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Global variation in isolated posterior cruciate ligament reconstruction

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Abstract

Purpose: In the setting of persistent instability or failed non-operative management, surgical reconstruction is commonly recommended for isolated posterior cruciate ligament (PCL) tears. The purpose of this study was to systematically review published studies to evaluate regional variation in the epidemiology of and surgical approaches to primary, isolated PCL reconstruction.

Methods: A systematic review was performed in June 2022 to identify studies examining operative techniques during primary, isolated PCL reconstruction. Collected variables consisted of reconstruction technique, graft type, graft source, tibial reconstruction technique, femoral and tibial drilling and fixation methods, and whether the remnant PCL was preserved or debrided. Studies were classified into four global regions: Asia, Europe, North America, and South America.

Results: Forty-five studies, consisting of 1461 total patients, were identified. Most of the included studies were from Asia (69%, $n=31/45$). Single bundle reconstruction was more commonly reported in studies out of Asia, Europe, and North America. Hamstring autografts were utilized in 51.7% ($n=611/1181$) of patients from Asia and 60.8% ($n=124/204$) of patients from Europe. Trans-tibial drilling and outside-in femoral drilling were commonly reported in all global regions. The PCL remnant was generally debrided, while remnant preservation was commonly reported in studies from Asia.

Conclusion: Surgical treatment of isolated PCL injuries varies by region, with the majority of published studies coming from Asia. Single-bundle reconstruction with hamstring autograft through a trans-tibial approach is the most commonly reported technique in the literature, with males reported to undergo isolated reconstruction more often than females.

Level of Evidence: Systematic review, Level IV.

Keywords: Posterior cruciate ligament, Reconstruction, Knee, Regional variation

Introduction

Injuries to the posterior cruciate ligament (PCL) have been reported with increasing frequency, accounting for up to 17% of all knee injuries [43]. The estimated annual incidence of isolated PCL injuries has been reported as 2 per 100,000 persons [57]. Injuries to the PCL have also become increasingly recognized as a common cause of morbidity and limited knee function [11], increasing the risk for the development of degenerative changes and reduced joint longevity [32, 57]. While an improved understanding of the anatomy and biomechanical function of the PCL has emerged in recent years [23, 27, 28, 51, 54, 73], along with advancements in surgical techniques and instrumentation for the treatment of PCL injuries [6], PCL reconstruction remains a complex and

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challenging surgical procedure. This complexity is compounded by a lack of familiarity with the operation due to the relatively low number of patients requiring the procedure, as well as the proximity of the neurovascular bundle [46].

While traditionally managed non-operatively, [16, 74] operative indications for isolated PCL injuries have expanded to include complete (grade III) injuries, and patients with grade II injuries with residual posterior laxity and disability following non-operative management in a structured rehabilitation program [50, 51, 61, 75]. Surgical reconstruction for isolated injuries has become increasingly performed, with biomechanical studies demonstrating greater sagittal and rotational translation in the PCL-deficient knee, resulting in higher patellofemoral and medial tibiofemoral contact pressures and the potential for damage within the joint [21, 36]. Two systematic reviews evaluating 27 ($n=5197$ patients) [59] and 23 studies ($n=781$ patients) [5] reported that patients undergoing surgical management for isolated PCL injuries possessed a greater reduction in posterior laxity when compared to patients treated non-operatively.

Despite the increased popularity of operative management for isolated PCL injuries, a variety of surgical reconstruction techniques and approaches have been reported [19]. Common variables include graft type and source, bundle number, femoral and tibial drilling technique, method of tibial and femoral graft fixation, and preservation versus debridement of the remnant PCL [34, 42, 53, 73]. To date, no investigation has evaluated the potential for global differences in isolated PCL reconstruction techniques. Geographic differences in any surgical technique can be attributed to a variety of causes reflective of differences in surgical training, personal experience, practice focus, cultural mores, and religious beliefs. Therefore, the purpose of this study was to systematically review the orthopedic literature to assess for regional variation in the epidemiology of and surgical approaches to primary, isolated PCL reconstruction. The authors hypothesized that regional differences would be present based on reconstruction technique and graft choice.

