

ORIGINAL ARTICLE



# Knee Laxity or Loss of Knee Range of Motion after PCL Reconstruction: A Systematic Review and Meta-Analysis

<sup>1,2</sup>Sholahuddin Rhatomy\*, <sup>3,4</sup>Dwikora Novembri Utomo, <sup>3,4</sup>Heri Suroto, <sup>3,4</sup>Ferdiansyah Mahyudin

<sup>1</sup>Department of Orthopedics and Traumatology, Dr. Soeradji Tirtonegoro General Hospital, Klaten, Indonesia. <sup>2</sup>Faculty of Medicine, Public Health, and Nursing, Universitas Gadjah Mada, Yogyakarta, Indonesia. <sup>3</sup>Department of Orthopaedic and Traumatology, Dr. Soetomo General Hospital, Surabaya, Indonesia. <sup>4</sup>Faculty of Medicine, Universitas Airlangga, Indonesia.

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## ABSTRACT

**Background.** PCL reconstruction is a successful method for enhancing the patient's quality of life but posterior knee laxity and knee stiffness have still occurred surgery. There is no study to evaluate knee laxity or loss of knee range of motion after surgery. **Objectives.** To assess the outcomes after PCL reconstruction, we: 1) evaluated the range of motion of the knee, 2) evaluated posterior knee laxity, and 3) determined the factors that influence laxity or the loss of range of motion after surgery. **Methods.** Articles that met the following criteria were enrolled in this review: 1) articles on peer-reviewed level 1 to 4 studies; 2) articles published in English; 3) articles on PCL reconstruction studies; 4) articles on isolated PCL rupture; 5) articles that describe laxity after surgery and 6) articles that describe the degree of range of motion after surgery. **Results.** Involving a total of 1711 patients. There was a loss of extension and flexion after PCL reconstruction (9.15% and 28.9%, respectively). Knee laxity was still observed at the final examination in the posterior drawer test, KT 1000/2000 test, and Telos radiographic view (64.8%, 42.8%, and 47.9%, respectively). In the subgroup analysis, there was no significant difference in laxity between allograft group vs autograft group using the KT 1000/2000 measurement (mean difference [MD] = -0.42, 95% confidence interval [-1.41, 0.56],  $p = 0.40$ ), Single Bundle vs Double Bundle (DB) using the KT 1000/2000 measurement (MD = -0.003, 95% CI [-1.35, 1.29],  $p < 0.00001$ ), and transtibial vs tibial inlay using the Telos radiograph measurement (MD = 0.03, 95% CI [-0.33, 0.39],  $p = 0.88$ ), but DB significantly improved knee stability using the Telos radiographic measurement (MD = 0.69, 95% CI [0.29, 1.09],  $p = 0.00008$ ). **Conclusion.** This study demonstrates that the loss of range of motion or laxity is still a problem after PCL reconstruction.

**KEYWORDS:** *Range of Motion, Laxity, Posterior Cruciate Ligament, PCL Reconstruction.*

## INTRODUCTION

Only a few studies have investigated the outcome after posterior cruciate ligament (PCL) reconstruction, and the outcome of the results after surgery of these studies vary and need further depth research. Recent studies revealed that PCL reconstruction is a successful method for enhancing the patient quality of life and that it has a significant

impact on patients' activity of daily living and back to the normal pre-injury activity, because can stabilize knee joint (1). However, in daily practice, we still observed and founded posterior knee laxity or knee stiffness after PCL reconstruction.

Posterior knee laxity or knee stiffness still always a problem after surgery and a challenge

\*. Corresponding Author:

Sholahuddin Rhatomy, MD

E-mail: doktergustomrhatomy@yahoo.com

for doctors and physiotherapists to prevent and manage it. There are many systematic reviews and meta-analyses on PCL reconstruction that have been reported before (1-8); however, none focused on laxity or stiffness after PCL reconstruction. This study aims to produce a systematic review and metaanalysis about laxity or stiffness of the knee after PCL reconstruction based on published literature.

## MATERIALS AND METHODS

**Review of Protocol.** Our review question was “What is the incidence rate of posterior knee laxity or loss of range of motion of the knee after PCL reconstruction and what factors influence it?”

**Outcomes Measure.** To assess the outcomes after PCL reconstruction, we: 1) evaluated the range of motion of the knee, 2) evaluated posterior knee laxity, and 3) determined the factors that influence laxity or the loss of range of motion after surgery.

**Literature Search and Study Selection.** In May 2020, we carried out a literature search using Cochrane Library, PubMed (Medline), Web of Science, and Scopus to identify all the studies published in English that describe the outcomes after PCL reconstruction. All studies were reported based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (9).

The keywords used for the search included “laxity,” “stiffness,” “range of motion,” “PCL,” “Posterior Cruciate Ligament,” “PCL Reconstruction,” and “outcome” alone and in various combinations using the Boolean operator “AND” or “OR.”

**Eligibility Criteria.** Inclusion criteria were: 1) articles on peer-reviewed level studies; 2) articles published in English; 3) articles on PCL reconstruction studies; 4) articles on isolated PCL rupture; 5) articles that describe laxity after surgery using the posterior drawer test, KT-1000/KT-2000 test, and radiographic stress (Telos) view; and 6) articles that describe the degree of range of motion after surgery. Articles that met these inclusion criteria were enrolled in this systematic review.

Non-English articles, articles on multiple ligament reconstruction, articles on studies that involved PCL reconstruction combined with other techniques, duplicate articles, literature reviews, articles on studies that involve in vitro, animals, until the cadaveric investigation, biomechanical study, letters to editors, instructional courses, and technical notes were excluded. We also excluded

articles with incomplete information on diagnosis, imaging, arthroscopic or surgical assessment of the associated lesions, clinical examination, follow-up duration, clinical postoperative outcomes, and no statistical analysis.

**Data Extraction.** To avoid bias, the following data were identified and recorded independently by all of the investigators: study design, types of graft, types of surgical technique, outcome after surgery, degree of knee laxity, range of motion, interventions, comparisons, duration of follow-up, main outcomes of studies, and complications.

**Methodological Quality Assessment and Risk of Bias.** The methodological quality of the included studies was assessed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (9). Two authors (D.N.U and S.R.) independently performed all the assessments.

Coleman Methodology Score (CMS) was used to quantify the quality of the article. The article’s methodology was assessed by CMS with a total score ranging from 0 to 100. The higher the CMS score of the article, the more valid its article because it spared from biases and confounding factors (10).

To avoid bias on the included and excluded articles were reviewed and re-assessed by all authors. If there was any disagreement between each author, the problem was solved by D.N.U. as a senior investigator.

**Data Synthesis.** We used RevMan 5 software (Version 5.3, the Cochrane Collaboration) and Stata 12.0 software for meta-analysis statistical analyses. The following tests were performed: the posterior drawer displacement test, KT 1000/2000 test, and the radiographic stress (Telos) view. The 95% confidence interval (CI) and Mean Difference (MD) were counted for continuous data. The Odds Ratio (OR) and 95% CI were calculated for dichotomous data. An alpha level of  $< 0.05$  was considered statistically significant.

The heterogeneity among the included studies was tested using the I-square tests and Chi-Square tests. The chi-square test was performed to quantify heterogeneity significance. The I-square test was performed to quantify the estimation of variability in the effect that occurred because of its heterogeneity. The result interpretation of the I-square test was quantified based on the Cochrane Handbook of Systemic Reviews. The result has its interpretation (0-40%, might not be important; 40-60%, may represent moderate heterogeneity; 60-90%, may represent substantial heterogeneity; 90-

100%, considerable heterogeneity). When there was no significant heterogeneity was present ( $I^2 < 50\%$ ,  $P > 0.1$ ), the fixed-effect model was used. If the result was significant heterogeneity, we were used a random effect model. Sensitivity analyses were conducted by individually removing each study to assess the heterogeneity and robustness of the pooled results. Datasets that caused significant changes in the pooled results were further analyzed to assess the cause of the changes. Subsequently, the results were evaluated for stability and laxity. If the heterogeneity was significantly large for analysis, descriptive analyses were presented. Subgroup analyses were performed on the laxity outcome at different comparisons.

## RESULTS

**Study Selection.** A total of 2041 articles were obtained from the database literature

search and 1207 articles were excluded based on the title or due to duplication. A total of 834 articles were eligible for further screening. Seven-hundred-and-twenty-six articles were excluded because they did not match the inclusion criteria resulting in a total of 108 articles. Sixty-one articles were excluded after the full-text screening was performed. We excluded these articles due to: the range of motion or laxity after surgery was not clearly stated ( $n = 49$ ), they were either technical notes, short communications, or reviews ( $n = 6$ ), they were cadaveric, laboratory, or biomechanical studies ( $n = 3$ ), or they were nonoperative studies ( $n = 3$ ). Thus, 47 full articles were included in this systematic qualitative review. The flow chart of the article enrolling was provided in [Figure 1](#).

