

RESEARCH ARTICLE

Proprioception in patients with posterior cruciate ligament tears: A meta-analysis comparison of reconstructed and contralateral normal knees

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Abstract

Posterior cruciate ligament (PCL) reconstruction for patients with PCL insufficiency has been associated with postoperative improvements in proprioceptive function due to mechanoreceptor regeneration. However, it is unclear whether reconstructed PCL or contralateral normal knees have better proprioceptive function outcomes. This meta-analysis was designed to compare the proprioceptive function of reconstructed PCL or contralateral normal knees in patients with PCL insufficiency. All studies that compared proprioceptive function, as assessed with threshold to detect passive movement (TTDPM) or joint position sense (JPS) in PCL reconstructed or contralateral normal knees were included. JPS was calculated by reproducing passive positioning (RPP). Five studies met the inclusion/exclusion criteria for the meta-analysis. The proprioceptive function, defined as TTDPM (95% CI: 0.25 to 0.51°; $P < 0.00001$) and RPP (95% CI: 0.19 to 0.45°; $P < 0.00001$), was significantly different between the reconstructed PCL and contralateral normal knees. The mean difference in angle of error between the reconstructed PCL and contralateral normal knees was 0.06° greater in TTDPM than by RPP. In addition, results from subgroup analyses, based on the starting angles and the moving directions of the knee, that evaluated TTDPM at 15° flexion to 45° extension, TTDPM at 45° flexion to 110° flexion, RPP in flexion, and RPP in extension demonstrated that mean angles of error were significantly greater, by 0.38° ($P = 0.0001$), 0.36° ($P = 0.02$), 0.36° ($P < 0.00001$), and 0.23° ($P = 0.04$), respectively, in reconstructed PCL than in contralateral normal knees. The proprioceptive function of PCL reconstructed knees was decreased, compared with contralateral normal knees, as determined by both TTDPM and RPP. In addition, the amount of loss of proprioception was greater in TTDPM than in RPP, even with minute differences. Results from subgroup analysis, that evaluated the mean angles of error in moving directions through RPP, suggested that the moving direction of flexion has a significantly greater mean for angles of error than the moving direction of extension. Although the level of differences between various parameters were statistically significant, further studies are needed to

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determine whether the small differences ($>1^\circ$) of the loss of proprioception are clinically relevant.

Introduction

Proprioception includes the ability to detect passive movement (kinaesthesia) and the awareness of joint position (joint position sense) as well as the cumulative neural input to the central nervous system from mechanoreceptors, which consist of Pacinian corpuscles and Ruffini corpuscles. Pacinian corpuscles are stimulated during rapid changes in velocity and direction, whereas Ruffini corpuscles are slow-adapting and related to the joint position registration.[1–3] Injuries to the posterior cruciate ligament (PCL) may lead to impaired proprioceptive function, deterioration of position sense, and cartilage damage, and are associated with subsequently degenerative changes in long-term follow-up¹. Therefore, PCL reconstruction for patients with PCL insufficiency is associated with proprioceptive function recovery through mechanoreceptor regeneration, with considerable afferent functions.[4,5] Although many studies on proprioception and mechanoreceptors of the anterior cruciate ligament (ACL) have been conducted,[6,7] few studies have assessed the PCL, and many results have been inconclusive because of the lower prevalence of PCL tears compared with ACL tears.[8,9] In addition, no systematic reviews or meta-analyses on this subject have been published.

Therefore, this meta-analysis compared the proprioceptive function of reconstructed PCL or contralateral normal knees in patients with PCL insufficiency by evaluating the threshold to detect passive movement (TTDPM) or reproducing passive positioning (RPP). We hypothesized that proprioceptive function would decrease more in reconstructed PCL than in contralateral normal knees.

Materials and methods

This meta-analysis was conducted according to the guidelines of the preferred reporting items for systematic reviews and meta-analysis (PRISMA) statement ([S1 PRISMA Checklist](#)).