Methods

A systematic review was conducted according to the 2020 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [52]. Following registration on the PROSPERO International Prospective Register of Systematic Reviews (*ID # 279879*), a literature search identifying studies evaluating outcomes following isolated PCL reconstruction from January 1995 to May 2022 was performed on June 21, 2022 using the following databases: PubMed, EMBASE, OVID, Scopus and the Cochrane Library. Each search included a variable combination of the following terms: 'posterior cruciate ligament' OR 'reconstruction,' OR 'isolated' OR 'knee' OR 'surgery' OR 'region' OR 'single-bundle' OR 'double bundle' OR 'transtibial' OR 'tibial inlay' OR 'tunnel' OR 'femur' OR 'tibia' OR 'fixation' OR 'graft' AND 'outcome measure.'

The inclusion criteria consisted of studies published in the English language or with English-language translation, reporting operative techniques and approaches for the primary treatment of isolated PCL injuries. Exclusion criteria consisted of: studies reporting the results of PCL surgery in the setting of multi-ligament knee injuries involving the anterior cruciate ligament, medial or lateral collateral ligament, primary PCL repair, biomechanical, anatomic or animal studies, epidemiological and national database studies, editorial articles, review articles, and systematic reviews/meta-analyses. Studies reporting on patients undergoing revision PCL reconstruction were also excluded, along with studies that failed to adequately describe surgical methods. Studies with overlapping patient data were considered separately with inclusion of those investigations reporting the most recent follow-up.

Two authors [D.M.K., V.G.] independently performed the initial search by screening articles in the following systematic approach: assessment of duplicate articles, content within the article title, content of the abstract, and full-text review. Any disagreements in study selection were discussed and decided by a third independent author R.H.B. To confirm that no studies were missing from the systematic review, all references cited in the included studies were also reviewed and reconciled.

Studies were classified into four global regions based on the primary investigative site: Asia, Europe, North America, and South America. Mean patient age and sex were recorded from each study. Reported injury mechanism(s) and graft source were analyzed based on the number of patients reported. Reconstruction technique (single- versus double-bundle), graft source (autograft versus allograft), tibial reconstruction technique (trans-tibial versus tibial inlay), femoral drilling method (outside-in versus inside-out), tibial fixation method, femoral fixation method, and whether the remnant PCL was preserved or debrided were analyzed based on the number of studies in which each variable was reported. When multiple surgical techniques or grafts were reported in the same study, each variable was separately recorded in its respective category. Patient reported outcome measures (PROMs) were recorded, when reported.

A methodological quality assessment of the included studies was performed by two authors (initials blinded for peer review) to ensure bias was minimized using the Newcastle–Ottawa Scale (NOS) for studies of level I-III evidence (Table 1) and the National Institute of Health (NIH) Quality Assessment for level IV evidence studies (Table 2). For each region, patient demographics, variation across surgical techniques, and proportion of studies reporting the most common patient-reported outcome measures (PROMs) were calculated and analyzed. Continuous variables were presented as means and standard deviations, while categorical variables were presented as percentages. Statistical analyses were performed using Microsoft Excel (V. 16.63.1, Microsoft, Redmond, WA, United States).

Results

Following the literature review, a total of 75 articles were identified. No disagreements between the two authors were encountered. The search process is outlined in the flow diagram (Fig. 1). During title and abstract assessment, a total of 62 studies were selected for full-text evaluation. Following full-text evaluation, a total of 45 articles meeting inclusion/exclusion criteria were identified, consisting of 1461 total patients.

Studies from Asia [1, 3, 4, 12–15, 18, 26, 33, 35, 37, 39, 40, 47–49, 56, 63, 65, 66, 69, 72, 76–80, 83–85] (69%, $n=31/45$) comprised the majority of included articles, followed by Europe [9, 20, 24, 25, 31, 38, 44, 58, 82] (20%, $n=9/45$), North America [22, 42, 55, 62] (8.9%, $n=4/45$), and South America [17] (2.2%, $n=1/45$) (Table 3, Additional file 1: Table S1). Males comprised 77% ($n=1120/1461$) of patients. Motor vehicle accidents were the most common injury mechanism in patients reported from studies out of Asia (55%, $n=453/827$) and South America (64%, $n=9/14$), while sports-related injuries represented the most common mechanisms of injury in patients from Europe (52%, $n=70/135$) and North America (56%, $n=19/34$). Single-bundle PCL reconstruction was reported in a higher number of studies from Asia (77%, $n=24/31$), Europe (78%, $n=7/9$) and North America (100%, $n=4/4$). Autografts were the most commonly utilized graft in patients reported in studies from Asia (66.7%, $n=788/1181$), Europe (96.6%, $n=197/204$), and South America (100%, $n=14/14$), while 69.4% ($n=43/62$) of patients from North America underwent isolated PCL reconstruction with allografts. Hamstring autografts were utilized in 51.7% ($n=611/1181$) of patients from studies out of Asia, 60.8% of patients from Europe ($n=124/204$), and 100% of patients from South America ($n=14/14$). The most common graft reported in patients from North America was the Achilles tendon allograft (58.1%, $n=36/62$). Use of the Ligament Advanced Reinforcement System (LARS) synthetic graft was reported in studies from Asia (4.8%, $n=57/1181$) and Europe (3.9%, $n=8/204$).