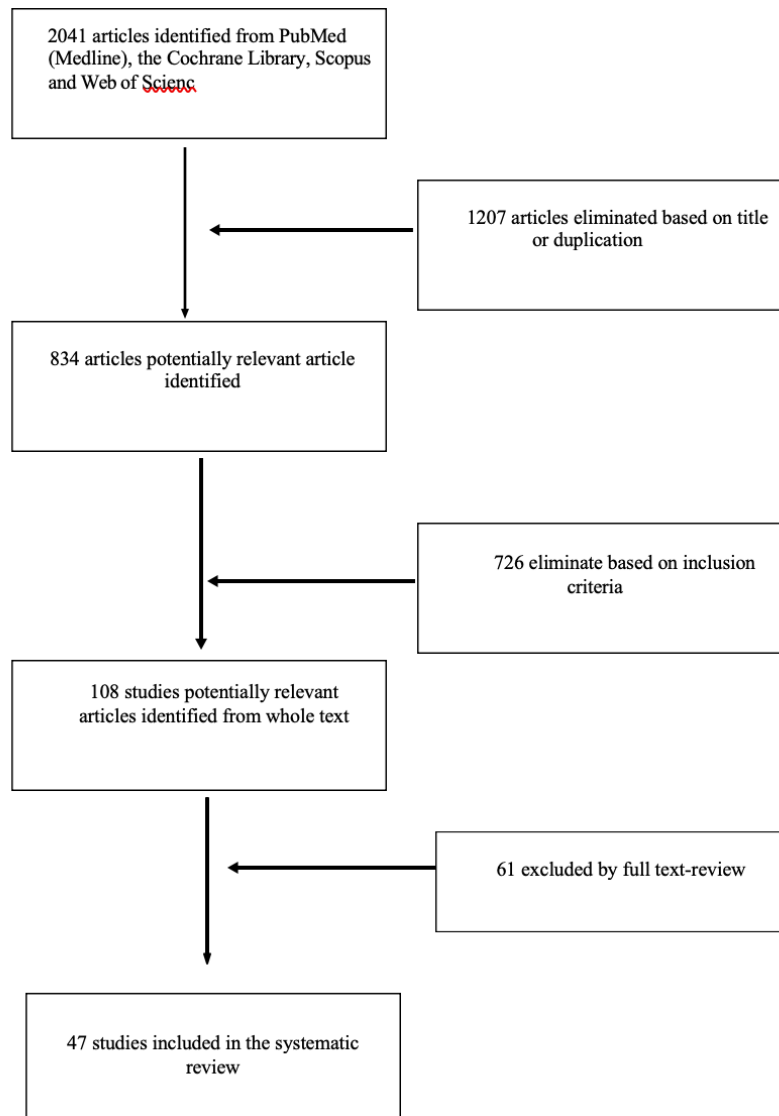


Figure 1. Flow Chart of Study Process Selection

**Demographics and Characteristics of Selected Studies.** Twenty-three studies (48.9%) were retrospective, 14 were prospective studies, six were case series, four were randomized control trials, and one was a non-randomized control trial. This systematic review included 1711 patients (1713 knees). There were 1293 male (75.5%) and 385 female (22.5%) patients. Two studies did not describe

the gender distribution (33 patients). The average age at the time of reconstruction was 30.4 years (range, 16-64 years). The average follow-up duration was 44.85 months (range, 12-148 months) (Table 1).

In all studies, the indication for surgery was the failure of conservative treatment or symptomatic PCL rupture with a minimum 2 positive (2+) on posterior drawer test.

**Table 1. Summary of Characteristics of the Included Studi**

No	Author and Year	Study Type	Sample Size	Follow-Up Period
1	P. P. Mariani et al,1997 (11)	Retrospective Study	24	26.5 months (range 24–53 months)
2	Sung-Jae Kim et al,2000 (12)	Prospective Study	55 (Two incision group: 10; One incision group:45)	45 months in Group I and 36 months in group II
3	John Nyland et al,2002 (13)	Retrospective Study	19	2 years
4	Chih-Hwa Chen et al,2002 (14)	Prospective Study	27	2 years
5	Chih-Hwa Chen et al,2002 (15)	Case Series Study	49 (22 quadriceps tendon group and 27 hamstring tendon group)	2 years
6	Ching-Jen Wang et al,2003 (16)	Retrospective Study	30	40 (range: 24–108) months
7	Yasumitsu Ohkoshi et al,2003 (17)	Nonrandomized Control Study	51(The 2-incision group: 22 patients, and endoscopic group: 29 patient)	1 year
8	Ching-Jen Wang et al,2004 (18)	Prospective Study	55 (group 1 autogenous graft: 23, group 2 allogenus: 32)	34 months
9	Ching-Jen Wang et al,2004 (19)	Prospective Study	35 (19 single bundle group and 16 double-bundle groups)	2 years
10	Thomas Houe et al,2004 (20)	Prospective Study	16	35 (25–51.5) months
11	Young bok Jung, et al,2004 (21)	Retrospective Study	11	52 month
12	Jin Hwan Ahn et al,2005 (22)	Retrospective Study	36 (18 patients received autogenous double-loop hamstring /group I and 18 Achilles tendon allograft /group II).	2 years
13	Kyoung Ho Yoon et al,2005 (23)	Prospective Study	26	25 months (range, 12 to 48 months).
14	LCDR Jon K. Sekiya et al,2005 (24)	Retrospective Study	21	Mean 5.9 years (range, 2.6 to 11 years),
15	John D. MacGillivray et al,2006 (25)	Retrospective Study	20 (13 traditional endoscopic transtibial group and 7 tibial inlay group).	Mean follow-up of 5.7 years (range, 2 to 15 years)
16	Yi-Sheng Chan et al,2006 (26)	Prospective Study	20	40 months (range, 36 to 50 months)
17	Raffaele Garofalo et al, 2006 (27)	Case Series	15	mean follow-up of 3.2 years (range, 2 to 5 years)
18	Chih-Hwa Chen et al,2006 (28)	Prospective Study	52	4 years
19	Jong-Keun Seon et al,2006 (29)	Retrospective Study	43 (21 The transtibial tunnel-group /group and 22 the tibial inlay group /group B )	2 years
20	Nobuo Adachi et al,2007 (30)	Prospective Study	29 (22/7)	2 years
21	Chin-Hsien Wu et al,2007 (31)	Prospective Study	22	66 months (range, 60-76)
22	Jinzhong Zhao et al,2007 (32)	Retrospective Study	43 (22 patients 7-strand hamstring graft (7SHG) group and 21 patients 4-strand hamstring graft (4SHG).	2 years

23	Bin Li et al, 2008 (33)	Retrospective Study	36 (4SHG group (n = 15) and a LARS group (n = 21)).	2 years
24	W. F. M. Jackson et al, 2008 (34)	Prospective Study	26	10 years
25	To Wong et al, 2008 (35)	Prospective Study	55 (28 A-M trans-tibia group and 27 A-L trans-tibia group)	48 § 15.9 months for A-M and 45.0 § 13.7 months for A-L.
26	Jinzhong Zhao et al, 2008 (36)	Case Series	18	2 years
27	Jin-Zhong Zhao et al, 2009 (37)	Randomized Control Trial	42 (21 Medial Side Augmentation group and 21 Lateral Side Augmentation group)	2 years
28	Sung-Jae Kim et al, 2009 (38)	Retrospective Study	29 (8 Transtibial single bundle group; 11 inlay single-bundle group; 10 inlays double-bundle group)	46.4 months in Group T, 36.3 months in Group II, and 29.4 months in Group I2
29	Baicheng Chen et al, 2009 (39)	Case Series	22	2 years
30	Stijn Hermans et al, 2009 (40)	Case Series	25 (9 with a bone-patellar tendon-bone autograft (BPTB), 15 with a semitendinosus gracilis (STG) autograft, and 1 with an Achilles tendon allograft )	Mean follow-up of 9.1 years (range, 6.5-12.6).
31	Oog Jin Shon et al, 2010 (41)	Retrospective Study	30 (14 Single bundles tibial inlay/group A and 16 Double bundles tibial inlay/ group B)	Group A mean 90.5 months and group B mean 64 months
32	Odd Arve Lien et al, 2010 (42)	Retrospective Study	43	48 month (17–109)
33	Kyoung Ho Yoon et al, 2011 (43)	Randomized Control Trial	53 (25 Single bundle group and 28 Double bundle group)	2 years
34	Rachad Zayni et al, 2011 (44)	Retrospective Study	21	29 months (range 12–48)
35	Yu-Chuan Lin et al, 2013 (45)	Retrospective Study	59 (25 Bone-patellar tendon-bone autograft and 34 hamstring autograft )	51.6 months in pPT group and 51.1 months in HT group
36	Sang Hak Lee et al, 2013 (46)	Retrospective study	89 (34 Transtibial groups, 40 SB inlay group, and 15 DB inlay group)	24 month
37	Bin Li et al, 2014 (47)	Retrospective Study	37 (18 Hamstring autograft group and 19 Tibialis anterior allograft)	2 years
38	Seyed Taghi Norbakhsh et al, 2014 (48)	Prospective Study	52	3 years
39	Eun-Kyoo Song et al, 2014 (49)	Cohort Study	66 (transtibial with a hamstring (36 patients) and tibial inlay with the patellar tendon (30 patients))	148 months (range, 98-196 months).
40	Daifeng lu et al, 2014 (50)	Randomized Control Trial	32 (17 improve tibial inlay and 15 traditional tibial inlay)	1 year
41	Xiujiang Sun et al, 2015 (51)	Retrospective Study	71 (36 Autograft group and 35 allograft group)	The autograft group was 3.2 ± 0.2 years and the allograft group was 3.3 ± 0.6 years
42	Vineet Jain et al, 2016 (52)	Retrospective Study	40 (18 Double bundle group and 22 Single bundle group )	24 month
43	Jia Li et al, 2016 (53)	Randomized Control Trial	80 (26 patients in the autograft group, 27 in the hybrid graft group, and 27 in the g-irradiated allograft group )	5 years
44	Terence Wai-kit Chan et al, 2016 (54)	Retrospective Study	21	50 months (24-60 months)
45	Rodrigo Salim et al, 2017 (55)	Retrospective Study	21	4.4 years (0.6–11 years)
46	Rhatomy et al, 2019 (56)	Retrospective Study	25	2 years
47	D. Saragaglia et al, 2019 (57)	Retrospective Study	16 (8 hamstring group; 8 LARS group)	24 month