Data and literature sources

This study followed the Cochrane Review Methods. Multiple comprehensive databases, including MEDLINE (January 1, 1976 to Dec 31, 2016), EMBASE (January 1, 1985 to Dec 31, 2016), Web of Science (January 1, 1980 to Dec 31, 2016), SCOPUS (January 1, 1980 to Dec 31, 2016), and the Cochrane Library (January 1, 1987 to Dec 31, 2016) were searched for studies that compared proprioceptive function as assessed with TTDPM or RPP between reconstructed PCL or contralateral normal knees. There were no restrictions on language. Search terms used in the title, abstract, MeSH, and keywords fields included ('posterior cruciate ligament' [Mesh] OR 'PCL' [tiab]) AND 'proprioception' [tiab] OR 'threshold to detect passive movement' [tiab] OR 'reproducing passive positioning' [tiab]). After the initial electronic search, relevant articles and their bibliographies were manually searched.

Study selection

From the title and abstract, two reviewers independently selected the relevant studies for full review. The full text copy of the article was reviewed if the abstract did not provide enough data to make a decision. Studies were included in the meta-analysis if they (1) assessed human

knees with a PCL tear followed by PCL reconstruction; (2) included study with level of evidence 1 to 3; (3) reported retrospective or prospective comparison of proprioceptive function between reconstructed PCL or contralateral normal knees; (4) included data on at least one of the following two parameters: TTDP and/or RPP. For the TTDP test, patients were asked to press a switch immediately on perception of sensation of motion of the knee during passive flexion or extension from a specific starting angle of the knee joint. The RPP test was assessed by passively moving the knee joint to a predetermined target angle. The patients were educated to remember that target position, and the knee was then returned to the starting positions. The patients were asked to press a switch when he or she felt that the angle of the knee joint had reached the target angle. Moreover, measurement of the TTDP and RPP used a similar dynamometer apparatus in the included studies; (5) fully reported the number of subjects in each group (PCL reconstructed and contralateral normal knees) and the means and standard deviations for the two parameters; and (6) used adequate statistical methods to compare these parameters between groups. Studies were excluded if (1) they dealt with human knees with PCL tear without reconstruction or before reconstruction, (2) they did the use of techniques to measure proprioception other than TTDP and/or RPP, (3) they did include missing or inadequate outcome data, such as standard deviation or range of values, or (4) they did include case series, expert opinions, reviews, commentaries, or editorials.

Data extraction

Two reviewers independently recorded data from each study using a predefined data extraction form. Disagreement between the reviewers was resolved by consensus or by discussion with a third investigator when consensus could not be reached. Recorded variables included those associated with proprioceptive function between reconstructed PCL or contralateral normal knees. Sample size and the means and standard deviations of TTDP and RPP in each group were also recorded. If a study presented different starting angles and moving directions of the knee for the TTDP and RPP, data from different starting angles and moving directions were analyzed as separate studies. If these variables were not included in the articles, the study authors were contacted by email to retrieve further information. Authors of one study offered measured parameters such as means and standard deviations in response to our requests.

Methodological quality assessment

Two reviewers independently assessed the methodological quality of the studies. For the Newcastle-Ottawa Scale,^[10] as recommended by the Cochrane Non-Randomized Studies Methods Working Group, we assessed the studies based on three criteria: selection of the study groups, comparability of the groups, and ascertainment of either the exposure or the outcome of interest for case-control and cohort studies. Studies with scores ≥ 6 points were defined as high quality. Any unresolved disagreements between reviewers were resolved by consensus or by consultation with a third investigator. Publication bias could not be assessed in these trials. Tests for funnel plot asymmetry are typically performed only when at least ten studies are included in the meta-analysis.^[11] As our analysis included only five studies, tests for asymmetry were not performed because these tests would not be able to differentiate asymmetry from chance.