Across all regions, the trans-tibial technique was most commonly utilized when compared to the tibial inlay technique (Table 3, Additional file 1: Table S1). In Europe, North America, and South America, 100% ($n=14/14$) of studies utilized the trans-tibial technique, compared to 93.5% ($n=29/31$) of studies in Asia. Femoral tunnel drilling with an outside-in technique was reported in 54.1% ($n=20/37$) of all studies. Tibial graft fixation primarily involved interference screws (71%, $n=30/42$), followed by spike/staple fixation (12%, $n=5/42$) and buttons (7%, $n=3/42$). Interference screw fixation was the most commonly reported method of femoral fixation (67%, $n=29/43$), followed by button fixation (19%, $n=8/43$) and mini-plates (7%, $n=3/43$). Debridement of the PCL remnant was performed commonly in studies from Europe (80%, $n=4/5$), North America (100%, $n=2/2$), and South America (100%, $n=1/1$), while remnant preservation was reported in 86.4% ($n=19/22$) of studies from Asia.

Lysholm knee score, Tegner activity level scale, and International Knee Documentation Committee (IKDC) score were the most commonly reported PROMs across all regions (Additional file 2: Table S2). Posterior drawer grades were similarly reported in studies across all regions. Additional outcome measures, including the Western Ontario and McMaster University Osteoarthritis Index (WOMAC), Cincinnati Knee rating system, and Hospital for Special Surgery (HSS) score were less commonly reported. There was infrequent reporting of absolute posterior tibial translation and/or side-to-side differences. Complications were reported in 53.3% ($n=24/45$) of studies comprising a total of 179 patients. The most commonly reported complications consisted of discomfort with kneeling (8.9%, $n=16/179$ patients), paresthesia (8.4%, $n=15/179$ patients), crepitus (6.7%, $n=12/179$ patients), symptomatic hardware requiring removal (6.1%, $n=11/179$ patients), infection (5.0%, $n=9/179$ patients), and decreased range of motion (2.8%, $n=5/179$ patients).

Discussion

The most important findings of this investigation were that the majority of studies of patients undergoing isolated PCL reconstruction were reported from Asia. Isolated PCL reconstruction was performed primarily in males in all regions, most often using a single-bundle hamstring autograft through a trans-tibial tunnel with interference screw fixation on the tibia and femur. Debridement of the remnant PCL was performed in all regions except in Asia where it was preserved in most studies.

Across all four global regions, males underwent isolated PCL reconstruction more commonly than females,

Table 1 Newcastle–Ottawa Scale (NOS) quality assessment of the included studies. Each study was evaluated on points: the selection of study groups; the comparability of the groups; and the ascertainment of the outcomes measured. A star indicates that the study met the requirements. Each study can be awarded a maximum of nine stars

