SB PCL reconstructions fail to restore native knee kinematics whereas double-bundle (DB) PCL reconstructions restore knee kinematics to a near native state.[13,14]

The available literature comparing PCL reconstruction techniques is limited and highly heterogeneous with respect to indications, timing, and outcome assessment. Additionally, despite the aforementioned biomechanical studies showing that DB PCL reconstruction is superior in restoring knee kinematics to the native state, data on clinical outcomes comparing the 2 techniques remain limited. To improve recommendations for future care of PCL injuries and to promote further research, this study aimed to perform a systematic review of the techniques and a meta-analysis of the functional and objective outcomes after SB versus DB PCL reconstructions. Our hypothesis was that both SB and DB PCL reconstruction would result in improved patient outcomes after surgery, but DB PCL reconstruction would result in increased objective stability after surgery compared with SB PCL reconstruction.

Methods

Article Identification and Selection

This study was conducted in accordance with the 2009 Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) statement.[15] A systematic review of the literature regarding the existing evidence for the outcomes and complications of SB versus DB PCL reconstruction was performed using the Cochrane Database of Systematic Reviews, the Cochrane Central Register of Controlled Trials, PubMed (1980-2014), EMBASE (1980-2014), and MEDLINE (1980-2014). The queries were performed in July 2016. Systematic review registration was done in August 2016 using the

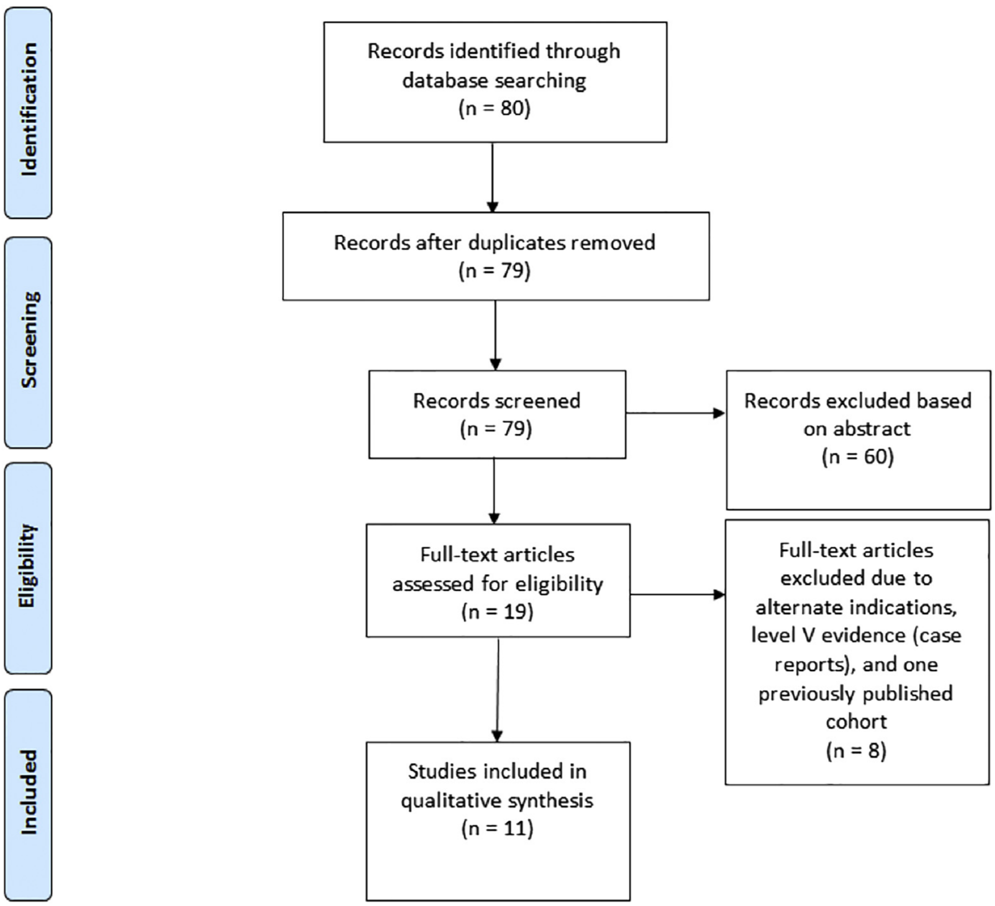

Fig 1. PRISMA flowchart of the study selection criteria.

Table 1. Exclusion Criteria or Reported Concomitant Pathology for Each Study

Study	Exclusion Criteria or Reported Concomitant Pathology
Li et al., 2014[29]	Exclusion criteria: • Patients with instability and/or combined multiple ligament injuries, fractures, or cartilage injuries
Yoon et al., 2011[22]	Exclusion criteria: • Patients with fractures, multiple ligament injuries, or cartilage injuries requiring operative treatment, such as microfracture and autologous chondrocyte implantation in the ipsilateral knee • Patients undergoing revision surgery or who had ligament injuries in the contralateral knee
Wang et al., 2004[30]	Concomitant injuries: • 2 femur fractures, 1 tibia fracture, 1 chondral injury, and 7 meniscal tears
Jain et al., 2016[28]	Exclusion criteria: • PCL avulsion fractures and patients with pre-existing degenerative changes on standing knee radiographs above grade II (Kellgren and Lawrence grading)
Deie et al., 2015[21]	Concomitant injuries: • Double bundle: 1 ACL reconstruction, 4 MCL reconstructions, and 4 PCL reconstructions in the single-bundle cases; and 1 ACL reconstruction, 2 MCL reconstructions, and 3 PCL reconstructions • Single-bundle: 2 MCL reconstructions and 2 PCL reconstructions and 10 double-bundle cases involving 1 MCL reconstruction and 2 PCL reconstructions. The follow-up ratio was 66.6% and 76.9% for single-bundle and double-bundle procedures, respectively
Fanelli et al., 2012[31]	Exclusion criteria: • Isolated posterior knee instability of greater than grade 2 (>10 mm) Concomitant pathology: • 5 lateral meniscus tears, 2 medial meniscus tears, and 1 chondral defect on the lateral femoral condyle
Kim et al., 2011[32]	Exclusion criteria: • Previous surgery on the affected knee, instability of the contralateral knee, isolated PCL injury without posterolateral corner insufficiency, significant cartilage lesion more than grade II based on the Outerbridge classification at the time of surgery, PCL avulsion fracture, multiple ligament injuries aside from PCL and posterolateral corner insufficiency, and varus thrust knee or varus malalignment
Shon et al., 2010[33]	Exclusion criteria: • Patients with posterolateral, posteromedial or anterior instability, and those suspected of having a multiligament injury
Kim et al., 2009[34]	Exclusion criteria: • Previous surgery on the affected knee, instability of the contralateral knee, isolated PCL injury without posterolateral corner insufficiency, significant cartilage lesion more than grade II based on Outerbridge classification at the time of surgery, PCL avulsion fracture, multiple-ligament injuries aside from PCL and posterolateral corner insufficiency, and varus thrust knee or varus malalignment
Hatayama et al., 2006[35]	Concomitant pathology: • Single bundle: Two 2-ligament injuries, four 3-ligament injuries, one dislocation • Double bundle: One 2-ligament injury, six 3-ligament injuries
Houe et al., 2004[23]	Exclusion criteria: • Chronic isolated unidirectional PCL instability after a straight sagittal trauma to the knee. Patients with objectively detectable posterolateral, posteromedial, or anterior instability, and thus suspected of having multiligament injuries