Data synthesis and analysis

The main outcomes of the meta-analysis were the standardized mean differences (SMDs) in TTDP and RPP between reconstructed PCL and contralateral normal knees. For all comparisons, SMDs and 95% confidence intervals (CIs) were calculated for continuous outcomes.

Heterogeneity was determined by estimating the proportion of between-study inconsistencies due to actual differences between studies, rather than differences due to random error or chance, using the I^2 statistic, with values of 25%, 50%, and 75% considered as low, moderate, and high heterogeneity, respectively. All statistical analyses were performed with RevMan version 5.2 software. Subgroup analysis based on the starting angles and the moving directions of the knee was performed for the TTDPM and RPP in an attempt to explore a potential source of heterogeneity. In addition, starting angles and the moving directions of the knee have been considered in TTDPM and RPP measurements because different muscles, tendons, and ligaments can be most active and thus different amounts of mechanoreceptors can be active in particular directions even though TTDPM tests appear to be more consistent than JPS tests due to its relative simplicity. As a result, two subgroups were created in each group: 15° flexion to 45° extension and 45° flexion to 110° flexion for the TTDPM/ flexion and extension for the RPP. Moreover, sensitivity analysis was performed by excluding one of the eligible studies at a time; 2 studies with retrospective data were included. Pooling of data was feasible for only two outcomes of interest, i.e. TTDPM (15° flexion to 45° extension) and RPP (flexion).

Results

Study identification

Details on study identification, inclusion, and exclusion are summarized in [Fig 1](#). An electronic search yielded 899 studies in PubMed (MEDLINE), 800 in EMBASE, 210 in Web of science, 821 in SCOPUS, and 22 in the Cochrane Library. Four additional publications were identified through manual searching. After removing 890 duplicates, 1866 studies remained; of these, 1855 were excluded based on abstract and full-text article review, and an additional six studies were excluded because they had unusable information or made inappropriate group comparisons. This eventually resulted in five studies that were included in the meta-analysis.[\[12–16\]](#)

Study characteristics and patient populations

The five studies we examined included 241 subjects with reconstructed PCLs and contralateral normal knees that underwent proprioceptive function by TTDPM or RPP. Three studies compared prospectively measured parameters, whereas the other two studies compared parameters measured by retrospective chart review. Three studies compared both TTDPM and RPP, one compared TTDPM alone, and one compared RPP alone. Of the 4 studies that compared TTDPM, one compared TTDPM at a knee angle of both 15° and 45°, one compared TTDPM at a knee angle of both 20° and 45°, and two compared TTDPM at a knee angle of both 45° and 110°. Of the 4 studies that compared RPP, one compared RPP at a knee angle of both 15° and 45°, one compared RPP at a knee angle of both 0° and 90°, one compared RPP at a knee angle of both 45° and 110°, and one compared RPP at a knee angle of 90° ([Table 1](#)).

Methodological quality assessment

The quality of the five studies included in the meta-analysis is summarized in [Table 1](#). The non-RCTs (three PCSs and two RCSs) were of high quality (Newcastle-Ottawa Scale > 6).

Threshold to detect passive movement (TTDPM)

Of the five studies, four compared TTDPM of reconstructed PCLs and contralateral normal knees, and included 484 subjects that had TTDPM performed in reconstructed PCL knees and 484 in contralateral normal knees. The pooled data showed that the mean TTDPM was 0.38°

