Outcomes of Posterior Cruciate Ligament Treatment: A Review of the Evidence

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Objectives: The purpose of this systematic review is to assess the current recommendations in an evidence-based manner with regard to posterior cruciate ligament (PCL) reconstruction.

Methods: We conducted a systematic review of multiple databases, evaluating studies on the outcomes of PCL treatment in isolation and in the multiligamentous injured knee.

Results: Twenty-one studies of isolated PCL reconstructions and 10 studies of combined PCL reconstruction were identified for inclusion. Eight studies reported graft failure as an outcome, with an overall rate of 11.6%. Three studies reported outcomes of single bundle PCL reconstruction using hamstring autograft; there were 12 graft failures in 96 reconstructions (12.5%). There were 2 graft failures in a total of 17 combined PCL/anterior cruciate ligament/posterolateral corner reconstructions (11.8%). In the combined PCL studies, return to preinjury activity level ranged from 19 to 68%. In the isolated PCL studies, 50 to 82% of patients were able to return to preinjury activity level. There were no significant differences in functional outcomes (Lysholm and IKDC). From 37% to 70% of patients in the combined PCL studies had a normal posterior drawer test at final follow-up. One study showed a significant difference in the mean posterior drawer test side-to-side difference between the 7-strand and 4-strand hamstring autograft groups (1.7 vs. 3.7 mm, $P < 0.05$).

Conclusions: Currently, firm recommendations on what treatment or technique to choose cannot be given based upon the available literature. There is a need for higher-quality clinical studies to guide treatment decisions. Generally good results are reported after PCL reconstruction, but the long-term studies available suggest that normal stability in the majority of patients is not restored.

Key Words: posterior cruciate ligament, systematic review, multiligamentous, ligaments, surgical outcomes, graft failure, functional assessment, activity level, posterior knee laxity

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Many controversies persist regarding the treatment of posterior cruciate ligament (PCL) injuries. PCL injuries occur in up to 44% of all acute knee injuries,[1] but isolated PCL injuries (PCL injuries in which no associated ligamentous injuries require repair and/or reconstruction) have a reported incidence of as little as 3.5%.[2] As compared with the anterior cruciate ligament (ACL), PCL injuries are infrequent and present to a sports medicine clinic in a ratio of 50 to 1.[3] Most PCL injuries occur in combination with other knee ligamentous injuries and are seen most commonly after knee dislocations in the setting of high-energy trauma.[4–7]

Debate is ongoing and no uniformly accepted treatment algorithm exists for the treatment of closed dislocations of the knee without associated neurovascular compromise.[8] The individualized treatment protocol is influenced in part by the natural history of the associated ligamentous injuries. Specifically, medial-sided injuries can reproducibly heal with appropriate nonoperative management in the acute setting.[9] In contrast, injuries to the lateral and posterolateral structures of the knee have been more successfully treated with surgical repair and/or reconstruction.[10,11] Simultaneous early reconstruction of both cruciates, when disrupted, has been advocated by many investigators.[4,12–15] However, early surgery may not be feasible in the polytraumatized patient or in the patient with life-threatening injuries.[16]

Unlike the multiligamentous injuries seen with knee dislocations that include PCL tears, reported results of nonoperative management of isolated PCL tears have been encouraging.[1,17] Some of these patients, however, will require surgical reconstruction owing to the development of chronic, symptomatic instability. Moreover, many studies have shown that nonoperative treatment may lead to degenerative changes in the knee over time.[18,19]

Surgical results after isolated PCL reconstructions have been less satisfactory as compared with results after ACL surgery. Contributing factors include: the paucity of PCL reconstructions carried out resulting in less surgeon experience; complex anatomy of the PCL; and a constant posterior gravity force on the PCL graft at rest.[3] On account of the relatively rare nature of these injuries and their surgical treatment, very few studies in the literature have focused on isolated PCL reconstructions. Moreover, the current literature lacks high-quality randomized controlled trials and prospective comparative studies, limiting the value of the available reported results.

The purpose of this systematic review is to assess the current recommendations in an evidence-based manner with regard to PCL reconstruction including: graft choice; single versus double-bundle reconstruction; transtibial compared with tibial inlay techniques; and the role of preservation of the remnant of the PCL. The primary aim is to report outcomes after management of isolated and combined PCL injuries from the available current literature. We defined combined PCL injuries as PCL injuries occurring in combination with other ligamentous injuries in which the PCL and at least one additional ligament requires repair and/or reconstruction.