ACL, anterior cruciate ligament; MCL, medial collateral ligament; PCL, posterior cruciate ligament.

Table 2. Weighted Demographic Means of Patients Included in the Studies

Study	LOE	Study Design	Tech	Patients (Sex)	Mean Age	Follow-up (months)	Time From Injury to Surgery (months)	Outcome Scales
Level II								
Li et al., 2014[29]	II	RCT	SB	22 (15 M, 7 F)	25.1	28.7	7.5	KT-1000, Lysholm score, IKDC, Tegner score
			DB	24 (18 M, 6 F)	23.5	30.4	6	
Yoon et al., 2011[22]	II	RCT	SB	25 (20 M, 5 F)	28.5	31	37	Stress radiography, ROM, IKDC, Lysholm score, Tegner score
			DB	28 (25 M, 3 F)	27.4	33	35	
Wang et al., 2004[30]	II	RCT	SB	19 (14 M, 5 F)	29.4	41	8.5	KT-1000, Reverse Lachman test, Lysholm score, Tegner score, IKDC
			DB	16 (12 M, 4 F)	28.2	28.2	6.5	
Level III								
Jain et al., 2016[28]	III	Case-control	SB	22 M	26.4	28.2	3.4	Stress radiography, IKDC, Lysholm score, MRI
			DB	18 M	27.4	28.2	3.8	
Deie et al., 2015[21]	III	Case-control	SB	27 (18 M, 9 F)	34	150	N/R	Lysholm score, arthrometer
			DB	13 (11 M, 2 F)	32	150	N/R	
Fanelli et al., 2012[31]	III	Case-control	SB	45 (23/20)	N/R	N/R	N/R	KT-1000, stress radiography, Lysholm score, Tegner score
			DB	45	N/R	46.4	N/R	
Kim et al., 2011[32]	III	Case-control	SB	23 (19 M, 4 F)	30.7	N/R	11.2	Stress radiography, Lysholm score, IKDC
			DB	19 (15 M, 4 F)	31.3	44.5	12.7	
Shon et al., 2010[33]	III	Case-control	SB	14 (11 M, 3 F)	34	90.5	11.3	Stress radiography, Lysholm score, Tegner
			DB	16 (15 M, 1 F)	36	64	7.1	
Kim et al., 2009[34]	III	Case-control	SB	8 TT, 11 AI	TT: 32.4, AI: 31.9	36.3	9.4	Stress radiography, Lysholm score, ROM
			DB	10 (7 M, 3 F)	33.6	29.4	9.4	
Hatayama et al., 2006[35]	III	Case-control	SB	10 (7 M, 3 F)	29.6	24	N/R	Stress radiography, IKDC
			DB	10 (8 M, 2 F)	34.5	24	N/R	
Houe et al., 2004[23]	III	Comparative cohort	SB	6	31	35	>6	Lysholm score, Tegner score, Rolimeter
			DB	10	31	35	>6	

AI, arthroscopic inlay; DB, double bundle; F, female; IKDC, Internation Knee Documentation Committee; LOE, level of evidence; M, male; MRI, magnetic resonance imaging; N/R, not reported; RCT, randomized clinical trial; ROM, range of motion; SB, single bundle; Tech, technique; TT, transtibial.

PROSPERO International prospective register of systematic reviews.

The literature search strategy inclusion criteria were as follows: the techniques and the functional and objective outcomes of clinical studies comparing SB versus DB PCL reconstruction, mean follow-up of at least 24 months, and a Level I, II, or III evidence within the English literature. The keywords used were *posterior cruciate ligament*, *reconstruction*, *single-bundle*, and *double-bundle*. Cadaveric studies, animal studies, basic science articles, editorial articles, and surveys were excluded. Three investigators (J.C., M.E.C., and G.M.) independently reviewed the abstracts from all identified articles. Full-text articles were obtained for review if necessary to allow further assessment of inclusion and exclusion criteria. Additionally, all references from the included studies were reviewed and reconciled to verify that no relevant articles were missing from the systematic review.

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Literature Quality Evaluation

The risk of bias and methodological quality of the included studies was assessed using the modified Detsky Quality Assessment score, as previously described.[16] As this was initially developed for randomized trials, an extra item was added to assess the comparability of the cohorts on the basis of study design and/or analysis. The total possible score was 21. A study with a score >75% of the total was considered

Table 3. Baseline Characteristics and Modified Detsky Scores of Included Studies

Study	Level of Evidence	Study Design	Detsky Score
Li et al., 2014[29]	II	RCT	16
Yoon et al., 2011[22]	II	RCT	15
Wang et al., 2004[30]	II	RCT	11
Jain et al., 2016[28]	III	Cohort	11
Deie et al., 2015[21]	III	Cohort	9
Fanelli et al., 2012[31]	III	Cohort	11
Kim et al., 2011[32]	III	Cohort	13
Shon et al., 2010[33]	III	Cohort	12
Kim et al., 2009[34]	III	Cohort	11
Hatayama et al., 2006[35]	III	Case series	10
Houe et al., 2004[23]	III	Cohort	9

The mean Detsky score was 11.6 (range 9-16). Of the 11 included studies, only 1 had Detsky score greater than 15 and could therefore be classified as high quality.