**Range of Motion.** Seventeen studies (511 patients, 29.8%) did not describe the range of motion after surgery. Thus, only 30 studies (1079 patients, 63.06%) reported a range of motion after surgery.

Knee extension deficit was evaluated using three categories; grade 1: nearly normal  $< 3^\circ$ , grade 2:  $3-5^\circ$ , and grade 3:  $> 6^\circ$ . Among the studies that reported range of motion outcomes, 96 patients (9.15%) experienced the loss of extension ( $< 3^\circ = 59$  (61.4%),  $3-5^\circ = 29$  (30.2%),

$> 6^\circ = 2$  (0.2%), and the degree of the loss of extension was not reported for five patients).

Knee flexion deficit was evaluated using four categories; grade 1: nearly normal  $< 5^\circ$ , grade 2:  $6-15^\circ$ , grade 3:  $16-25^\circ$ , and grade 4 (severe flexion deficit)  $> 25^\circ$ . Three hundred and twelve patients (28.9%) experienced the loss of flexion ( $< 5^\circ = 134$  (42.9%),  $6-15^\circ = 60$  (19.2%),  $16-25^\circ = 4$  (1.2%), severe flexion deficit ( $> 25^\circ = 8$  (2.5%)), and the degree of the loss of range of motion was not reported for 106 patients (Table 2).

**Table 2. Outcomes Measures of Posterior Cruciate Ligament Reconstruction.**

No	Author and Year	Graft Type	PCLR Technique and Fixation Device	Sample Size (male/female)	Range of Motion Outcome	Knee Laxity Outcome
1	P. P. Mariani et al, 1997 (11)	BPTB Autograft	Single bundle PCL reconstruction Both ends of the graft were secured with interference screws	24 (16/8)	18 patients (75%) complete ROM 2 patients (8%) experienced a lack of extension of between $3^\circ$ and $5^\circ$ 6 patients (25%) loss of flexion, between $6^\circ$ and $15^\circ$ 4 pts loss of extension of less than $3^\circ$ .	KT 2000 Measurement 0–2mm: 6; 3–5 mm: 13; 6–10: 3; > 10: 2
2	Sung-Jae Kim et al, 2000 (12)	Group 1; BPTB autograft Group 2: 11BPTB allograft and 34 BPTB autograft	Single Bundle PCL Reconstruction Femoral Fixation: Interference Screw Tibial Fixation: Interference Screw	55 (42/13)	1 patient in group I and 10 patients in group II lost terminal flexion, an average of $10^\circ$ (range, $5^\circ$ to $20^\circ$ ). There was no extension loss or extension lag at the last follow-up.	KT-1000 or KT-2000 arthrometer (testing at 20-lb force) was 2.10 mm (range, 1 to 4 mm) in group I and 2.38 mm (range, 0 to 6 mm) in group II
3	John Nyland et al, 2002 (13)	allograft (anterior tibialis tendon $n=17$ , semitendinosus-gracilis tendon $n=2$ )	double-bundle PCL reconstruction (using allograft tissue) Biodegradable interference screws were used for all graft fixation procedures.	19 (14/5)	All patients had normal ( $n=19$ ) or near normal ( $n=1$ ) passive knee joint extension ( $< 3^\circ$ ) and flexion ( $0-5^\circ$ deficient) compared to the opposite knee joint.	Posterior drawer tests at $70^\circ$ knee flexion revealed all normal ( $n=11$ ) or nearly normal results ( $n=8$ ) Knee arthrometry measurements showed $2.4 \pm 2$ mm posterior displacement.
4	Chih-Hwa Chen et al, 2002 (14)	Hamstring tendon autograft	Single bundle PCL reconstruction Both ends of the graft were secured with interference screws	27 (18/9)	Eighty-five percent ( $n=23$ ) of the patients had full ROM, a 3-degree or less difference A 3-	Posterior drawer and posterior sag testing and KT-1000 examination demonstrated: 8 (29%) the patients exhibited a

			and screw and washer		to the 5-degree difference in extension or a 6- to a 15-degree deficit in flexion from the opposite limb was recorded for 11% (n: 3) of the patients. An extension deficit of more than 6 degrees or a flexion deficit of more than 16 degrees was found in one patient (4%).	0- to 2-mm total anteroposterior translation. 15 (56%) percent revealed a 3- to 5-mm ligament laxity. 4 patients (15%) demonstrated a 6- to 10-mm laxity.
5	Chih-Hwa Chen et al,2002 (15)	Quadriceps tendon autograft and quadruple hamstring tendon autograft.	Single bundle PCL reconstruction Femoral: titanium interference screw Tibia: Bicortical screw and washer and bioscrew	49 (32/17)	The normal rating was recorded for 77% (N:17) of the quadriceps tendon group and 85% (N: 23) of the hamstring tendon group. The nearly normal rating was recorded for 18% (N: 4) of the quadriceps tendon group and 11% (N: 3) of the hamstring tendon group. The abnormal present for 5% (N:1) of quadriceps tendon patients and 4% (N: 1) of hamstring tendon patients.	Posterior drawer and posterior sag testing and KT-1000 examination showed that 32% (N: 7) of the quadriceps tendon group and 29% (N: 8) of the hamstring tendon group exhibited a 0- to 2-mm total anterior-posterior translation. 56% percent (N: 13) of the patients in the quadriceps tendon group and 56% (N: 15) in the hamstring tendon group revealed a 3- to 5-mm ligament laxity. Two patients (9%) with quadriceps tendon graft and 4 patients (15%) with hamstring tendon grafts showed a 6- to 10-mm laxity.
6	Ching-Jen Wang et al,2003 (16)	Autografts (patellar bone-tendon-bone and quadriceps tendon) Allografts (Achilles tendon and patellar bone-tendon-bone).	Single bundle PCL reconstruction Both ends of the graft were secured with interference screws	30 (22/8)	-	Posterior drawer test 0: 16 (51.6%); 1:12 (38.7%); 2:3 (9.7%); 3:0
7	Yasumitsu Ohkoshi et al,2003 (17)	Autogenous hamstring tendons,	Single bundle PCL reconstruction Femoral side: endo button. Tibial side: screw and spiked washer.	51 (33/18)	-	KT-1000, the manual maximum was $3.95 \pm 1.96$ mm in the 2-incision group and $2.38 \pm 1.42$ mm in the endoscopic group