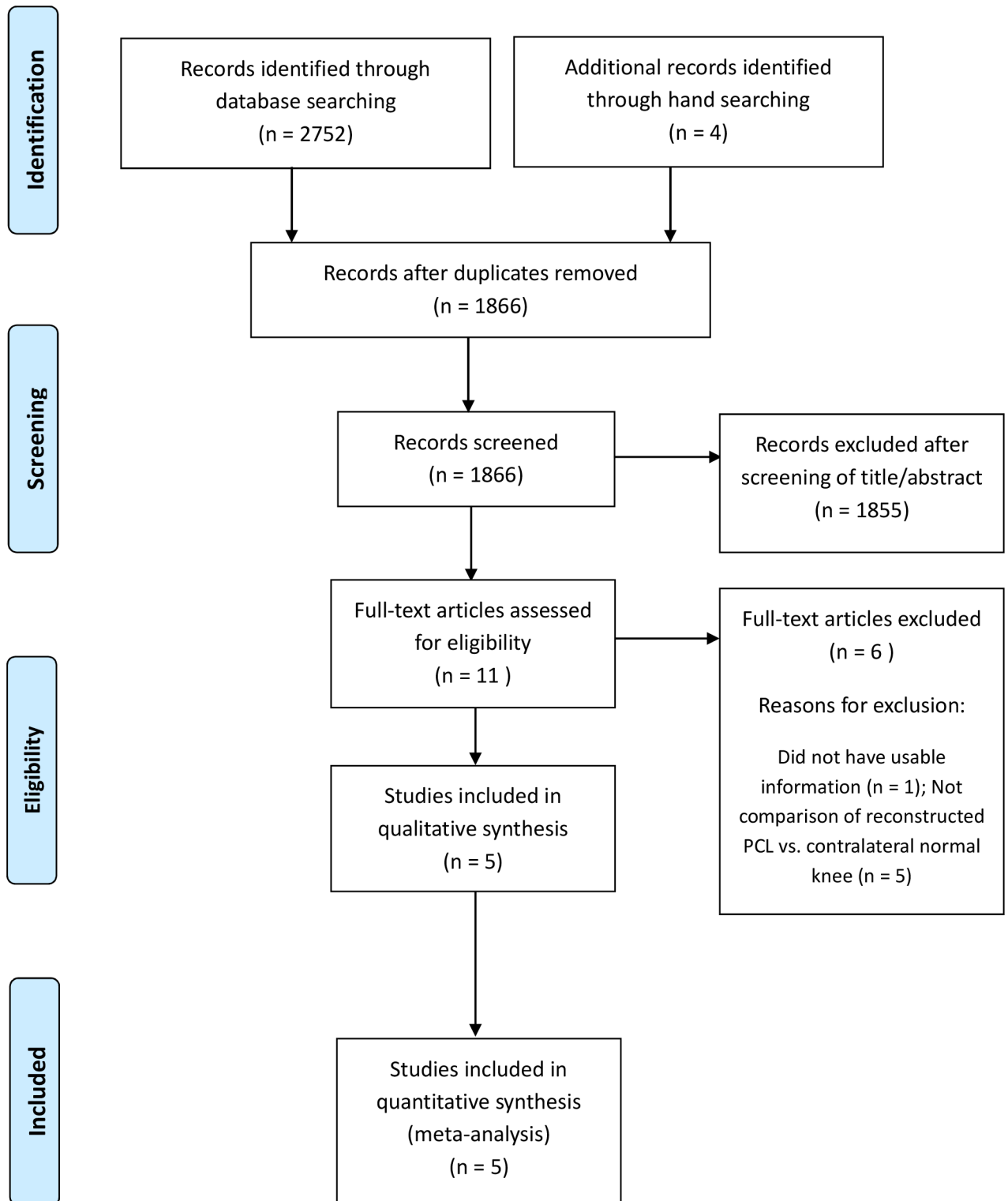


Fig 1. Preferred reporting items for systemic reviews and meta-analyses (PRISMA) flow diagram of literature selection.

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Table 1. Summary of patient characteristics of the included studies.