RCT, randomized clinical trial.

high quality.[16,17] Any disagreements between the 2 reviewers (T.J.R., J.C.) were resolved through discussion.

Data Collection and Processing

The level of evidence of the studies was assigned according to the classification as specified by Wright et al.[18] Patient demographics, follow-up, surgical techniques, and objective and subjective outcomes were extracted and recorded. For continuous variables (e.g. age, timing, follow-up, outcome scores), the means, standard deviations (SDs), interquartile ranges, and ranges (if reported) were collected. Data were recorded into a custom spreadsheet using a modified information extraction table.[19]

Means and SDs were required to calculate weighted mean differences of continuous outcomes between SB and DB PCL reconstructions. For studies that only reported on ranges, the SD was imputed as range divided by 4 or interquartile range divided by 1.35.[20] For one study, which did not report the SD for arthrometer measurements,[21] the value of the highest SD among reporting studies was imputed. Studies that only reported median subjective scores[22,23] were not included in the synthesis calculations because these outcome scales are known to have ceiling effects postoperatively, and thus the median is not considered a good estimate of the mean.[24]

Quantitative Synthesis

Meta-analyses were conducted to compare SB versus DB PCL reconstructions with respect to functional outcomes (Lysholm, Tegner, and objective International Knee Documentation Committee [IKDC] scores) and objective measurements (posterior tibial translation [PTT] assessed by Telos 90 and arthrometer). Technique differences were expressed using weighted mean differences (WMDs) for continuous data and odds ratios for binary classification of IKDC objective measures (grade C or D vs IKDC grade A or B), both presented with 95% confidence intervals (CIs). Random-effects models, estimated using the DerSimonian Laird method, were chosen to combine studies because formal heterogeneity tests are known to have low statistical power when a few studies are combined.[25] Heterogeneity among studies was assessed using the I^2 metric and reported with 95% CIs. For quantitative syntheses involving multiple Level II and multiple Level III studies, subgroup meta-analyses were presented for each level of evidence group. The statistical software R was used for all analyses and to produce forest plot figures (R [R Foundation for Statistical Computing] with additional package metafor).[26,27]

Bias

Studies classified as level of evidence III can potentially be affected by selection and performance bias because of the lack of randomization, especially in populations characterized by heterogeneity of injuries. Selected studies were reviewed to ensure that authors minimized bias while recognizing the constraints present with such studies.

Results

Study Selection

The systematic search performed using the previously mentioned keywords identified 11 studies, after removing duplicates and applying exclusion criteria.[21-23,28-35] Three studies were prospective randomized controlled trials comparing SB PCL to DB PCL reconstructions (level of evidence II), and the other 8 studies were case-control studies (level of evidence III). Figure 1 shows the selection criteria of the studies found with our search. After review of all references from the included studies, no additional studies met inclusion criteria. Of note, Kim et al.[34] compared 3 different techniques (transtibial SB procedure; arthroscopic inlay SB procedure; and arthroscopic inlay DB procedure) and therefore were considered as 2 separate studies for the outcomes analyses. Exclusion criteria and concomitant pathology are detailed in Table 1.

Demographics

A total of 441 patients were included in this review. Two hundred thirty-three patients were treated with an SB PCL reconstruction, whereas 208 were treated with a DB PCL reconstruction (Table 2). The weighted mean age of all the enrolled patients was 29.8 years—29.9 years for SB PCL and 29.6 years for DB PCL reconstruction. The weighted mean follow-up was 60.8 months. The weighted mean time from injury to

Table 4. Detailed Surgical Technique Information for Double- Versus Single-Bundle PCL Reconstruction

	Graft Positioning	Graft Type (Diameter)	Graft Fixation	Graft Fixation Angle
Level II				
Li et al., 2014[29]	SB: Tibial: 1.5 cm distal to medial plateau, inferolateral to anatomic PCL tibial insertion Femoral: anterior/distal portion of AL footprint DB: Tibial: AL: superolateral corner, PM: inferomedial corner Femoral: AL: same as SB; PM: posterior, proximal portion of PM footprint	SB: Tibialis anterior allograft (10 mm) DB: Tibialis anterior allograft (AL: 6 mm, PM: 7 mm)	SB: Femoral: EndoButton; Tibial: bioabsorbable screw used for tibial fixation (10 mm) DB: Femoral: EndoButton; Tibial: bioabsorbable screw	N/R
Yoon et al., 2011[22]	SB: Tibial: 10 mm above the hamstring tendon insertion Femoral: distal portion of the remnant AL bundle, 7 mm from distal cartilage border DB: Tibial: same as SB Femoral: AL: same as SB except for 5 mm from distal cartilage border; PM: posterior, proximal to remnant PM fibers 10 mm from distal cartilage border	SB: Achilles allograft (10 mm) DB: Achilles allograft (AL: 6 mm, PM: 6 mm)	SB: 8-mm metal interference screw for tibial fixation. DB: 6.5-mm cancellous screw, a spiked washer or staples, and if necessary, bioabsorbable interference screws	N/R
Wang et al., 2004[30]	SB: Tibial: 4 cm below the medial joint line, 1-2 cm posterior to anterior tibial surface Femoral: 4-5 mm proximal to articular surface, centered between anterior and posterior articular margins of the MFC DB: Tibial: same as SB Femoral: Within PCL footprint on MFC, near anatomic AL, PM insertion sites	SB: Doubled or tripled semitendinosus/gracilis (NR) DB: Doubled or tripled semitendinosus/gracilis graft (NR)	SB: 25-mm bioabsorbable interference screw DB: 30-mm bioabsorbable interference screw	SB: 75° flexion DB: Larger semitendinosus graft tensioned at 90° flexion, smaller gracilis graft tensioned at 20° flexion