8	Ching-Jen Wang et al, 2004 (18)	Autogenous grafts ( quadriceps tendon- patellar bones and quadruple hamstrings Allogeneous grafts (Achilles tendon and anterior tibial tendons 0	Single Bundle PCL Reconstruction Femoral Fixation: Bioabsorbable Screw Tibial Fixation: Bioabsorbable Screw, titanium screw	55 (41/14)	Range of Motion: Autograft group: Mean: $125 \pm 14^\circ$ Range 80-140° Allograft group: mean: $127 \pm 6^\circ$ range 115-135°	Posterior Drawer: 1. Autograft group: $0.92 \pm 0.69$ (0-3) 2. Allograft group: $0.61 \pm 0.58$ (0-2) KT-1000 1. Autograft group: $3.16 \pm 2.60$ (1-10) 2. Allograft group: $2.83 \pm 1.70$ (1-6)
9	Ching-Jen Wang et al, 2004 (19)	Hamstring tendon autograft	Single and double-bundle posterior cruciate ligament (PCL) Both ends of the graft were secured with bioabsorbable interference	35 (26/9)	SB: $126 \pm 12$ (90-140) DB: $124 \pm 14$ (80-140)	Posterior drawer: SB: $1.16 \pm 0.6$ (0-2); DB: $1.13 \pm 0.6$ (0-2) KT 1000: SB: $7.1 \pm 3.7$ (3-15); DB: $6.7 \pm 4.5$ (2-16)
10	Thomas Houe et al, 2004 (20)	BPTB Autograft Hamstring tendon autograft	A posterior cruciate ligament (PCL) with one versus two tunnels femoral One tunnel-group both ends of the graft were secured with interference screws Two tunnel-group; femoral side: endobutton, tibial side: interference screw	16 (6/8)	-	One tunnel group:: 30 deg: 2 (2-4); 70 deg: 2 (2-4) Two tunnel group: 30 deg: 3 (1.3-3.8); 70 deg: 3 (1.3-4)
11	Young bok jung, et al, 2004 (21)	BPTB Autograft	Single bundle PCL reconstruction Femoral Fixation: Interference Screw Tibial Fixation: Screw and washer	11	-	The mean side-to-side difference in displacement (and standard deviation) was $3.4 \pm 2.4$ mm on the stress radiographs and $1.8 \pm 1.2$ mm as measured with the KT-1000 arthrometer.
12	Jin Hwan Ahn et al, 2005 (22)	Autogenous double-loop hamstring tendon (group I) and Achilles tendon allograft (group II).	Single bundle PCL reconstruction Both ends of the graft were secured with button bioabsorbable interference screws	36 (27/9)	1 patient who had received Achilles tendon allograft (group II) had knee joint stiffness (range of motion, $0^\circ$ to $90^\circ$ ).	Telos stress test The group I mean was 2.2 mm (range, 0 to 7 mm; SD, 1.8) and the group II mean was 2.9 mm (range, 1 to 7 mm; SD, 1.9)
13	Kyoung Ho Yoon et al, 2005 (23)	Achilles allograft	Arthroscopic double-bundle technique using a split Achilles allograft AL bundle is fixed with 1 bioabsorbable interference screw using an outside-in method. PM bundle is fixed with bioabsorbable interference screw and outside-in method. The 2	26 (19/7)	-	Radiographic Side-to-Side Differences of Posterior Tibial Translation 0-2 mm: 18; 3-5 mm: 6; 6-10 mm: 3; > 10mm: 0



			tendon ends are additionally fixed by a 6.5-mm cancellous screw and washer. Tibial tunnel is fixed to the tibial tunnel with a metal interference screw			
14	LCDR Jon K. Sekiya et al,2005 (24)	Achilles tendon allograft	Single bundle PCL R Femoral Fixation: Metal Interference Screw Tibial Fixation: screw and soft tissue washer	21 (15/6)	The average loss of flexion $5^{\circ} \pm 5^{\circ}$ (range, $-1^{\circ}$ to $18^{\circ}$ ). The average loss of extension $1^{\circ} \pm 3^{\circ}$ (range, $6^{\circ}$ more extension to $5^{\circ}$ loss of extension on the involved side).	No patient had a normal posterior drawer test. 50% had a nearly normal posterior drawer 50% had an abnormal posterior drawer. KT-1000 posterior laxity measurement: 62% had less than a 3-mm side-to-side difference, 31% had a 3- to 5-mm side-to-side difference 8% had a 6- to 10-mm side-to-side difference.
15	John D. MacGillivray et al,2006 (25)	Bone-patellar tendon-bone [BPTB] autograft, BPTB allograft, and Achilles tendon allograft	Single bundle PCL reconstruction Tibial inlay group versus transtibial group Femoral fixation was consistent for both groups, with primary interference screw fixation backed up with either a ligament button, a screw, and washer, or a staple.	20 (15/5)	-	Posterior Drawer Test 1. Tibial Tunnel Group: Grade 1:3; Grade 2:6; Grade 3:4 2. Tibial Inlay Group: Grade 1:3; Grade 2:2; mGrade 3:2 KT-1000 1. Tibial Tunnel Group: Grade 1:6; Grade 2:5; Grade 3:1 2. Tibial Inlay Group: Grade 1:4; Grade 2:3; Grade 3:0
16	Yi-Sheng Chan et al,2006 (26)	Hamstring tendon autograft	Single bundle PCL reconstruction Femoral side: BioScrew and washer Tibia side: bicortical screw and washer and BioScrew	20 (15/5)	17 (85%) patients with a difference at full extension of $3^{\circ}$ or less, or full flexion of $5^{\circ}$ or less, One patient (5%) with $3^{\circ}$ to $5^{\circ}$ difference in extension. Two (10%) patients with a $16^{\circ}$ to $25^{\circ}$ deficit in flexion. No patient had a severely abnormal rating (an extension deficit $>10^{\circ}$ or a flexion deficit $>25^{\circ}$ ).	Posterior Drawer Test Grade I (0–5 mm) 16; Grade II (6–10 mm) 3; Grade III (11–15 mm) 1; Grade IV ( $\geq 15$ mm) 0 KT-1000 Test Normal (0–2 mm): 10; Nearly normal (3–5 mm) 7; Abnormal (6–10 mm) 3; Severely abnormal ( $> 10$ mm) 0
17	Raffaele Garofalo et al, 2006 (27)	Autograft bone-patellar tendon-bone (BPTB)	Double-bundle posterior cruciate ligament (PCL) reconstruction. Both bundles were secured with bioresorbable interference screws and 3.5-mm AO	15 (14/1)	Loss of flexion between $5^{\circ}$ and $10^{\circ}$ in 4 patients (26.4%).	Posterior Drawer Test: 3 patients (20%) had a normal posterior drawer 10 (67%) had a grade 1 posterior drawer 2 (13%) had a grade 2 posterior drawer Telos

			cortical screw with a metallic washer at the tibia.			Radiography: the mean value of posterior translation was 8.06 mm (range, 5 to 13 mm; SD, 3.7 mm) and the mean side-to-side difference was 5.9 mm (range, 2 to 12 mm; SD, 2.63 mm).
18	Chih-Hwa Chen et al, 2006 (28)	Quadruple hamstring tendon autograft	Single bundle PCL reconstruction Both ends of the graft were secured with interference screws and screw and washer	52 (35/17)	34 (65%) patients were rated as having normal status. 11 (21%) patients who presented flexion deficit 6 (11%) patients presented extension deficit were rated as nearly normal. 1 patient (2%) had a 16°–25° deficit in flexion.	Posterior drawer test Grade I (0–5 mm): 42; Grade II (6–10 mm): 10; Grade III (11–15 mm): 0; Grade IV ([15 mm) 0 KT-1000 measurement Normal (0–2 mm): 32; Nearly normal (3–5 mm): 10; Abnormal (6–10 mm): 8; Severely abnormal (>10 mm): 2
19	Jong-Keun Seon et al, 2006 (29)	Quadrupled hamstring autograft, bone-patellar tendon-bone autograft	Single bundle PCL reconstruction Fixation Transtibia group Femoral side using an LA Screw Tibia side: bioabsorbable interference screw Tibial inlay Femoral side: interference screw Tibial side: screw and washer	43 (36/7)		Posterior Drawer Transtibia: Grade I (0–5 mm): 19; Grade II (6–10 mm): 2; Grade III (>10 mm): 0 Tibia inlay: Grade I (0–5 mm): 20; Grade II (6–10 mm): 2; Grade III (>10 mm): 0 Telos Device (20 N) Mean side-to-side differences were 3.7 ± 2.1 at the final follow-up in group A and 3.3 ± 1.6 mm in group B Transtibia: 0–2 mm: 2; 3–5 mm: 14; 6–10 mm: 5; >10 mm: 0 Tibial inlay: 0–2 mm: 3; 3–5 mm: 15; 6–10 mm: 4; >10 mm: 0
20	Nobuo Adachi et al, 2007 (30)	Hamstrings tendon autografts	Single bundle PCL reconstruction Femoral side: Button Tibia side: double spike staples	29 (22/7)	-	Stress radiology: mean 3.5 mm ± 2.7 Posterior laxity measured by KT-2000 mean 3.7 mm ± 2.4,
21	Chin-Hsien Wu et al, 2007 (31)	Quadriceps tendon autograft	Single bundle PCL reconstruction with a quadriceps Femoral side: titanium interference screw Tibial side: bicortical screw and washer and Bioscrew	22 (17/5)	Knee ROM was normal in 18 (82%) Near normal (3°–5° difference in extension) in 1 patient (4.5%) Abnormal (one in 6° to 10° difference in extension and one in 16° to 15° deficit in	KT-1000 examination: Grade 0 - 2 mm: 10 (46%) patients, grade 3 to 5 mm: 8 (36%) patients, grade > 5-mm: 4 (18%) patients.