Newcastle–Ottawa Quality Scale ★

	Selection				Comparability		Outcome			
Study (Year)	**Representativeness of treated cohort**	**Selection of comparative cohort**	**Ascertainment of treated cohort records**	**Outcome of interest was not present at start**	**Controls for age/sex**	**Controls for any additional factor**	**Assessment of outcome**	**Long enough follow-up**	**Adequacy of follow-up**	**Total Quality Score**
Chen et al. (2002) [14]	★	★	★	★	★	★	★	★	★	9
Lee et al. (2013) [33]	★	★	★	★	0	0	★	★	★	7
Li et al. (2014) [37]	★	★	★	★	★	★	★	★	★	9
Li et al. (2015) [35]	★	★	★	★	★	★	★	★	★	9
Lin et al. (2013) [40]	★	★	★	★	★	★	★	★	★	9
MacGillivray et al. (2006) [42]	★	★	★	★	★	★	★	★	★	9
Ochiai et al. (2019) [49]	★	0	★	★	0	0	★	★	★	6
Rhatomy et al. (2021) [56]	★	★	★	★	★	★	★	★	★	9
Saragaglia et al. (2020) [58]	★	★	★	★	★	★	★	★	★	9
Seon et al. (2006) [63]	★	★	★	★	0	0	★	★	★	7
Song et al. (2014) [66]	★	★	★	★	★	★	★	★	★	9
Tachibana et al. (2021) [69]	★	★	★	★	★	★	★	★	★	9
Wang et al. (2004) [72]	★	★	★	★	0	★	★	★	★	8
Wong et al. (2009) [76]	★	★	★	★	0	★	★	★	★	8
Xu et al. (2014) [78]	★	★	★	★	★	★	★	★	★	9
Yang et al. (2012) [79]	★	★	★	★	★	★	★	★	★	9
Yoon et al. (2019) [80]	★	★	★	★	0	★	★	★	★	8
Zhao et al. (2007) [83]	★	★	★	★	0	★	★	★	★	8
Zhao et al. (2009) [85]	★	0	★	★	0	0	★	★	★	6

Table 2 The National Institute of Health (NIH) Quality Assessment Tool quality assessment. Study quality was rated as 0 for poor (0–4 out of 14 questions), i for fair (5–10 out of 14 questions), or ii for good (11–14 out of 14 questions)

NIH Quality Assessment ✓

Study (Year)	Was the research question or objective in this paper clearly stated?	Was the study population clearly specified and defined?	Was the participation rate of eligible persons at least 50%?	Were all the subjects selected or recruited from the same or similar populations?	Was a sample size justification, power description, or variance and effect estimates provided?	For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?	Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?	For exposures that can vary in amount or level, did the study examine different levels of the exposure?	Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	Was the exposure(s) assessed more than once over time?	Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented? consistently across all study participants?	Were the outcome assessors blinded to the exposure status of participants?	Was loss to follow-up after baseline 20% or less?	Were key potential confounding variables measured and adjusted statistically for their impact on the relationship? between exposure(s) and outcome(s)?	Summary Quality
Adachi et al. (2007) [1]	✓	✓	✓	✓	X	✓	✓	X	X	✓	✓	✓	✓	X	i
Ahn et al. (2006) [4]	✓	✓	✓	✓	X	✓	✓	X	✓	X	✓	✓	✓	X	i
Ahn et al. (2013) [3]	✓	✓	✓	✓	✓	✓	✓	X	✓	X	✓	✓	✓	X	ii
Boutefnouchet et al. (2013) [9]	✓	✓	✓	✓	X	X	✓	X	✓	X	✓	✓	✓	X	i
Chan et al. (2006) [12]	✓	✓	✓	✓	X	✓	✓	X	✓	X	✓	X	✓	X	i
Chen et al. (2009) [13]	✓	✓	✓	✓	X	✓	✓	X	✓	X	✓	X	✓	X	i
Chen et al. (2012) [15]	✓	✓	✓	✓	X	✓	✓	X	✓	X	✓	X	✓	X	i
Cury et al. (2012) [17]	✓	✓	✓	✓	X	✓	✓	✓	✓	X	✓	X	✓	X	i
Eguchi et al. (2014) [18]	✓	✓	✓	✓	X	✓	✓	X	✓	✓	✓	X	✓	X	i
Garofalo et al. (2006) [20]	✓	✓	X	✓	X	✓	✓	✓	✓	X	✓	X	✓	X	i
Gill et al. (2009) [22]	✓	✓	✓	✓	X	✓	✓	X	✓	X	✓	X	✓	X	i
Hermans et al. (2009) [24]	✓	✓	✓	✓	X	X	✓	X	✓	X	✓	✓	✓	X	i
Ihle et al. (2014) [25]	✓	✓	X	✓	X	X	✓	✓	✓	X	✓	X	✓	X	i

Table 2 (continued)