METHODS

A systematic literature review was performed with the following data sources used: MEDLINE with OVID and

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PUBMED (basic search, related articles, clinical queries search), EMBASE, and the Cochrane Central Register of Controlled Trials, for relevant articles in the English language. Bibliographies of identified articles on this topic were also reviewed.

Initial inclusion criteria limited the inclusion of studies to the following: studies with a primary aim at assessing outcomes after PCL reconstruction [single bundle (SB) vs. double bundle (DB); tibial inlay vs. transtibial; comparison of different graft options; preservation of the PCL remnant (Pr)]; all levels of evidence; publication in a peer-reviewed journal from 1985 to the present; and minimum of 2-year follow-up after PCL reconstruction. After this initial search our inclusion criteria were further refined to include, in addition to the above stated criteria, a minimum sample size of 10 patients and a minimum of 80% follow-up. Studies were excluded if any of the following applied: nonclinical studies (animal or cadaveric studies); biomechanical studies; in vitro studies; primary PCL repairs; treatment of PCL avulsion injuries; revision procedures; papers with mixed populations of isolated and combined PCL reconstructions in which the outcomes were not reported separately; synthetic, LARS (Ligament Augmentation and Reconstruction System), prosthetic, and LAD (Ligament Augmentation Device) reconstructions; and if > 20% of patients were lost before final follow-up. Moreover, to be included as a combined PCL study, all combinations of multiligamentous knee reconstructions must have included a PCL reconstruction.

All studies identified in the initial search were screened for duplications by entering them into a computer-based reference management system. All eligible articles were then screened first by title and abstract, followed by an in-depth review of each article's methodology and outcomes. The results of this search are shown in Tables 1 and 2, which include the studies of isolated and combined PCL reconstructions meeting the above criteria. A modified standardized data extraction form was used to retrieve data from each article on study design, population, interventions, and outcomes.[50] Outcomes of particular interest included return to preinjury level of activity, graft failure rate, laxity measurements, knee range of motion, and standardized knee outcomes scores. We defined graft failure rate as either revision PCL reconstruction, displacement of the medial tibial plateau posterior to the femoral condyle/grade III posterior drawer test, and/or > 10 mm increase in posterior tibial displacement on physical examination. We did not include KT-1000 measurements as a criterion for failure because of variability in testing.

RESULTS

General Description of Studies (Tables 1, 2).

Twenty-one studies of isolated PCL reconstructions and 10 studies of combined PCL reconstructions met our initial inclusion criteria and were published after 1997. Data for each study was collected using a worksheet developed by the investigators. The basic details of the studies are shown in Tables 1 and 2, including sample sizes, length of follow-up, techniques of reconstruction, graft types, and the methods of fixation of the grafts.

Of the 21 studies included for isolated PCL reconstructions, only 1 was a prospective level of evidence II study, in which the investigators compared functional outcomes of an anteromedial (AM) vs. anterolateral (AL) transtibial tunnel drilling technique in SB arthroscopic PCL reconstruction using hamstring tendon (HT) autograft and preservation of the PCL remnant.[23] Seven studies were retrospective comparative studies (level of evidence III) comparing functional outcomes of 4-strand HT versus 7-strand HT autografts; SB versus DB; transtibial and tibial inlay techniques; 1-incision versus 2-incision arthroscopic PCL reconstruction; and autograft versus allograft (quadriceps tendon (QT) and 4-strand HT were used in the autograft group and achilles and tibialis anterior grafts were used in the allograft group).[20,23,25–27,32,33,40] The remaining studies were retrospective case series of functional outcomes following isolated PCL reconstructions.

All 10 studies meeting inclusion and exclusion criteria for combined PCL reconstructions were retrospective case series (Table 2). Three studies assessed outcomes after combined reconstruction of the PCL and posterolateral corner.[47–49] The reconstruction technique used for all 3 studies was a SB, transtibial technique using a variety of graft types. Four studies reported outcomes after combined reconstruction of the anterior cruciate ligament (ACL) and PCL.[41,43,45,46] In 1 study by Zhao et al,[46] DB PCL reconstructions were evaluated; the remainder involved case series of SB reconstructions. One study evaluated outcomes after ACL/PCL/posterolateral corner combined reconstructions in 17 patients[44] and the remaining 2 studies evaluated various combinations of multiligamentous knee reconstructions.[4,42]

Outcomes

Graft Failure Rate (Table 3)