					flexion) in 2 patients (9%).1 patient (4.5%) severely abnormal (a flexion deficit of more than 25°).	
22	Jinzhong Zhao et al,2007 (32)	Hamstring tendon autograft	Single bundle posterior cruciate ligament (PCL) The femoral side: mini-plate Tibial side titanium button or screw post	43 (34/9)	Normal hyperextension of 5° was lost in two 4SHG patients and one 7SHG, Loss of 5° of full flexion occurred in two 4SHG patients and one 7SHG	Posterior Drawer 4HS Group: Grade 1: 11; Grade:2 5; Grade 3: 4; Grade 4:1 7HS Group: Grade 1: 15; Grade 2: 5; Grade 3: 2; Grade 4: 0 KT 1000 Examination: 4HS Group: Grade 1: 12; Grade 2: 5; Grade 3: 4; Grade 4: 0 7HS Group: Grade 1: 17; Grade 2: 4; Grade 3: 1; Grade 4: 0
23	Bin Li et al, 2008 (33)	Fur-strand hamstring graft autograft and a LARS artificial ligament.	Single bundle PCL reconstruction Both ends of the graft were secured with interference screws and screw and washer	36 (30/6)	-	Posterior Drawer - 4HS Group: Grade 1: 6; Grade 2:5; Grade 3: 4; Grade 4: 0 - LARS Group: Grade 1: 16; Grade 2: 5; Grade 3: 0; Grade 4: 0 KT 1000 Examination 4HS Group: Grade 1: 4;Grade 2: 3; Grade 3: 6; Grade 4: 2 ARS Group: Grade 1: 10; Grade 2: 8; Grade 3: 3; Grade 4: 0
24	W. F. M. Jackson et al,2008 (34)	Hamstring Tendon autograft	Single bundle PCL reconstruction Femoral fixation: titanium round-head cannulated interference screw Tibial fixation: RCI screw	26 (25/1)	21 patients had less than 3° of loss of extension 20 patients had less than 5° of loss of flexion	8 patients had grade 0 laxity. 12 patients had grade 1 laxity 2 patients had grade 2 laxity. The mean side to side difference in posterior translation was 1.1 mm (SD 1.9)
25	To Wong et al,2008 (35)	Hamstring tendon autograft	Single-bundle PCL reconstruction Both bundles were secured with bioresorbable interference screws	55 (41/14)		Posterior Drawer: Anteromedial Group: 0.9 ± 0.5 (0–3) Anterolateral group: 0.9 ± 0.7 (0–3) KT-1000 Examination: Anteromedial Group: 2.8 ± 1.6 (1–6) Anterolateral group: 3.3 ± 2.8 (1–10)
26	Jinzhong Zhao et al,2008 (36)	Autogenous hamstring tendons	Single bundle PCL reconstruction The femoral tunnel side: Button Tibia side: titanium button	18 (14/4)	1 patient lost the normal 5° of hyperextension 2 patients had a 5° flexion limitation.	The side-to-side difference in posterior laxity was 0.7 ± 0.9 mm. 17 (94.4%) had a negative posterior drawer test and KT-1000 examination (90° of flexion and 30 lb), < 3 mm. 1 patient had a 1+ posterior drawer test and a KT-1000

						side-to-side difference of 5 mm.
27	Jin-Zhong Zhao et al, 2009 (37)	Seven strands of hamstring tendon Autograft	Single bundle PCL reconstruction The femoral side Button Tibia side titanium button	42 (33/9)	1 patient in each of the MSA and LSA group had 5° extension limitation; 2 patients in each of the MSA and LSA groups had 5° flexion limitation	KT-1000 examination showed MSA group: 0 to 2 mm: 15 patients (78.9%); 3 to 5 mm: 3 (15.8%) and 6 to 10 mm: 1 (5.3%), with an average of $1.6 \pm 1.2$ mm. LSA group: 0 to 2 mm: 14 patients (82.3%); 3 to 5 mm: 2 (11.8%) and 6 to 10 mm: 1 (5.9%), with an average of $1.5 \pm 1.3$ mm. The posterior drawer test: MSA Group; Grade 1+: 4 and Grade 2+: 1; LSA Group; Grade 1+: 1; Grade 2+: 2
28	Sung-Jae Kim et al, 2009 (38)	Achilles tendon allograft	Transtibial single bundle group (group T); Arthroscopic inlay single-bundle procedure group (Group I1), Arthroscopic inlay double-bundle procedure (Group I2) Femoral Fixation: Bioabsorbable interference Screw. Tibial Fixation: Bioabsorbable Interference Screw	29 (20/9)	Final examination with a goniometer knee flexion to be $2.8^\circ \pm 0.70^\circ$ in Group T, $4.1^\circ \pm 2.59^\circ$ in Group I1, and $3.4^\circ \pm 0.84^\circ$ in Group I2.	The mean side-to-side differences in posterior tibial translation as measured with Telos stress radiography were $5.6 \pm 2.00$ mm in Group T; $4.7 \pm 1.62$ mm in Group I1, and $3.6 \pm 1.43$ mm in Group I2
29	Baicheng Chen et al, 2009 (39)	Autogenous hamstring tendons	Double-bundle posterior cruciate ligament (PCL) reconstruction using 8 strands of autogenous hamstring tendon The grafts were fixed by the use of a non-hardware suspension fixation technique.	22 (17/5)	1 patient had a 5° flexion limitation, 1 patient had a 10° flexion limitation 1 patient who had a 5° extension limitation	Posterior Drawer Test. Grade 0: 17 patients (89.5%); Grade 1+: 1 patient (5.3%); Grade 2+: 1 patient (5.3%) The mean KT-1000 examination results mean $1.0 \pm 1.0$ mm postoperatively. The stress radiography results in $2.0 \pm 1.2$ mm postoperatively
30	Stijn Hermans et al, 2009 (40)	Bone-patellar tendon-bone autograft (BPTB), Semitendinosus gracilis (STG) autograft, and Achilles tendon allograft	Anterolateral bundle reconstruction of the PCL Femoral side: a cannulated interference screw (RCI) Tibial side: interference screw (RCI) and a back-up staple fixation were used.	25 (22/3)	A mean loss of 8° of flexion in comparison with the contralateral knee was present.	The posterior drawer test results Grade 0: (n=2), Grade 1(n=15), or Grade 2(n=5) Telos Radiology BpTB mean 6.2 mm (SD: 2.6); Hamstring mean 3,9 mm (SD: 2,6) KT-1000 examination. BpTB: mean 2.1mm (SD:1.9); Hamstring: mean 2,2 mm (SD:1,4)
31	Oog Jin Shon et al, 2010 (41)	Bone-patellar tendon-bone (BPTB) allografts and	Single bundle tibial inlay PCL reconstruction (Group A) and	30 (26/4)	1 patient in group A and 2 patients in group B showed	Posterior drawer test Group A: Grade I (0–5 mm): 13; Grade II (6–10 mm): 1; Grade III