NIH Quality Assessment ✓															
Study (Year)	**Was the research question or objective in this paper clearly stated?**	**Was the study population clearly specified and defined?**	**Was the participation rate of eligible persons at least 50%?**	**Were all the subjects selected or recruited from the same or similar populations?**	**Was a sample size justification, power description, or variance and effect estimates provided?**	**For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?**	**Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?**	**For exposures that can vary in amount or level, did the study examine different levels of the exposure?**	**Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?**	**Was the exposure(s) assessed more than once over time?**	**Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented? consistently across all study participants?**	**Were the outcome assessors blinded to the exposure status of participants?**	**Was loss to follow-up after baseline 20% or less?**	**Were key potential confounding variables measured and adjusted statistically for their impact on the relationship? between exposure(s) and outcome(s)?**	**Summary Quality**
Jung et al. (2004) [26]	✓	✓	✓	✓	X	✓	✓	X	✓	X	✓	X	✓	X	i
Lahner et al. (2012) [31]	✓	✓	X	✓	X	✓	✓	✓	✓	X	✓	X	✓	X	i
Lien et al. (2010) [38]	✓	✓	✓	✓	X	✓	✓	X	✓	X	✓	✓	✓	X	i
Lim et al. (2010) [39]	✓	✓	✓	✓	X	✓	✓	X	✓	X	✓	✓	✓	X	i
Mariani et al. (1997) [44]	✓	✓	✓	✓	X	✓	✓	✓	✓	X	✓	X	✓	X	i
Noh et al. (2017) [47]	✓	✓	✓	✓	✓	✓	✓	✓	✓	X	✓	X	✓	X	ii
Norbakhsh et al. (2014) [48]	✓	✓	✓	✓	X	✓	✓	✓	✓	X	✓	X	✓	X	i
Rauck et al. (2019) [55]	✓	✓	✓	✓	X	✓	✓	✓	✓	X	✓	X	✓	X	i
Sekiya et al. (2005) [62]	✓	✓	✓	✓	X	✓	✓	✓	✓	X	✓	✓	✓	X	ii
Shon et al. (2010) [65]	✓	✓	✓	✓	X	✓	✓	✓	✓	X	✓	X	✓	✓	ii
Wu et al. (2007) [77]	✓	✓	✓	✓	X	✓	✓	✓	✓	X	✓	X	✓	X	i
Zayni et al. (2011) [82]	✓	✓	✓	✓	X	✓	✓	X	✓	X	✓	X	✓	X	i
Zhao (2008) [84]	✓	✓	✓	✓	X	✓	✓	✓	✓	✓	✓	X	✓	X	ii