Of the studies meeting our inclusion criteria, we evaluated graft failure rates and included all patients with a final follow-up posterior drawer test of grade 3 or greater (defined as $\geq$ 10 mm increase in posterior tibial displacement or displacement of the medial tibial plateau posterior to the femoral condyle) and/ or patients that required revision PCL surgery. The results of the graft failure analysis are shown in Table 3. In 3 studies that evaluated outcomes after isolated SB PCL reconstruction using autograft HT, there were 12 graft failures in 96 reconstructions (12.5%).[20,23,39] The study by Zhao et al[20] compared 4-strand HT autograft with 7-strand HT autograft and the 1 failure reported was in the 4-strand HT group. In the study by Strobel et al,[44] 2 graft failures were seen in a total of 17 combined ACL/PCL/posterolateral corner reconstructions (11.8%). In this study the PCL was reconstructed using 4-strand HT autograft in a SB technique. Two studies, in which the PCL was reconstructed using bone-patellar tendon-bone (PT) autograft, 3 graft failures were reported out of a total of 39 procedures (7.7%).[29,42] One study reported their outcomes on 22 isolated PCL reconstructions using QT autograft in a SB technique; there were 2 graft failures in this group (9.1%). One study reported 6 graft failures in 20 SB PCL reconstructions (30%), using a mixture of PT autograft, PT allograft, and Achilles (Ac) tendon allograft.[29] In this study they compared the tibial inlay versus transtibial techniques; they reported 2 graft failures out of 7 reconstructions in the tibial inlay group (28.6%) and 4 graft failures out of 13 total in the transtibial group (30.8%). Overall the graft failure rate for the 8 studies where failure was reported as

TABLE 1. Details of Isolated PCL Reconstruction Studies

Study (Level of Evidence)	Year of Publication	Mean Age (y) (Range)		Sample Size (N) (% f/u)	Mean Follow-up (mo) (range)‡	Techniques and Grafts Compared		Method of Fixation			
								Grp 1		Grp 2	
		Grp 1	Grp 2			Grp 1	Grp 2	Tibia	Femur	Tibia	Femur
Zhao et al (III)[20]	2007	(23-46)	(19-45)	43 (84)	30	4HT	7HT	Variable	*P*	Eb	*P*
Zhao et al (IV)[21]	2008	34 (19-42)		18 (100)	24	8HT (Pr)		Eb	P	—	—
Wu et al (IV)[22]	2007	27 (18-49)		22 (100)	66 (60-76)	Au/QT/SB/TT/AM/2I		ScW + IfSc	IfSc	—	—
Wong et al (II)[23]*	2009	30 (16-60)		55 (92)	48 vs. 45	AM/HT/ SB/Pr	AL/HT/ SB/Pr	IfSc	IfSc	IfSc	IfSc
Wang et al (IV)[24]	2003	32 (16-57)		31 (100)†	40 (24-108)	SB		Variable	IfSc	—	—
Wang et al (III)[25]	2004	29 (16-54)	30 (16-64)	55 (100)	33 (24-71)	Au (QT,4HT)	Al (Ac,TA)	IfSc	IfSc	IfSc	IfSc
Wang et al (III)[26]	2004	29 (17-60)	28 (16-47)	35 (97)	41 vs. 28	SB/HT	DB/HT	IfSc	IfSc	IfSc	IfSc
Seon et al (III)[27]	2006	29 (17-56)	29 (18-50)	43 (100)	32 vs. 36	TT/4HT	TI/PT	IfSc	LA	ScW ± St	IfSc
Nyland et al (IV)[28]	2002	36 (NA)		18 (95)	27	DB/Al (TA, HT)		IfSc	IfSc	—	—
Mariani et al (IV)[29]	1997	26 (16-39)		24 (100)	26 (24-53)	Au/PT/SB		Sc	IfSc	—	—
Macgillivray et al (IV)[30]	2006	29 (17-49)		20 (90)	66 (24-180)	TT	TI	IfSc	IfSc + Eb/ SW/St	ScW	IfSc + Eb/ SW/St
Lim et al (IV)[31]	2010	36 (18-59)		22 (100)	33 (24-60)	Al/Ac/SB		Cp	IfSc	—	—
Kim et al (III)[32]	2009	32.4 31.9 33.6		29 (100)	46 vs. 36 vs. 29	TT/SB TI/SB TI/DB (All Ac/Al)		IfSc (TT)	IfSc (TT)	IfSc + PW (both TI)	IfSc (both TI grps)
Kim et al (III)[33]	2000	32 (18-46)	33 (17-60)	55 (100)	45 vs. 36	1I/PT 2I/PT (Al, Au)		IfSc	IfSc	IfSc	IfSc
Jung et al (IV) [34]	2005	29 (17-56)		11 (91)	52 (24-80)	PT/SB/TI/Pr		Sc + W/St	IfSc	—	—
Hermans et al (IV)[35]	2009	31 (17-52)		22 (88)	109 (78-151)	SB/TT (variable grafts)		IfSc +/- St	IfSc	—	—
Garofalo et al (IV)[36]	2006	27 (17-43)		15 (100)	NA (24-60)	Au/DB (PT + 2HT)		ScW	IfSc	—	—
Chen et al (IV)[37]	2002	27 (20-52)		49 (90%)	30 vs. 26	Au/QT	Au/4HT	ScW	IfSc	IfSc + ScW	IfSc + ScW
Chen and Garo (IV)[38]	2009	39 (19-53)		19 (86)	(24-29)	Au/8HT/TT/DB		B	B	—	—
Chan et al (IV)[39]	2006	29 (20-57)		20 (100)	40 (36-50)	Au/4HT/TT/SB/2I		IfSc + ScW	IfSc	—	—
Ahn et al (III)[40]	2005	30 (16-58)	31 (17-60)	36 (88)	35 vs. 27	Au/4HT	Al/Ac	IfSc + PW	IfSc + ScW	IfSc + PW	IfSc + ScW