(continued)

Table 4. Continued

	Graft Positioning	Graft Type (Diameter)	Graft Fixation	Graft Fixation Angle
Level III				
Jain et al., 2016[28]	SB: Tibial: 8-10 mm distal to the articular margin Femoral: 15-18 mm below the tibial articular surface DB: Tibial: 15-18 mm below tibial articular surface Femoral: AL: 5-6 mm from articular margin; PM: 8-10 mm off articular margin	SB: Semitendinosus/gracilis autograft (NR) DB: Semitendinosus/gracilis autograft (NR)	SB: Bioabsorbable interference screw DB: Bioabsorbable interference screw	SB: 90° flexion DB: Femoral AL tensioning at 90° flexion; Femoral PM at 20°-30° flexion; Tibial tensioning at 90° flexion
Deie et al., 2015[21]	SB: Tibial: PCL footprint Femoral: 5 mm posterior to articular margin, 5 mm distal from the Blumensaat line DB: Tibial: PCL footprint Femoral: anatomic attachments of AL, PM bundles	SB: Hamstring autograft (NR) DB: Hamstring autograft (NR)	SB/DB: Double staples on anterior surface of tibia; Femoral: NR	N/R
Fanelli et al., 2012[31]	SB: Tibial: ~1 cm below tibial tubercle Femoral: footprint of anatomic PCL DB: Tibial: same as SB Femoral: AL: native AL footprint, PM: native PM footprint	SB: Achilles allograft (NR) DB: AL: Achilles allograft, PM: Tibialis anterior (NR)	SB/DB: Bioabsorbable interference screws	SB/DB: 70°-90° flexion
Kim et al., 2011[32]	SB: Tibial: 1 cm distal to tibial tuberosity, 15 mm distal from articular cartilage of medial plateau Femoral: Footprint of native PCL DB: Tibial: same as SB Femoral: AL: 2-3 mm posterior to articular margin, PM: 4-5 mm posterior to articular margin	SB: Achilles allograft (11 mm) DB: Posterior tibialis allograft (AL: 9 mm, PM: 7 mm)	SB: Bioabsorbable interference screw DB: Femoral: bioabsorbable interference screws; Tibial: suture washer	SB: 70° flexion DB: 90° flexion

(continued)

Table 4. Continued

	Graft Positioning	Graft Type (Diameter)	Graft Fixation	Graft Fixation Angle
Shon et al., 2010[33]	SB: Tibial: 7 mm proximal to articular cartilage margin of MFC Femoral: anatomic footprint of PCL DB: Tibial: same as SB Femoral: 9 mm proximal to the articular cartilage margin	SB: BTB (NR) DB: Achilles allograft (NR)	SB/DB: Bioabsorbable interference screw and staple	SB/DB: 90° flexion
Kim et al., 2009[34]	SB: Tibial: AL cortex of tibia Femoral: 2-3 mm proximal to articular surface DB: Tibial: same as SB with Achilles bone plug preparation Femoral: AL: same as SB, PM: 4-5 mm from articular surface	SB: Achilles allograft (NR) DB: Achilles allograft (11 mm)	SB: Bioabsorbable interference screws DB: Bioabsorbable interference screws and suture washer	SB/DB: Initial femoral fixation at 30°-45° flexion, followed by final tensioning at 90° flexion
Hatayma et al., 2006[35]	SB: NR DB: NR	SB: Hamstring autograft (9-10 mm) DB: Hamstring autograft (AL: 7-8 mm, PM: 6 mm)	SB/DB: Femoral: EndoButton; Tibial: spike staples	SB: 70° flexion DB: AL: 70° flexion, PM: 20-30° flexion
Houe et al., 2004[23]	SB: Tibial: 2 cm distal from tibial plateau and 1 cm lateral from deepest part of posterior groove of proximal tibia Femoral: 5 mm posterior from the MFC cartilage rim DB: Tibial: same as SB Femoral: AL: same site on MFC as SB, PM: 5-6 mm posterior to edge of AL tunnel	SB: patella BTB (15 mm proximal, 20 mm distal) DB: hamstring autografts (AL: 8 mm, PM: 8 mm)	SB: 8- × 20-mm interference screw DB: 10- × 30-mm interference screws	SB/DB: 70° flexion

AL, anterolateral; BTB, bone-tendon-bone; DB, double bundle; MFC, medial femoral condyle; NR, not reported; PCL, posterior cruciate ligament; PM, posteromedial; SB, single bundle.

Table 5. Detailed Rehabilitation Data for the Entire Cohort

	Brace	Weeks 1-5	Weeks 6-10	Week 10+
Level II				
Li et al., 2014[29]	Long leg brace	NWB × 6 weeks; mild knee flexion starting 1 week post-op	FWB at 8 weeks	Continue brace until week 12; RTS at week 52
Yoon et al., 2011[22]	Long leg splint	Long leg splint and NWB × 3 weeks; goal of 90° flexion by week 6	Goal of 135° flexion by week 12	Continue brace until week 12; RTS at week 52
Wang et al., 2004[30]	Knee brace	Knee brace × 6 weeks; no hamstring activation × 6 weeks; limited ROM exercises	FWB and full ROM after 6 weeks	Earliest RTS at 24 weeks
Level III				
Jain et al., 2016[28]	Long knee brace	Brace locked in extension with quadriceps activation at POD 2; NWB for 3 weeks, PWB after 3 weeks	FWB by week 7-8; knee brace removed and flexion to 90° after 6 weeks	Progress to 120° of flexion by week 12; full ROM encouraged thereafter
Deie et al., 2015[21]	Knee brace followed by PCL brace	Knee brace for 2 weeks then PCL brace.	NR	PCL brace removed at 18 weeks, patients allowed to start jogging. RTS at weeks 30-36
Fanelli et al., 2012[31]	Knee brace	NWB ×5 weeks, brace locked in extension	Progressive ROM increase and 20% WB weeks 6-10	D/C brace; strength training, agility drills, RTS by week 52
Kim et al., 2011[32]	Hinged knee brace	Hinged knee brace in extension till week 5; protected ROM from weeks 2-4; toe-touch WB	Unlock knee brace, continue to wear till week 9. Increase flexion to 110°, PWB; closed-chain exercises at weeks 6-8	At week 10, stationary bike, stair stepping, single-leg stances initiated; full flexion or squatting prohibited until week 18; at week 24, single-leg hop test administered, if 90% allowed to return to activity
Shon et al., 2010[33]	Long leg cast followed by knee brace	After 3 weeks, cast removed and brace applied in full extension; knee flexion and partial WB allowed week 3-4	NR	At 12 weeks brace removed and full WB permitted; full return to activity at 24 weeks
Kim et al., 2009[34]	Leg splint in full extension followed by knee brace	Leg splint in full extension for 2 weeks; after 2 weeks splint removed and knee brace fitted; motion to 90° flexion permitted	Closed-chain exercises allowed at 6 weeks	Low-impact sports 24 months after surgery
Hatayama et al., 2006[35]	NR	Partial WB 2 weeks after surgery; full WB at 4 weeks	ROM progress from 90° at 4 weeks to 120° at 8 weeks	NR
Houe et al., 2004[23]	Knee brace	Knee brace fixed in extension for 2 weeks, WBAT	From week 2 to 20, PCL brace was used with free ROM, gradually removed after 8 weeks	NR