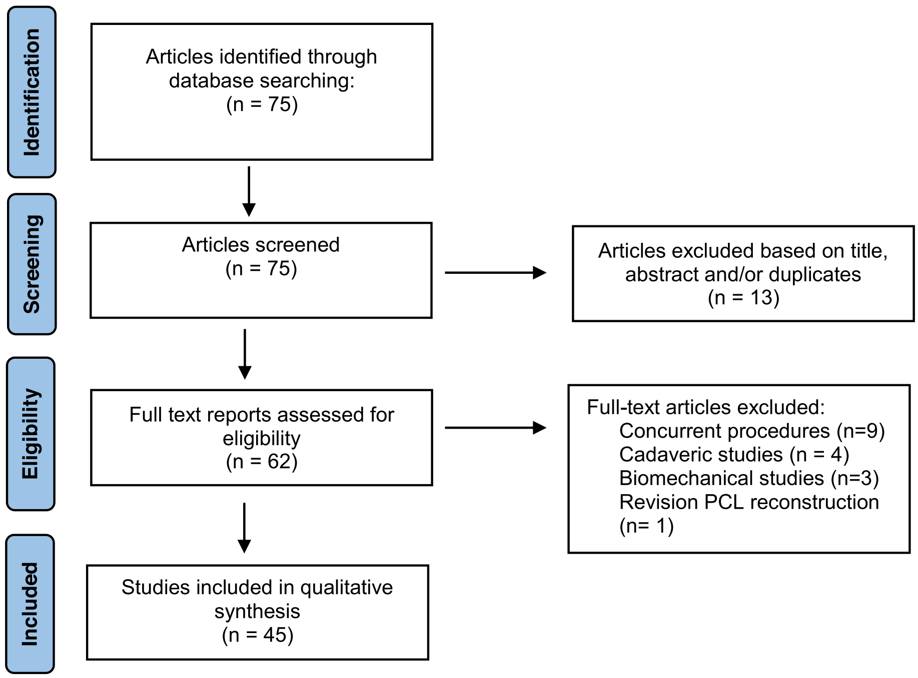

Fig. 1 Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) flowchart of study

which is in agreement with prior investigations [32, 60]. Specifically, LaPrade et al. [32] observed that PCL injuries were more prevalent in males, whether isolated or combined with other injuries when compared to females. This finding may be related to the higher rate of male participation in contact sports, such as Association football and cricket in Asia, American football and basketball in North America, and soccer in Europe and South America. Participation in these activities, especially at a high level, may require surgical reconstruction, even in the presence of isolated PCL injuries, to restore stability and allow successful and effective return to sport [68]. Meanwhile, other traumatic mechanisms of injury, such as motor vehicle injuries and falls remain a potential etiology behind PCL injuries [20, 38]. There remains limited evidence regarding the influence of anatomic differences between males and females sustaining PCL injuries. Van Kujik et al. [71] reported on radiographic measures of intercondylar notch width and shape in 94 patients with PCL rupture compared to 168 age and sex-matched controls. The authors observed that patients with PCL injuries possessed a smaller and more sharply angled notch. However, no separate analyses evaluating differences between male and female patients was performed. Meanwhile, Liu et al. [41] found in their investigation analyzing 103 patients ($n=41$ females; $n=62$ males) with PCL ruptures compared to age and sex-matched controls, that the greatest risk factor for PCL injury was a greater coronal notch width in females and decreased coronal condylar width in males. Further studies identifying specific epidemiologic and anatomic factors contributing to the higher reported prevalence of isolated PCL reconstruction in males are warranted.

Single-bundle PCL reconstruction was the most common graft configuration reported in the majority of studies. The relative worth of single- versus double-bundle reconstruction continues to be debated in the current literature [31]. Biomechanical investigations have demonstrated that the anterolateral and posteromedial bundles each resist posterior tibial translational at different degrees of knee flexion, supporting the concept of codominant, synergistic roles for the two PCL bundles [2, 27]. Traditional single-bundle reconstruction techniques have been shown to primarily restore the anterolateral bundle [51, 73]. Wijdicks et al. [73] observed in their biomechanical study that the double-bundle reconstruction effectively enabled restoration of near normal knee kinematics with improved rotational stability when compared to the single-bundle reconstruction. Several clinical investigations have similarly observed improved restoration of native knee anatomy and kinematics using a double-bundle reconstruction [6, 24, 29, 54]. Kim et al. [30] reported that single-bundle PCL reconstruction improved posterior knee laxity, as well as clinical outcome scores based on Lysholm and IKDC scores; however, restoration

Table 3 Overview of study variables during isolated posterior cruciate ligament reconstruction based on global region