		Achilles tendon allografts, and Achilles tendon allografts.	double-bundle tibial inlay PCL reconstruction (Group B) Fixation. Group A. Femoral Side: absorbable interference screw and a staple with an Achilles allograft and a nonabsorbable interference screw with a BPTB allograft. Tibial side: cancellous screw and washer. Group B: Femoral Side: absorbable interference screw Tibial side: bio-interference screw and a staple		approximately 10° of knee flexion limitation	(11–15 mm): 0; Grade IV ([15 mm): 0 Group B: Grade I (0–5 mm):15; Grade II (6–10 mm):1; Grade III (11–15 mm): 0; Grade IV (>15 mm): 0 TELOS Radiography: Group A 3.0 mm ± 1.1; Group B 2,6 mm ± 0,49
32	Odd Arve Lien et al,2010 (42)	Bone-patellar tendon-bone (BPTB) autograft, allografts and hamstring autograft	Single bundle /double bundle PCL reconstruction Both ends of the graft were secured with interference screws	43 (29/14)	Maximum flexion: 133 (SD = 7.5)	KT 1000 (n: 37): 9.2 mm (SD = 4.1) Stress Radiograph (n: 41): 8.4 mm (SD = 4.8)
33	Kyoung Ho Yoon et al,2011 (43)	Achilles allograft	Single bundle PCL reconstruction Femoral Side: cancellous screw and spiked washer or staples, as well as bioabsorbable interference screws for the double fixation. Tibial side: metal interference screw	53 (45/8)	SB Group: 138° 6 3.3° DB Group: 136° 6 4.2° Limited range of motion was observed as a postoperative complication in 1 case of the SB group (4%) and 2 cases of the DB group (7%)	Telos posterior stress radiographs SB Group: 4,5 ± 2,3 DB Group: 3,1 ± 2,4
34	Rachad Zayni et al, 2011 (44)	Quadriceps tendon autograft	Single bundle PCL (anterolateral bundle) reconstruction using a quadriceps tendon autograft Femoral side: resorbable interference screw and non-resorbable bicortical screw inserted proximally Tibial side: resorbable interference screw	21 (18/3)	2 patients (9.5%) presented a moderate flexion deficit of 6° - 15°.	The mean side-to-side differential posterior laxity was 3.6 mm (range 0–7)
35	Yu-Chuan Lin et al,2013 (45)	Bone-patellar tendon-bone autograft and hamstring autograft	Single Bundle PCL Reconstruction Group bone-patellar tendon-bone graft (PT Group) and group hamstring graft (HT Group) Femoral tunnel was fixed first with an interference screw Tibial tunnel was fixed with an	59 (44/15)	PT Group: 135.9 ± 4.3 (128–145) HT Group: 133.5 ± 7.2 100–142	Posterior drawer test PT Group: Grade 0: 4(16%); Grade 1: 17 (68 %); Grade 2: 4(16%); Grade 3: 0(0%) HT Group: Grade 0: 16 (47 %); Grade 1: 16 (47 %); Grade 2: 2(6%); Grade 3: 0(0%) KT1000 side-to-side difference

			interference screw (metal interference was used in PT group and bio-absorbable interference screws were used in HT group. The fixation in each tunnel was further secured by a post- screw with a washer.		(mm) PT Group: $2.8 \pm 1.6$ (1–6.5). HT Group: $2.6 \pm 1.5$ (1–7.5)
36	Sang Hak Lee et al, 2013 (46)	Achilles tendon allograft, autogenous hamstring tendon w	Group 1: ALB reconstruction using the transtibial tunnel technique; Group 2: ALB reconstruction using the modified inlay; and Group 3: double-bundle reconstruction using the modified inlay technique Fixation: biodegradable interference screw at the femoral tunnel additionally, and a post and tie were made with a screw and washer in both the tibial and femoral sides	89 (82/7)	Group 1: Stress radiography: mean $2.3 \pm 1.4$ mm at the last follow-up. 23 patients (67.1%) less than 3 mm, 8 patients (23.5%) had between a 3 and 5 mm, and 3 patients (8.8%) exceeding 5 mm. One case showed a displacement greater than 10 mm KT-1000 arthrometer: mean $2.2 \pm 2.2$ mm at the last follow-up Group 2: Stress radiography: mean $2.3 \pm 1.5$ mm at the last follow-up. 23 patients (57.5%) less than 3 mm, 15 patients (37.5%) had between a 3- and 5-mm displacement, and 2 patients (5.0%) exceeding 5 mm. KT-1000 arthrometer mean: $2.0 \pm 1.4$ mm at the last follow-up Group 3 Stress radiography mean $4.0 \pm 2.5$ mm at the last follow-up. 3 patients (20%) less than 3 mm, 9 patients (60%) had between a 3- and 5-mm displacement, and 3 patients (20%) showed displacement exceeding 5 mm. One case showed a displacement greater than 10 mm KT-1000 arthrometer mean: $3.6 \pm 1.9$ mm at the last follow-up
37	Bin Li et al, 2014 (47)	Hamstring autograft group and tibialis anterior allograft	Single Bundle PCL Reconstruction Group A [4-strand hamstring tendon autograft (4SHG), $n = 18$ ] and group B [2-strand tibialis anterior allograft	37 (25/12)	Arthrometer (mm) Group A: $4.1 \pm 1.7$ ; Group B: $3.3 \pm 1.8$ Posterior Drawer: Group A grade 0: 3; grade 1: 1; grade 2: 4; grade 3: 0 Group B

			(2STAG), $n = 19$ Femoral Fixation: endobutton Tibial Fixation: cannulated interference screw.			grade 0: 8; grade 1:9; grade 2:2; grade 3:0
38	Seyed Taghi Norbakhsh et al,2014 (48)	Hamstring tendon autograft	Single-bundle PCL reconstruction (the anterolateral part of the PCL) Femoral side: Cross pin femur Tibial side: bio-interference Screw	52 (42/10)	Eighty-five percent ( $n = 52$ ) full ROM. Seven (13.5 %) of the patients A 3–5- degree difference in extension or 6–15° deficit in flexion. Three patients (5.7 %) reported severely abnormal knee ROM which was defined as a flexion deficit of more than 25°.	Posterior drawer test: Grade I (0–5 mm): 41; Grade II (6–10 mm): 9; Grade III (11–15 mm): 2; Grade IV ([15 mm): 0 KT-1000 test: Normal (0–2 mm): 25; Nearly normal (3–5 mm): 17; Abnormal (6–10 mm): 10; Severely abnormal (>10 mm): 0
39	Eun-Kyoo Song et al, 2014 (49)	Hamstring and tibial inlay with patellar tendon	Single bundle PCL reconstruction Trans tibial group Femoral side: the LA screw Tibia side: a bio-interference screw Tibial inlay group Femoral side: interference screw Tibial side: 2 screws and washers.	66 (58/8)	Some patients showed an extension deficit of less than 5° (5 transtibial cases and 6 tibial inlay cases),	Laxity: Transtibial group: 30 patients (83.3%): grade I (0-5 mm); 6 patients (16.7%): grade II (5-10 mm) Tibial inlay group: 26 patients (86.7%): normal or grade I; 4 patients (13.3%): grade II laxity The mean side-to-side difference (Telos) Transtibial group: 4.1 mm (range, 0-8 mm) Tibial inlay group: 4.2 mm (range, 1-8 mm)
40	Daifeng lu et al,2014 (50)	Quadricep Tendon autograft	Double bundle PCL reconstruction (17 Atoscopic group and 15 traditional tibial inlay group) Tibial with mini-steel-plate and tied to fix the plate onto the wall of the anteromedial tibial Femoral with interference screw	32 (28/3)	-	Posterior Drawer test + in 2 pts group 1 and 1 pts in group 2
41	Xiujiang Sun et al,2015 (51)	Hamstring tendon autograft and allograft	Single bundle PCL reconstruction (36 Autograft group and 35 allograft group) Both ends of the graft were secured with bioabsorbable interference screws	71 (54/17)	The average ROM was $132.3 \pm 2.2^\circ$ in the autograft and $134.6 \pm 1.8^\circ$ in the allograft group	KT-1000 test Autograft group: Grade 0: 23; grade 1: 8; grade 2: 5; grade 3: 0 Allograft group: Grade 0: 11; grade 1: 15; grade 2: 9; grade 3: 0
42	Vineet Jain et al,2016 (52)	Hamstring tendon autograft	PCL reconstruction Single bundle versus double-bundle PCL (18 Double bundle	40 (40/0)	-	KT-1000 (side-to-side difference in mm) DB 1.78 mm (range 0–6 mm); SB 2.44 mm

			group and 22 Single bundle group) all ends of the graft were secured with interference screws			(range 0–7 mm) Average posterior translation (kneeling X ray) DB 1.33 mm; SB 1.95 mm
43	Jia Li et al, 2016 (53)	Allograft (tibialis anterior tendons) Hybrid (irradiated tibialis anterior tendon allograft and semitendinosus tendon autograft) Autograft (Semitendinosus and gracilis)	Single bundle PCL reconstruction 26 patients in the autograft group, 27 in the hybrid graft group, and 27 in the g-irradiated allograft group Femoral side EndoButton Tibia side: bioabsorbable interference screw	80 (50/30)	-	Knee Laxity According to Instrumented Anteroposterior Measurements Autograft $2.1 \pm 1.0$ Hybrid graft $2.6 \pm 1.2$ g-Irradiated allograft $3.5 \pm 1.1$ Posterior Drawer Test Autograft: Grade 0: 11; Grade I: 15; Grade II:0; Grade III:0 Hybrid: Grade 0: 10; Grade I: 16; Grade II:1; Grade III:0 Allograft: Grade 0: 9; Grade I: 15; Grade II:3; Grade III:0
44	Terence Wai-kit Chan et al, 2016 (54)	Quadrupled hamstrings autografts	Arthroscopic transtibial single-bundle PCL Femoral side: endo button and a bioabsorbable interference screw Tibial side: screw post and a bioabsorbable interference screw	21 (21/0)	-	Drawer Test: Grade I (0-5 mm): 54.5% (12); grade II (5-10 mm): 18.2% (4/22),
45	Rodrigo Salim et al, 2017 (55)	Autogenous hamstring tendons	Single bundle PCL reconstruction Femoral side: interference screw Tibia side: screw dan washer	21	No deficit of extension >4 degrees was observed in any patient. The median range flexion was 132 degrees	-
46	Rhatomy et al, 2019 (56)	Quadrupled hamstrings autografts	Single bundle PCL reconstruction Femoral side: button Tibial side: bioabsorbable interference screws	25 (10/15)	3 patients (21%) had ROM restriction (0-110°).	None
47	D. Saragaglia et al, 2019 (57)	Hamstring tendon autograft an artificial ligament (ligament advanced reinforcement system (LARS®))	Single bundle PCL reconstruction 8 using a hamstring tendon autograft (hamstring group), and 8 using an artificial ligament (LARS group) Femoral side: interference screw and two serrated staples. Tibia side: absorbable interference screw	16 (15/1)	-	X-ray posterior drawer (mm) hamstring group: 7.37 mm (6–8, SD 0.74) and LARS group: 5.25 mm (3–7, SD 1.3)