D/C, discontinue; FWB, full weight bearing; NR, not reported, NWB, non—weight bearing; PCL, posterior cruciate ligament; POD, postoperative day; post-op, postoperation; PWB, partial weight bearing; ROM, range of motion; RTS, return to sport; WB, weight bearing; WBAT, weight bearing as tolerated.

surgery was 14.5 months (range, 3.4-37 months) and was reported in 7 studies (Table 2).

Literature Quality Assessment

The methodological quality, as determined by the modified Detsky score, is shown in Table 3. The mean Detsky score was 11.6 (range 9-16). Of the 11 included studies, 4 satisfied the threshold for a satisfactory level of methodological quality (>75%) and only 1 had a Detsky score greater than 15 and could therefore be classified as high quality.

Surgical Techniques

There was relative heterogeneity with regard to graft choice, size, and positioning in the 11 SB and DB PCL reconstruction techniques. Detailed information regarding the described reconstruction techniques is reported in Table 4.

Bracing and Rehabilitation

All 11 studies used postoperative brace for their patients and employed the same rehabilitation protocol after both SB and DB PCL reconstruction. There was significant

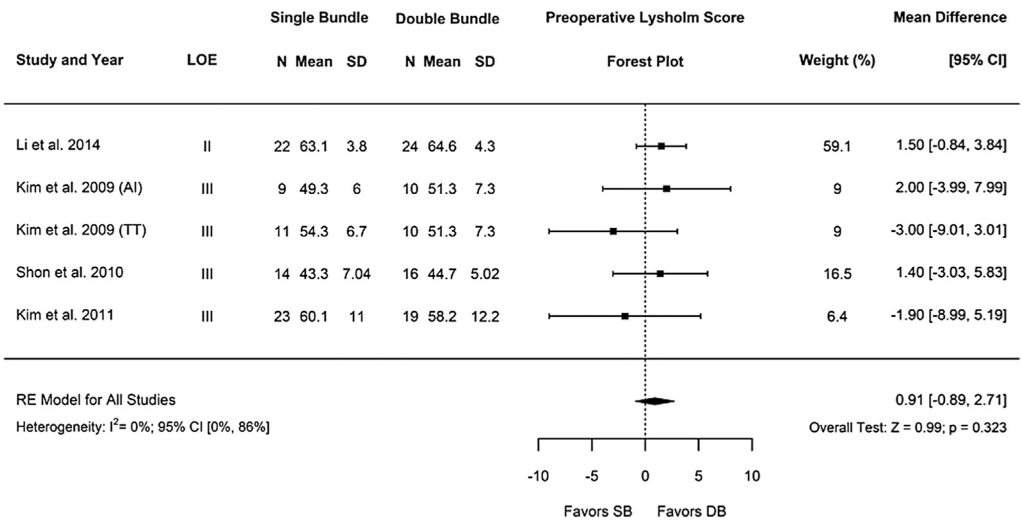

Fig 2. Forest plot for preoperative Lysholm scores before a single-bundle (SB) or double-bundle (DB) posterior cruciate ligament (PCL) reconstruction. Squares represent mean DB Lysholm minus mean SB Lysholm for each study.

heterogeneity in the type of bracing and postoperative rehabilitation between the studies. For further detail, see Table 5.

Patient-Reported Outcomes

There were no significant differences in either the Lysholm (WMD = 0.91, 95% CI, −0.89, 2.71; P = .323) or Tegner (WMD = 0.08, 95% CI, −0.31, 0.48; P = .686) scores at the preoperative time point between the SB PCL and the DB PCL reconstruction groups (Fig 2).

Postoperative Lysholm scores were reported in 9 studies, and 4 studies reported postoperative Tegner Scores.[22,23,29,33] No significant difference was found between the SB and DB PCL groups with respect to Lysholm (WMD = 0.60, 95% CI, −0.98, 2.18; P = .457) or Tegner scores (WMD = 0.37, 95% CI, −0.19, 0.92; P = .199) (Figs 3 and 4).