	Asia (*n* = 31)	**Europe (*n* = 9)**	**N. America (*n* = 4)**	**S. America (*n* = 1)**
Age	30.7 +—3.7	28.4 +—2.31	32.6 +—4.8	31.0 +—0
Gender (% male/total patients)	.772 (912/1181)	.765 (156/204)	.694 (43/62)	.643 (9/14)
Injury Mechanism (*n* = # patients reported)				
Motor Vehicle Accident	.548 (453/827)	.429 (58/135)	.294 (10/34)	.643 (9/14)
Sports	.320 (265/827)	.519 (70/135)	.559 (19/34)	.357 (5/14)
Falls	.047 (39/827)	0 (0/135)	.112 (4/34)	0 (0/14)
Other	.084 (70/827)	.052 (7/135)	.029 (1/34)	0 (0/14)
Bundle Number (*n* = # of studies reporting)				
Single	0.774 (24/31)	0.778 (7/9)	1.000(4/4)	0 (0/1)
Double	0.258 (8/31)	0.333 (3/9)	0.250 (1/4)	1 (1/1)
Graft Source (*n* = # of patients reported)				
Hamstring autograft	.517 (611/1181)	.608 (124/204)	.032 (2/62)	1 (14/14)
Achilles tendon allograft	.203 (240/1181)	.044 (9/204)	.581 (36/62)	0 (0/14)
Quadriceps tendon autograft	.051 (60/1181)	.103 (21/204)	.113 (7/62)	1 (14/14)
Tibialis Anterior allograft	.107 (126/1181)	0 (0/204)	0 (0/62)	0 (0/14)
Bone-patellar-tendon-bone autograft	.054 (64/1181)	.328 (67/204)	.177 (11/62)	0 (0/14)
Bone-patellar-tendon-bone allograft	.008 (10/1181)	0 (0/204)	.113 (7/62)	0 (0/14)
Other	.045 (53/1181)	0 (0/204)	0 (0/62)	0 (0/14)
Autograft	.667 (788/1181)	.966 (197/204)	.322 (20/62)	1 (14/14)
Allograft	.318 (376/1181)	.147 (30/204)	.694 (43/62)	0 (0/14)
Artificial Graft (LARS)	.048 (57/1181)	.039 (8/204)	0 (0/62)	0 (0/14)
Tibial Technique (*n* = # of studies reporting)				
Transtibial	.935 (29/31)	1 (9/9)	1 (4/4)	1 (1/1)
Tibial Inlay	.129 (4/31)	0 (0/9)	.5 (2/4)	0 (0/1)
Femoral Tunnel Drilling (*n* = # of studies reporting)				
Outside-In	.462 (12/26)	.571 (4/7)	1 (3/3)	1 (1/1)
Inside-Out	.538 (14/26)	.429 (3/7)	0 (0/3)	0 (0/1)
Tibial Fixation (*n* = # of studies reporting)				
Screw	.645 (20/31)	.875 (7/8)	1 (2/2)	1 (1/1)
Spike/Staple	.129 (4/31)	.125 (1/8)	0 (0/2)	0 (0/1)
Button	.097 (3/31)	0 (0/8)	0 (0/2)	0 (0/1)
Other	0 (0/31)	0 (0/8)	0 (0/2)	0 (0/1)
Femoral Fixation (*n* = # of studies reporting)				
Screw	.581 (18/31)	.875(7/8)	1 (3/3)	1 (1/1)
Button	.226 (7/31)	.125(1/8)	0 (0/3)	0 (0/1)
Mini-Plate	.097 (3/31)	0(0/8)	0 (0/3)	0 (0/1)
Other	.097 (3/31)	0(0/8)	0 (0/3)	0 (0/1)
Remnant (*n* = # studies reporting)				
Preserved	0.864 (19/22)	.2 (1/5)	0 (0/2)	0 (0/1)
Debrided	.182 (4/22)	.8 (4/5)	1 (2/2)	1 (1/1)
Reported PROMs (*n* = # studies reporting)				
Lysholm	.903 (28/31)	.889 (8/9)	.5 (2/4)	1 (1/1)
Tegner	.613 (19/31)	1 (9/9)	.5 (2/4)	0 (0/1)
IKDC	.774 (24/31)	1 (9/9)	.75 (3/4)	1 (1/1)
Posterior Drawer	.419 (13/31)	.444 (4/9)	.5 (2/4)	1 (1/1)

Legend: *LARS* Ligament Advanced Reinforcement System, *PROM* Patient reported outcomes measures, *IKDC* International Knee Documentation Committee of native knee stability was not re-established. Similarly, Li et al. [37] reported improved side-to-side differences in posterior tibial translation in patients undergoing double-bundle PCL reconstruction (2.2 mm) when compared to single-bundle reconstruction (4.1 mm). A systematic review and meta-analysis comparing single- and double-bundle PCL reconstructions by Chahla et al. [10] observed significant improvement in posterior tibial translation and objective IKDC scores in patients undergoing double-bundle reconstruction without significant differences in postoperative Lysholm or Tegner scores. Despite the concern for persistent posterior laxity with single-bundle reconstruction, this technique is still more commonly reported, especially in studies performed in Asia. The specific reasoning behind this finding, whether secondary to cost, operative time, or the complexity associated with the double-bundle technique, warrants further investigation.

The use of autograft tissue, with the most common source being the hamstrings, represented the most frequently reported graft type. Clinical studies comparing autograft and allograft PCL reconstruction are limited. Sun et al. [67] reported that despite comparable functional scores following PCL reconstruction, patients treated with autografts possessed improved posterior knee stability when compared to allografts. Li et al. [35] similarly observed equivalent outcomes in patients undergoing single-bundle PCL reconstruction utilizing hamstring tendon autografts versus tibialis anterior allografts. Wang et al. [72] reported that despite comparable outcomes in patients reconstructed with autograft versus allograft tissue, there was an increased risk of complications with autografts related primarily to infection and donor-site morbidity. A meta-analysis of five studies (1 randomized controlled trial [RCT], 4 non-RCTs) performed by Tian et al. [70] reported no significant differences in Lysholm, IKDC, or posterior stability in patients reconstructed with autograft tendons compared to those treated with allografts ($p = 0.04$). However, the authors concluded that there is currently insufficient evidence to determine the superiority of one graft type over the other. Therefore, the optimal graft source for isolated PCL reconstruction remains controversial, with the frequent use of autograft across all global regions potentially related to limited allograft availability, high costs, surgeon bias, or concerns for disease transmission or graft rejection [70].