Study	Year	Study type	Sample size	Mean age (years)	Mean follow-up (Months)	Time from surgery to proprioception test (Months)	Measured parameters	Quality score
Adachi et al. [12]	2007	PCS	29	31.9	42	Mean 24	RPP (90°)	8
Lee et al. [13]	2013	RCS	20	36	61.3	At least 24	TTDPM (45°, 110°), RPP (45°, 110°)	7
Lee et al. [14]	2014	RCS	92	35.6	48.2	At least 24	TTDPM (20°, 45°), RPP (0°, 90°)	8
Li et al. [15]	2016	PCS	90	31.4	67.2	Mean 60	TTDPM (15°, 45°), RPP (15°, 45°)	8
Safran et al. [16]	1999	PCS	10	31	27	Mean 27	TTDPM (45°, 110°)	8

Abbreviations: PCS, prospective comparative study; RCS, retrospective comparative study; RPP, reproducing passive positioning; TTDPM, threshold to detect passive movement.

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(95% CI: 0.25 to 0.51°; $P < 0.00001$; $I^2 = 0\%$, Fig 2), indicating that TTDPM was significantly greater in reconstructed PCL than in contralateral normal knees. Five studies were assigned to the 15° flexion to 45° extension subgroup, and six studies were assigned to the 45° flexion to 110° flexion subgroup. The 15° flexion to 45° extension subgroup was associated with a mean angle of error that was significantly greater by 0.38° (95% CI: 0.19 to 0.58°; $P = 0.0001$; $I^2 = 41\%$, Fig 2) in the reconstructed PCL than in the contralateral normal knees. Similarly, 45° flexion to 110° flexion subgroup showed a mean angle of error that was significantly greater,