Abbreviation: PBTB: Patellar Bone-Tendon-Bone, SHG/HS: Strand Hamstring Group, MSA: medial side augmentation, LSA: lateral side augmentation, SB: Single Bundle, DB: Double Bundle, ALB: Anterolateral bundle



**Posterior Laxity.** In this review, we evaluated laxity using three methods: the posterior drawer displacement test, KT 1000/2000 test, and radiographic stress (Telos) view.

**Posterior Drawer Displacement Test.** The outcome of the test was grouped into four categories: grade 1 (0-5 mm), grade 2 (6-10 mm), grade 3 (11-15 mm), and grade 4 (> 15 mm).

Twenty-nine studies involved the posterior drawer displacement test (1051 patients [61.4%]). According to the posterior drawer test, 682 patients (64.8%) still had laxity (grade 1 = 553 (52.6%), grade 2 = 109 (10.4%), grade 3 = 19 (1.8%), and grade 4 = 1(0.09%)).

**KT 1000/2000 Arthrometer Test.** The outcome of the test was grouped into four categories: grade 1 (normal, 0-2 mm), grade 2 (nearly normal, 3-5 mm), grade 3 (abnormal, 6-10 mm), and grade 4 (severely abnormal, > 10 mm).

Thirty studies reported the posterior drawer displacement in patients (1202 patients, 70.25%). The various categories and their corresponding numbers of patients are as follows: grade 1 (normal) = 687 (57.1%), grade 2 (nearly normal) = 361 (30.0%), grade 3 (abnormal) = 148 (12.3%), and grade 4 (severely abnormal) = 6 (0.49%). Thus, 515 patients (42.8%) still had laxity (grades 2, 3, and 4).

**Radiographic Stress (Telos) View.** The outcome of the test was grouped into four categories: grade 1 (normal, 0-2 mm), grade 2 (nearly normal, 3-5 mm), grade 3 (abnormal, 6-10 mm), and grade 4 (severely abnormal, >10 mm).

Eighteen studies reported the radiographic stress (Telos) outcomes in patients (678 patients/ 39.6%). The various categories and their corresponding numbers of patients are as follows: grade 1 (normal) = 353 (52.06%), grade 2 (nearly normal) = 228 (33.6%), grade 3 (abnormal) = 95 (14.0%), and grade 4 (severely abnormal) = 2 (0.29%). According to the radiographic stress (Telos) View Measurement, 325 patients (47.9%) still had laxity (grade 2, 3, and 4).

**Comparison of Knee Laxity between the Autograft and Allograft Groups According to the KT 1000/2000 Measurement.** Four studies (one randomized controlled trial, two retrospective studies, and one prospective study) reported laxity using the KT 1000/2000 arthrometer measurement. There was no

significant difference in outcome between the autograft and allograft groups (MD = -0.42, 95% CI [-1.41, 0.56],  $p = 0.40$ , Figure 2), and there was a high heterogeneity in the groups ( $I^2 = 81\%$ ,  $p < 0.00001$ ). Through the one-by-one elimination of studies, the sensitivity analysis revealed that the heterogeneity remained high.

**Comparison of Knee Laxity between Single Bundle and Double Bundle Groups According to the KT 1000/2000 Measurement.** Three articles (two prospective studies and one retrospective study) compared the laxity after surgery following the KT 1000/2000 measurement between the single bundle (SB;  $n = 49$ ) and double-bundle (DB;  $n = 42$ ) groups. A random-effects model was applied because of the high statistical heterogeneity ( $I^2 = 75\%$ ,  $p = 0.02$ ). There was no significant difference in laxity between the SB and DB groups based on the KT 1000/2000 measurements (MD = -0.003, 95% CI [-1.35, 1.29],  $p < 0.00001$ , Figure 3).

**According to the Radiographic Stress (Telos) View.** Four articles (three prospective studies and one randomized control trial study) compared the laxity after surgery following the radiographic stress (Telos) view between the SB ( $n = 69$ ) and DB ( $n = 72$ ) groups. A fixed-effects model was applied because a low statistical heterogeneity was observed ( $I^2 = 34\%$ ,  $P = 0.21$ ). There was a significant difference in laxity outcome between the SB and DB groups based on the radiographic stress (Telos) view (MD=0.69, 95% CI [0.29, 1.09],  $p = 0.00008$ , Figure 4). This shows that the laxity outcome was significantly higher in the SB group than in the DB group after surgery.

**Comparison of Knee Laxity between Transtibial and Tibial Inlay Groups using the Radiographic Stress (Telos) View.** Four articles (one prospective study and three retrospective studies) compared laxity after surgery based on the radiographic stress (Telos) view between the Transtibial (TT;  $n = 99$ ) and Tibial Inlay (TI;  $n = 103$ ) groups. A fixed-effects model was applied because a low statistical heterogeneity was observed ( $I^2 = 0\%$ ,  $p = 0.63$ ). There was no significant difference in the laxity outcome between the TT and TI groups based on the radiographic stress (Telos) view (MD = 0.03, 95% CI [-0.33, 0.39],  $p = 0.88$ , Figure 5).

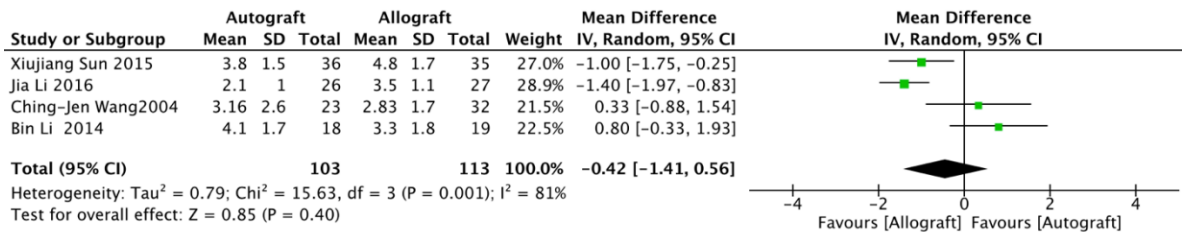


Figure 2. Comparison of Knee Laxity between Autograft and Allograft Groups According to KT 1000/2000 measurement

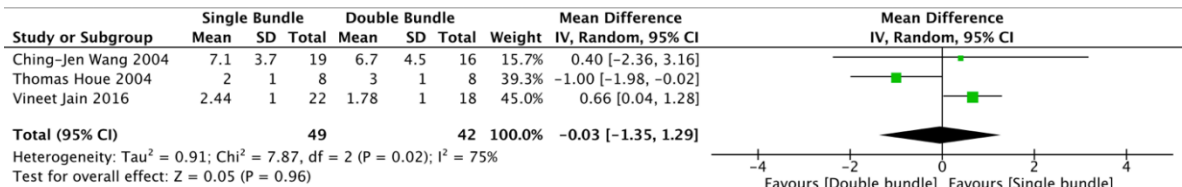


Figure 3. Comparison of Knee Laxity between Single Bundle and Double Bundle Groups According to the KT 1000/2000 measurement

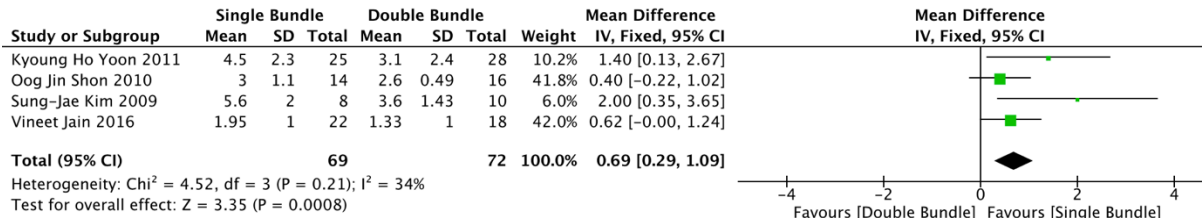


Figure 4. Comparison of Knee Laxity between Single Bundle and Double Bundle Groups According to Radiographic stress (Telos) View