Objective IKDC Evaluation

Inferior results as defined by an IKDC grade C or D were significantly less common in the DB PCL group when evaluating Level II studies only (log odds ratio = 0.96, 95% CI, 0.06, 1.85; P = .036). A significant difference between SB and DB PCL reconstruction patients was not observed when

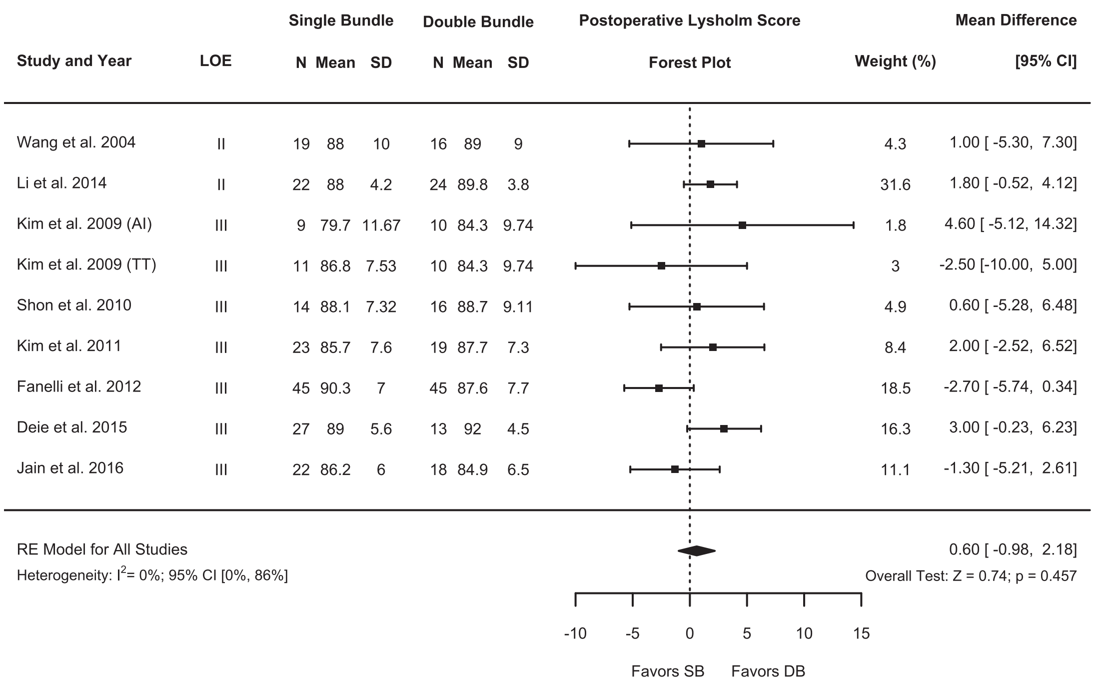

Fig 3. Forest plot for Lysholm score of the knee after single-bundle (SB) or double-bundle (DB) posterior cruciate ligament (PCL) reconstruction. Squares represent mean DB Lysholm minus mean SB Lysholm for each study.

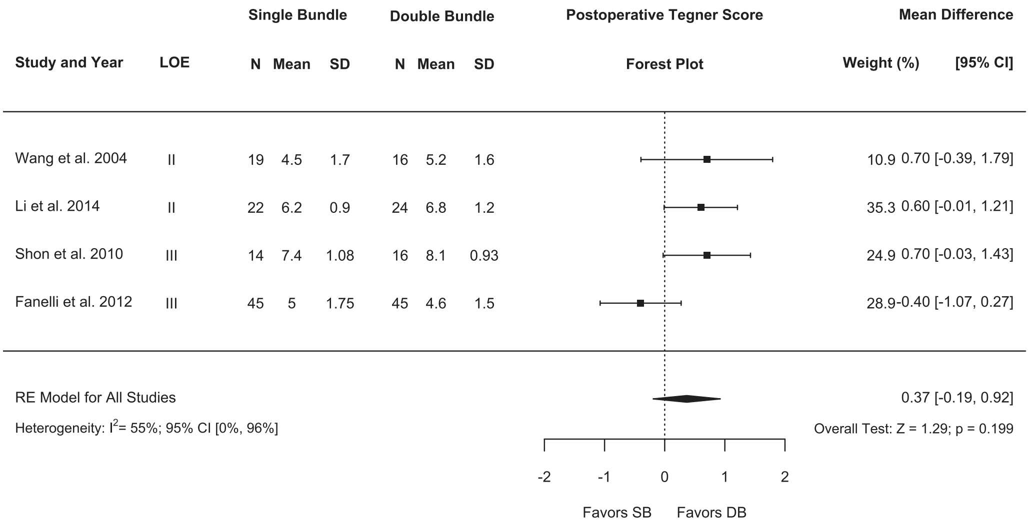

Fig 4. Forest plot for Tegner activity scale score of the knee after single-bundle (SB) or double-bundle (DB) posterior cruciate ligament (PCL) reconstruction. Squares represent mean DB Tegner minus mean SB Tegner for each study.

simultaneously analyzing all 6 studies reporting IKDC objective measures (Fig 5).

Objective Posterior Laxity Evaluation

All 11 studies reported on postoperative posterior stress evaluation, using either the arthrometer, Telos at 30° and 90°, kneeling stress radiographs or the Rolimeter technique. Preoperative PTT was not significantly different in the DB reconstruction group than in the SB reconstruction group ($P = .249$). Seven studies[22,31-35] reported on postoperative Telos PTT side-to-side differences at 90° for both SB and DB PCL reconstructions. Meta-analysis revealed that postoperative side-to-side difference in posterior laxity as measured with the Telos at 90° was significantly lower for the DB reconstruction group (WMD = −0.51, 95% CI, −1.06, −0.10; $P = .019$) (Fig 6). No significant group difference was found when comparing postoperative KT-1000 arthrometer side-to-side differences (WMD = −0.36, 95% CI, −1.47, 0.74; $P = .514$) (Fig 7).

Complications

Five studies reported on complications after surgery.[22,29,30,32,33] Limited range of motion was reported in 2 patients with SB PCL reconstruction (1%) and in 4 with DB PCL (2%). Donor site pain was