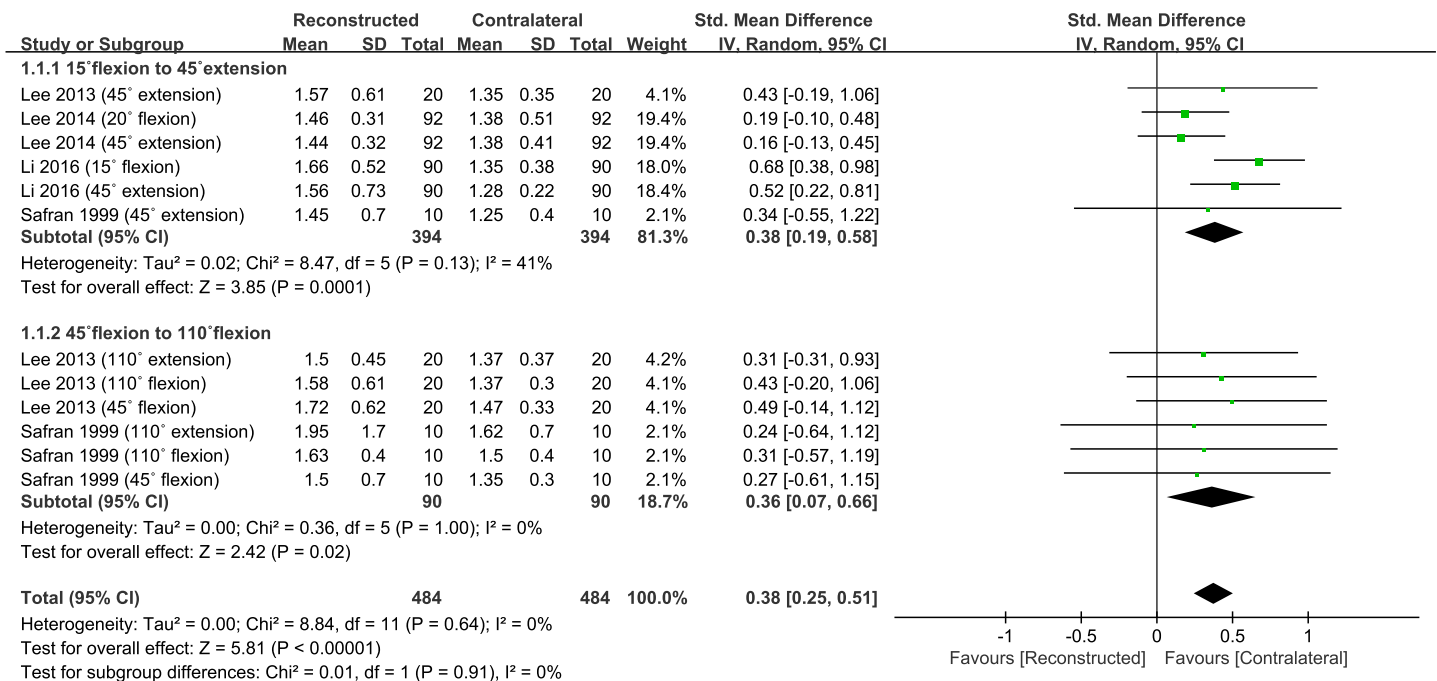


Fig 2. Results of aggregate analysis for comparison of threshold to detect passive movement (TTDPM) according to different modalities, including subgroup analysis based on the starting angles and the moving directions of the knee by 15° flexion to 45° extension and 45° flexion to 110° flexion.

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Table 2. Sensitivity analysis.

Study	Parameter	Before exclusion	After exclusion	Statistical significance
Lee et al. [13] (2013)	TTDPM (15° flexion to 45° extension)	SMD = 0.38, 95% CI = 0.19 to 0.58, Z = 3.85, P = 0.0001	SMD = 0.38, 95% CI = 0.16 to 0.60, Z = 3.36, P = 0.0008	No difference
	RPP (flexion)	SMD = 0.36, 95% CI = 0.21 to 0.52, Z = 4.51, P < 0.00001	SMD = 0.34, 95% CI = 0.17 to 0.51, Z = 3.92, P < 0.0001	No difference
Lee et al. [14] (2014)	TTDPM (15° flexion to 45° extension)	SMD = 0.38, 95% CI = 0.19 to 0.58, Z = 3.85, P = 0.0001	SMD = 0.57, 95% CI = 0.37 to 0.76, Z = 5.70, P < 0.00001	No difference
	RPP (flexion)	SMD = 0.36, 95% CI = 0.21 to 0.52, Z = 4.51, P < 0.00001	SMD = 0.41, 95% CI = 0.22 to 0.60, Z = 4.22, P < 0.0001	No difference

TTDPM, threshold to detect passive movement; RPP, reproducing passive positioning; SMD, standardized mean difference

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by 0.36° (95% CI: 0.07 to 0.66°; P = 0.02; I² = 0%, Fig 2) in the reconstructed PCL than in the contralateral normal knees. The results of sensitivity analysis were not significantly different from those of the original analysis, including that the findings are robust to the decisions made in the process of obtaining them (Table 2).

Reproducing passive positioning (RPP)

Of the five studies, four compared RPP of reconstructed PCL and contralateral normal knees, and included 473 subjects that had RPP performed in reconstructed PCL knees and 473 in contralateral normal knees. The pooled data showed that the mean RPP was 0.32° (95% CI: 0.19 to 0.45°; P < 0.00001; I² = 0%, Fig 3), indicating that RPP was significantly greater with