Trans-tibial drilling was more commonly reported when compared to a tibial inlay technique. While initially designed to avoid the sharp angle ("killer curve") present at the proximal aperture of the tibial tunnel, potentially leading to graft damage and failure [7, 8], it is likely that the necessity of performing an open posterior approach, increasing risk of injury to the saphenous nerve or popliteal neurovascular structures, may be responsible for the infrequent performance of the open tibial inlay technique [81]. In addition, the risk of nonunion of the inlay bone plug, along with the development of popliteal adhesions to the posterior capsule complicating revisions procedures, may account for the popularity of trans-tibial drilling [32]. The recent evolution of an all-arthroscopic inlay technique that avoids the posterior exposure may increase the popularity of the inlay method in that it not only avoids the "killer curve" associated with a trans-tibial tunnel, but also some neurovascular risks associated with the open inlay procedure.

Significant differences in either biomechanical or clinical outcomes between the trans-tibial and tibial inlay techniques have not been reported. McAllister et al. [45] found no significant differences in mean knee laxities between the tibial tunnel and tibial inlay techniques at any knee flexion angle; as both reconstruction techniques restored mean knee posterior laxity to within 1.6 mm of the intact knee values over the entire range of knee motion. Shin et al. [64] observed no significant differences in their systematic review of 7 studies comparing outcomes in patients undergoing trans-tibial drilling versus either open or arthroscopic tibial inlay during single-bundle PCL reconstruction. Meanwhile, Song et al. [66] found similar clinical and radiographic outcomes between the two techniques in 66 patients after a mean follow-up of 148 months. Therefore, despite comparable outcomes, the potential risks and complexity associated with the open tibial inlay procedure have likely tempered surgeon interest in this procedure. Further studies comparing the trans-tibial and arthroscopic inlay techniques are warranted.

This study is not without limitations. Due to the heterogeneity of reported surgical techniques in the four global regions examined, we could not perform any direct comparison of outcomes based on the techniques utilized in each region. Moreover, due to the small number of studies meeting our inclusion criteria, especially in the North and South American regions, the performance of any meaningful statistical analyses was limited. Evaluation of outcomes based on posterior laxity was not performed due to the significant variation of techniques used to assess posterior tibial laxity, including KT-1000 arthrometer and various stress radiographic techniques [51]. The incidence and severity of osteoarthritic development were not analyzed due to the large variation in reported follow-up. The higher prevalence of isolated PCL reconstructions performed in a certain global region does not imply that the procedure and techniques are preferentially performed by the majority of surgeons in that region. This study was only able to evaluate the published literature, which was generated predominantly by academic centers. Unfortunately, there are no comprehensive international repositories of surgical data that would be required to definitively determine the procedures and techniques that are actually being performed by all surgeons in each global region. Despite this study being limited to patients sustaining isolated PCL injuries, the true prevalence of concurrent meniscal and chondral injuries requiring intervention that were not reported or overlooked during intervention, cannot be inferred, leading to a potential bias in interpreting the data. We did not include surgical treatment of multi-ligamentous knee injuries, which may be the most common indication for PCL reconstruction. Lastly, due to the infrequent reporting of injury grade, this variable was not accounted for in our analysis.

Conclusions

Surgical treatment of isolated PCL injuries varies by region, with the majority of published studies coming from Asia. Single-bundle reconstruction with hamstring autograft through a trans-tibial approach is the most commonly reported technique in the literature, with males reported to undergo isolated reconstruction more often than females.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40634-022-00541-4.

Additional file 1: Table S1. Overview of included studies based on global region.

Additional file 2: Table S2. Outcomes following isolated PCL reconstruction.

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Authors' contributions
DMK: Study conception, literature review, data analysis, manuscript preparation. VG: Literature review, data analysis. MVS: Data analysis, manuscript preparation. MJM: Data analysis, manuscript preparation. RHB: Study conception, data analysis, manuscript preparation. The author(s) read and approved the final manuscript.

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