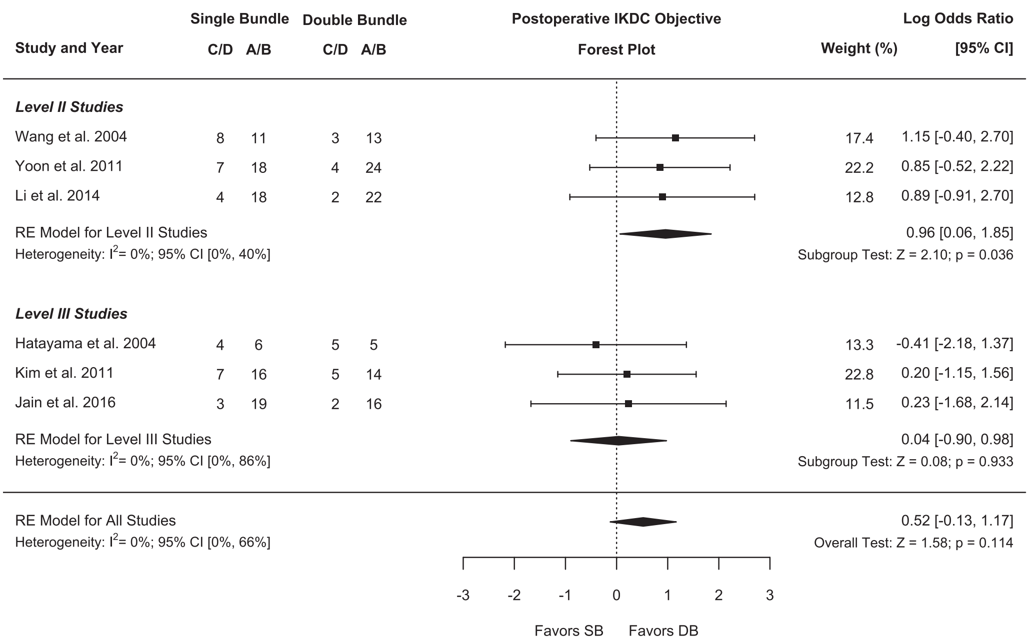

Fig 5. Forest plot of postoperative objective IKDC scores. Squares represent the log odds ratio for the risk of grade C or D objective IKDC score for single-bundle (SB) relative to double-bundle (DB) posterior cruciate ligament (PCL) reconstruction.

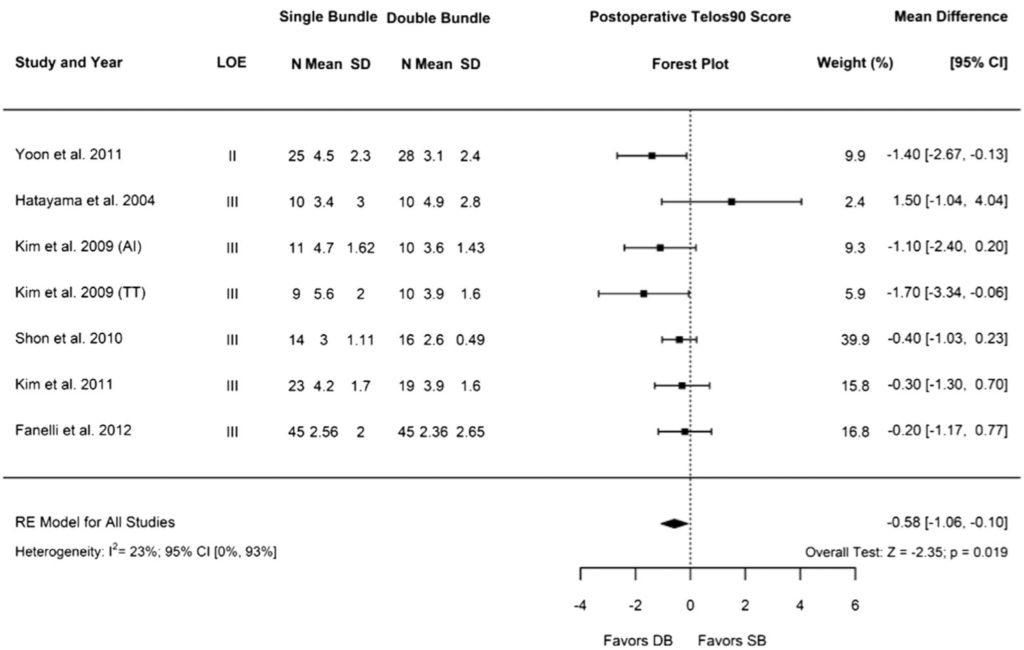

Fig 6. Forest plot showing outcomes of posterior tibial translation laxity using Telos 90° between single-bundle (SB) and double-bundle (DB) posterior cruciate ligament (PCL) reconstruction. Squares represent mean DB posterior translation laxity minus mean SB posterior translation laxity for each study.

reported in 2 patients with SB PCL[30] (1%) and in 2 with DB PCL reconstruction (1%); pain around the staples was reported in 2 patients[33]; 1 patient had reflex sympathetic dystrophy in the SB group[30]; and 1 had acute infection in the DB PCL group.[30]

Discussion

The most important finding of this study was that surgical treatment of PCL injuries improved patient functional outcomes at minimum 24 months' follow-up. Both the SB and DB PCL procedures resulted in a similar improvement in patient-reported outcomes; however, when subanalyzing prospective randomized clinical trials, objective IKDC scores after DB PCL reconstruction revealed superior results. Furthermore, DB PCL reconstruction significantly improved objective posterior tibial translation knee stability overall.

For both the SB and DB PCL procedures, the majority of the studies used an arthroscopic transtibial procedure.[21,22,29-32,34] SB PCL grafts were most commonly fixed at a minimum of 70° of knee flexion. DB PCL grafts were most commonly fixed at 70° to 90° of knee flexion for the ALB graft and at 20° to 30° of knee flexion for the PMB graft. The most commonly used graft in SB PCL reconstruction was an Achilles allograft.[21,28,30,35] For DB PCL reconstructions, the most commonly used graft was an Achilles allograft with a diameter ranging from 6 to 9 mm for ALB grafts,