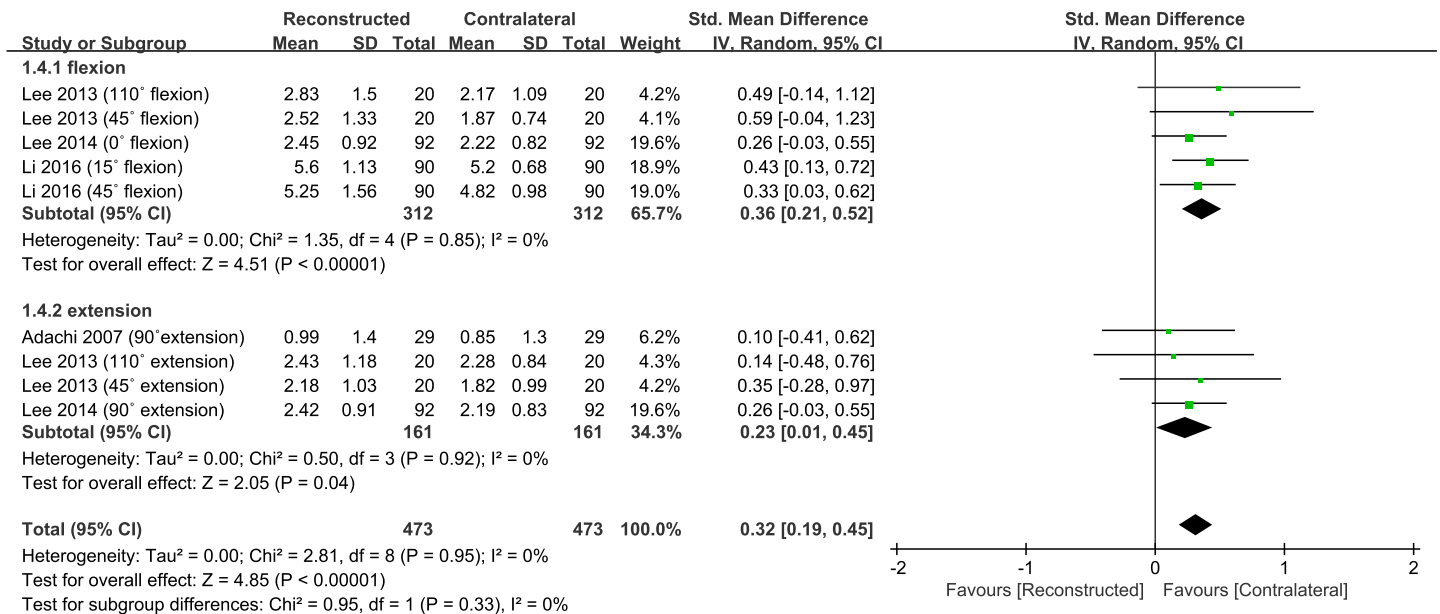


Fig 3. Results of aggregate analysis for comparison of reproducing passive positioning (RPP) according to different modalities, including subgroup analysis based on the moving directions of the knee by flexion and extension.

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PCL reconstruction than in contralateral normal knees. Five studies were assigned to the flexion subgroup, and four studies were assigned to the extension subgroup. The flexion subgroup showed mean angle of error that was 0.36° greater (95% CI: 0.21 to 0.52°; $P < 0.00001$; $I^2 = 0\%$, Fig 3) in the reconstructed PCL than in the contralateral normal knees. Similarly, the extension subgroup indicated a mean angle of error that was 0.23° greater (95% CI: 0.01 to 0.45°; $P = 0.04$; $I^2 = 0\%$, Fig 3) in the reconstructed PCL than in the contralateral normal knees. The results of sensitivity analysis were not significantly different from those of the original analysis, including that the findings are robust to the decisions made in the process of obtaining them (Table 2).

Discussion

The most important finding of this meta-analysis was that proprioceptive function of reconstructed PCL knees was decreased compared with contralateral normal knees, as determined by both TTDPM and RPP. In addition, the amount of loss of proprioceptive function was greater in TTDPM than in RPP, even with minute differences.