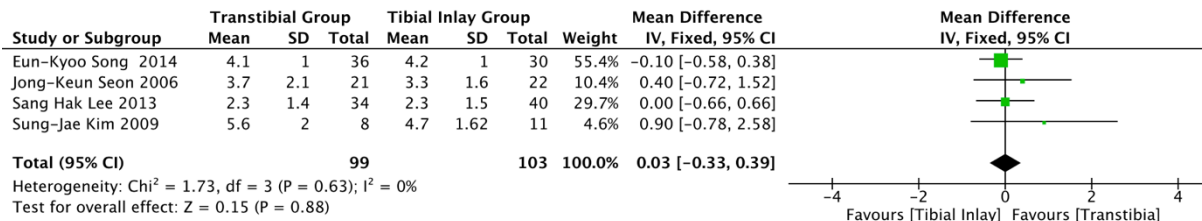


Figure 5. Comparison of Knee Laxity between Transtibial and Tibial Inlay Groups using the Radiographic Stress (Telos) View

**DISCUSSION**

The posterior cruciate ligament (PCL) has an important role as a knee joint stabilizer. Some studies have revealed that PCL reconstruction is contributed to enhancing patient knee function. PCL reconstruction aims to restore the normal knee kinematics to improve joint function and to gain nearly normal objective restrain posterior tibial translation post-operatively (40). The indication for surgery in the studies in this review was the failure of conservative treatment or symptomatic PCL rupture with a minimum of 2 positives (2+) posterior drawer test.

The first aim of this review was to evaluate the range of motion after PCL reconstruction. No uniformity was found among studies that evaluated the normal range of motion parameters. There is some agreement to use deficit or loss in knee extension or flexion. In this review, 96 patients (9.15%) experienced the loss of extension (<3° = 59 (61.4%), 3-5° = 29 (30.2%), > 6° = 2 (0.2%)), and 312 patients (28.9%) experienced the loss of flexion (<5° = 134 (42.9%), 6-15° = 60 (19.2%), 16-25° = 4 (1.2%) and severe flexion deficit (> 25° = 8 (2.5%)). Some studies stated that knee loss of motion and stiffness post-operative were harder to treat than

instability. The patient is encouraged to participate in motion exercises and physical therapy to prevent knee loss of function and stiffness (58).

The second aim of this review was to evaluate posterior knee laxity after PCL reconstruction. Posterior knee laxity was evaluated with multiple modalities such as posterior drawer test, stress radiography (Telos) view, and KT-2000 or KT-1000 arthrometry. Most studies declared a posterior laxity deterioration after PCL reconstruction.

According to the posterior drawer test outcomes, even though there was a decrease in the grade of laxity after surgery, 64.8% of the patients still experienced laxity (most patients (52.6%) had grade 1 laxity). Some studies (0.09%), however, reported severe laxity outcomes (grade 4).

KT 1000/2000 arthrometer measurement. From these studies, we found that 42.8% of patients still had laxity, and most of them (30%) had grade 2 (nearly normal) laxity. Radiographic stress (Telos) view showed that 47.9% of patients still had laxity. Most of them (33.6%) had grade 2 (nearly normal) laxity.

Young Mo Kim et al. (4) reviewed high-grade isolated PCL rupture that was performed with arthroscopic PCL reconstruction using single-bundle transtibial. This procedure can reduce one-grade posterior knee laxity. Normal or nearly normal knee function was reported by approximately 75% of patients. Some studies on SB transtibial PCL reconstruction reported improvement in posterior laxity and no stability restoration. MacGillivray et al. reported that whatever method that has been used in tibial fixation (transtibial or inlay) in SB graft PCL reconstruction, could not restore anteroposterior stability of the knee (25, 42).

A study by Fanelli et al. revealed that there was 12 of 41 with chronic PCL/ PLC reconstruction that developed abnormality of posterior drawer test in 2 until 10 years (3). Chen et al. concluded that 56% of patients developed posterior translation of 3 to 5 mm after PCL reconstruction using SB quadruple hamstring tendon autograft with a 2-year follow-up (59).

The third goal of this review was to detect the factors that influence laxity or the loss of range of motion after surgery. We performed a sub-group meta-analysis involving the autograft and

allograft groups, SB and DB groups, and TT and TI groups.

In this review, the laxity of the knee joint in the autograft and allograft groups was assessed using the KT 1000/ 2000 measurement test. There was no significant difference between the autograft and allograft groups in the outcome (MD = -0.42, 95% CI [-1.41, 0.56],  $p = 0.40$ , Figure 2).

A study by Ahn et al revealed that there was a significant radiographic stress view (Telos) in patients who were done PCL reconstruction using SB with either double loop hamstring tendon autograft or Achilles tendon autograft. The postoperative mean displacement was no significant between each group, with 2.2 mm (range, 0-7 mm) for autograft and 2.9 mm (range, 1-7 mm) for allograft ( $p = 0.14$ ) (34). A previous systematic review about the impact of graft origin on joint laxity and activity level post-operative concluded that there was a significant enhancement in functional outcome post-operative, regardless of tendon graft used (2).

We also evaluated the laxity of the knee joint in the SB and DB groups after PCL reconstruction. Three articles provided data on the KT 1000/2000 measurement test. There was no significant difference in the laxity outcome between the SB and DB groups (MD = -0.003, 95% CI [-1.35, 1.29],  $p < 0.00001$ , Figure 3). However, four articles reported significant differences in laxity outcomes between the SB and DB groups (MD = 0.69, 95% CI [0.29, 1.09],  $p = 0.00008$ , Figure 4) based on the radiographic stress (Telos) view. This shows that the laxity outcome was significantly higher in the SB group than in the DB group after surgery.

A previous systematic review and meta-analysis study by Jorge Chahla et al. reported that PCL procedures using SB or DB has resulted in identical progress in patient-reported outcomes. DB PCL reconstruction was significantly improved in the posterior tibial translation of the knee stability overall based on a randomized controlled clinical trial (60). Another meta-analysis by Dong Yeong Lee et al. revealed that there were no significant differences in side-to-side differences between the SB and DB groups (61). According to our review, there is no significant difference in knee stability if measured using the KT 1000/2000; however, the DB technique significantly improved knee stability if measured using Telos radiography.

Four articles (one prospective study and three retrospective studies) evaluated the laxity of the knee joint based on the radiographic stress (Telos) view in groups that were treated using either the transtibial technique (n = 99) or the tibial inlay technique (n = 103). There was no significant difference in the laxity outcome between the Transtibial (TT) and Tibial Inlay (TI) groups (MD=0.03, 95% CI [-0.33, 0.39]).

Similar to the previous systematic review by Young-Soo Shin et al., we did not identify any significant difference in residual laxity between TT and TI technique. All seven enrolled studies compared the Telos radiographs in 149 knees with TT technique and 148 knees with TI techniques. There was no difference in residual posterior laxity between the groups. Knee with grade 2 or greater posterior laxity showed no difference between two groups in the analysis of the five studies (7).

According to our review, there is a loss of extension and flexion deficit after PCL reconstruction (9.15% and 28.9%, respectively). Knee laxity was still observed at the final examination based on the results of the posterior drawer test, KT 1000/ 2000 test, and Telos radiographs (64.8%, 42.8%, and 47.9%, respectively). In a subgroup analysis that compared the laxity outcome between groups that were treated using allograft and autograft, SB and DB, and TT and TI, we found no significant differences between groups; however, DB significantly improved knee stability based on Telos radiographic measurements.

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Based on the included studies, the keys to successful PCL reconstruction include identifying and treating all pathologies, using strong graft materials, making accurate tunnels placement in the anatomic insertion sites, using a mechanical graft tensioning device, minimizing graft bending, using primary and back-up graft fixation, and using the suitable postoperative rehabilitation protocol.

In conclusion, PCL reconstruction is enhanced with functional outcome scores and joint laxity. Current studies suggest that both the loss of range of motion and laxity still occur after surgery. Further studies are needed to determine the factors that cause the loss of range of motion and laxity and how they can be prevented.

This review has some limitations mainly related to the lack of uniformity. Additionally, few of the included studies emphasize the difficulties encountered when treating this pathology and the need for more high-quality studies.

## APPLICABLE REMARKS

- PCL reconstruction is enhanced with functional outcome scores and joint laxity.
- The loss of range of motion and laxity still occurs after surgery.
- Further studies are needed to determine the factors that cause the loss of range of motion and laxity and how they can be prevented.

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