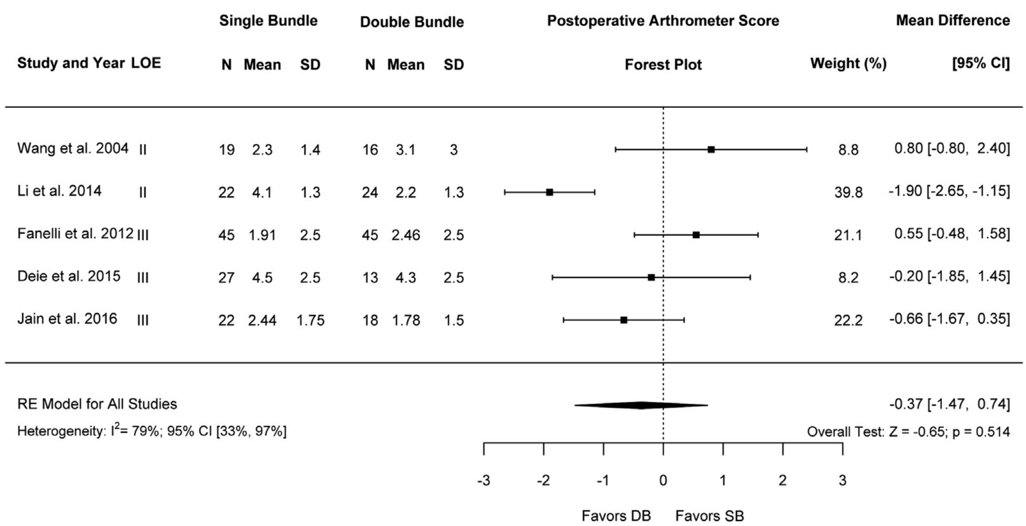

Fig 7. Forest plot of postoperative arthrometer data. Squares represent mean DB arthrometer measurement minus mean SB arthrometer measurement for each study.

and 6 to 7 mm for PMB grafts. Graft fixation was most commonly achieved with a bioabsorbable screw. Data regarding the effect of graft choice for PCL reconstruction on outcomes remains sparse and needs to be investigated further. However, a recent study comparing SB PCL reconstructions with bone-tendon-bone versus semitendinosus plus gracilis tendons found no difference in Lysholm or stress radiographs side-to-side differences at a minimum of 1-year follow-up.[36] Furthermore, another recent study showed that an Achilles allograft may be a superior graft choice because it does not alter the biomechanics of the quadriceps, which plays a synergistic role with the PCL in resisting posterior tibial translation.[37] A biomechanical study of a DB PCL reconstruction using an 11-mm Achilles allograft for the ALB and a 7-mm tibialis anterior allograft for the PMB was reported to restore the knee kinematics to near intact state.[14,38]

Spiridonov et al. suggested that minor variations in technique may lead to improved clinical outcomes after DB PCL reconstruction.[39] In this regard, the use of 2 different fixation angles during tibial graft fixation (ALB at 90° and PMB at full extension) has been validated to diminish graft loading, which would avoid graft attenuation or, ultimately, failure over time.[38,40] The fact that several of these studies fixed their single or PMB grafts at nonoptimal fixation angles validated on robotic biomechanical studies could somewhat explain their inferior objective outcomes after a DB PCL reconstruction. In addition, the use of dynamic force bracing has also been reported to contribute to a more physiologic loading, rather than a sole static force, compared with a static-force PCL knee brace on a PCL-reconstructed knee, which would protect a PCL reconstruction graft(s).[41] The dynamic-force braces have been reported to produce significantly greater forces at higher flexion angles, which would protect and unload the PCL graft where it is maximally loaded in vivo, and therefore their use should be advocated and universalized to make technique outcome comparisons more valid.[41] Finally, to objectively quantify PCL reconstructions, PCL stress radiography with either the kneeling or Telos technique has been reported to yield superior objective results to both arthrometer and clinical posterior drawer testing for objectively determining the PCL or PCL graft status.[42] When different stress methods were compared, Jung et al. suggested that although kneeling indicates a greater rotational error than Telos, it seems to be a reliable alternative for quantifying posterior tibial displacement in a more simplistic and rapid manner in a clinical setting.[43]

All studies reported improved postoperative Lysholm scores[22,23,28,29,32-35]; however, only 6 studies[22,23,29,32-34] reported both preoperative and postoperative outcomes scores, making a more comprehensive analysis difficult.[22,30,32-34] The 6 studies with pre- and postoperative outcome data reported increased Lysholm scores from pre- to postoperative status but failed to find a significant difference between SB and DB PCL reconstruction.[22,30,32-34] This finding suggests that although the recent literature has highlighted that the DB PCL reconstruction is biomechanically superior,[14] from a patient outcomes standpoint, clinically significant differences were not detected, likely because of the lack of power to reveal differences as well as the limited follow-up period.

All studies reviewed reported the side-to-side difference in PTT in the SB and DB PCL groups; however, the methods reported were not always comparable. When meta-analyzed for PTT (the most consistent reported method was Telos 90°), the data favored DB reconstruction procedures when pooling 7 studies reporting on the Telos at 90°. Postoperative improvement in Telos at 90° was greater for DB PCL patients in 4 studies,[22,32-34] greater for SB PCL in 1 study, and no significant difference in 2 studies. To objectively quantify PCL status, PCL stress radiography has been reported to be superior to both the arthrometer and clinical posterior drawer testing.[42] When different stress methods were compared, Jung et al. suggested that although kneeling indicates a greater rotational error than Telos, it seems to be a reliable alternative for quantifying posterior tibial displacement in a more simple and fast way.[43]

Limitations

The authors acknowledge some limitations to the present study. First, there was heterogeneity in the reporting of subjective and objective outcomes, which makes a true comparison amongst studies somewhat challenging. Because not every study reported on both pre- and postoperative objective outcomes, the differences could not be calculated, and consequently only the postoperative side-to-side differences were taken into account for the meta-analysis. Furthermore, surgeon-specific indications for performing an SB or DB PCL reconstruction may have affected the results in the included studies. Additionally, only 4 of the 11 studies reached a satisfactory level of methodological quality, with only 1 study being regarded as high-quality study. This further emphasizes the need for well-designed randomized clinical trials. Finally, some of the included studies included concomitant pathology and/or procedures, which may have altered the outcomes. As with all systematic reviews, it is possible that relevant articles or patient populations were not identified with our search criteria.

Conclusion

Improved patient-reported outcomes and knee stability were achieved with both SB and DB PCL reconstruction surgery. DB PCL reconstruction provided significantly improved objective posterior tibial stability and objective IKDC scores when compared with SB PCL reconstruction in randomized clinical trials. No significant difference was found for the other patient-reported outcomes.

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