This meta-analysis showed that both TTDPM (0.38°) and RPP (0.32°) were significantly greater with PCL reconstruction than in contralateral normal knees, even with minute differences which are unlikely to be clinically relevant.[17] A proprioceptive deficit of more than 5° is considered to be clinically relevant.[18] It is possible that the PCL reconstructed knees did not have a proprioception deficit large enough to affect functional declines because of PCL reconstruction with remnant preservation and the fact that the duration from surgery to proprioception test was longer than 24 months, resulting in recovering proprioceptive function gradually, similar to findings in knee with ACL reconstruction.[19] Preserving the remnant PCL fibers may help restore sensation for joint motion and position by saving mechanoreceptors, which can lead to proprioceptive function recovery to the level of the contralateral normal knees.[20] These results were consistent with those of the Eguchi *et al.* study that evaluated the TTDPM between preoperative assessment and any follow-up point and did not find any significant differences between PCL reconstructed knees with remnant preservation and contralateral normal knees, regardless of the starting angles and the moving directions of the knees.[9] This result was similar to previous findings that showed that remnant preserving PCL reconstruction was effective in restoring proprioception, such as TTDPM and RPP, to the level of the contralateral normal knees.[13] Another factor that can explain these results may be a loss of proprioception in the contralateral normal knees, suggesting that the altered afferent information from the articular mechanoreceptors, such as Pacinian corpuscles and Ruffini corpuscles in the PCL reconstructed knees, may contribute to and alter the sense of stability in the contralateral normal knees, which could impact the number of proprioceptive deficits than in healthy subjects.[6,21]

Previous findings have indicated that there are no available valid measurement tools for detecting the clinically significant importance of proprioceptive function.[22] For example, most joint position sense (JPS) findings could be attributable to a lack of reliability and validity because of relatively complicated measurements caused by various confounding factors such as starting angle, direction of movement, target angle, and angular velocity.[23,24] In addition, TTDPM detects the low threshold response and rapid-adapting mechanoreceptors, such as Pacinian corpuscles, which may make it more sensitive than JPS, which has a low threshold but slow-adapting mechanoreceptors such as Ruffini corpuscles.[25,26] Therefore, TTDPM may not completely detect the real differences, resulting in a lower magnitude of change compared to JPS. In contrast with our expectations, the current meta-analysis found that the mean difference in angle of error between reconstructed PCL and contralateral normal knees was

0.06° greater by TTDPM than by RPP, suggesting that the TTDPM results are less constant than for JPS. These results may be attributable to the fact that information from other sensory pathways in patients with TTDPM may have unexpectedly influenced the mean angle of error. For example, previous studies found conflicting results, including a reported mean angle of error of 2.4° for elderly patients after knee arthroplasty and 2.7° for young dancers.[27,28]

Many studies reported that healthy subjects with JPS measurements had greater mean angles of error in the moving direction of flexion than the moving direction of extension. These results can be explained by the fact that the moving direction of flexion may offer fewer levels of afferent feedback because of less muscle spindle activation in the smaller hamstring muscle group, compared with the larger quadriceps muscle group contraction during the moving direction of extension.[29,30] Indeed, our subgroup analysis findings that evaluated mean angles of error in the moving directions through RPP, suggested that the moving direction of flexion (0.36°) is significantly greater for mean angles of error than the moving direction of extension (0.23°).

This study had several limitations. All five studies were observational, which caused some inherent heterogeneity due to uncontrolled bias, even though the studies had high quality scores. In addition, the heterogeneity of the included studies could be explained by slight differences in other factors affecting proprioceptive function, including the use of a wide variety of rehabilitation programs and variability in directions of movement and starting angles. Finally, proprioception during dynamic activities or weight-bearing was not evaluated.

Conclusions

The proprioceptive function of PCL reconstructed knees was decreased compared with contralateral normal knees, as determined by both TTDPM and RPP. In addition, the amount of loss of proprioception was greater in TTDPM than in RPP, even with minute differences. Results from subgroup analysis that evaluated mean angles of error in terms of the moving directions through RPP suggested that the moving direction of flexion is significantly greater in mean angles of error than the moving direction of extension.

Supporting information

S1 PRISMA Checklist. PRISMA checklist.
(DOC)

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Supervision: Young-Soo Shin.

Validation: Jung-Ro Yoon, Young-Soo Shin.

Writing – original draft: Young-Soo Shin.

Writing – review & editing: Young-Soo Shin.

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