1I indicates 1 incision technique; 2I, 2 incision technique; Ac, Achilles tendon graft; Al, allograft; AL, anterolateral transtibial tunnel; AM, anteromedial transtibial tunnel; Au, autograft; B, sutures tied over bone bridge; Cp, cross-pins; DB, double bundle; Eb, endobutton; HT, hamstring tendon graft (number preceding denotes number of graft strands); IfSc, interference screw; LA, ligament anchor screw; NA, not available; P, plate; Pr, preservation of PCL remnant; PT, Bone-patellar tendon-Bone; PW, post + washer; QT, quadriceps tendon graft; SB, single bundle; Sc, screw; W, washer; ScW, screw and washer; St, staples; Su, sutures; TA, tibialis anterior tendon graft; TI, tibial inlay; TT, transtibial.

*All reconstructions SB/HT/Pr.

†30 patients with 31 knees.

‡All follow-up periods minimum 24 mo.

TABLE 2. Details of Combined PCL Reconstruction Studies

Study (Level of Evidence)	Year of Publication	Mean Age (y) (Range)	Sample Size (N) (% Follow-up)	Mean Follow-up (mo) (Range)	Ligamentous Injury Pattern(s)	PCL Reconstruction Technique	PCL Graft (Fixation)	Chronic Injuries (> 3 mo)
Fanelli et al (IV)[4]	2002	NR	35 (100)	NR (24-120)	19 ACL/PCL/PLC; 9 ACL/PCL/MCL; 6 ACL/PCL/PLC/MCL; 1 ACL/PCL	SB/TT	Variable grafts; (tib ScW + IfSc; fem ScW)	16/35
Lo et al (IV)[41]	2009	33 (19-48)	11 (100)	55 (36-78)	ACL/PCL	SB/TT	Au/QT; (fem/tib IfSc)	5/11
Mariani et al (IV)[42]	2001	25 (18-35)	15 (93)	36 (24-56)	8 ACL/PCL; 5 ACL/PCL/MCL; 2 ACL/PCL/LCL	SB/TT	Au/PT; (fem/tib IfSc)	NR
Shi et al (IV)[43]	2008	24 (17-44)	15 (100)	38 (36-40)	ACL/PCL	SB/TT	Al/Ac	NR
Strobel et al (IV)[44]	2006	30 (15-58)	17 (80.9)	NR (24-66)	ACL/PCL/PLC	SB/TT	Au/4HT; (tib IfSc + Eb; fem Eb)	17/17
Zhao et al (IV)[45]	2006	27 (18-56)	12 (100)	32	ACL/PCL	SB/TT	Au/6-8HT; (fem P; tib Eb)	9/12
Zhao et al (IV)[46]	2008	27 (18-56)	21 (100)	24	ACL/PCL	DB/TT	Au/8HT; (fem P; tib Eb)	14/21
Fanelli et al (IV)[47]	2004	NR (15-40)	41 (80.4)	NR (24-120)	PCL/PLC	SB/TT	Al/Ac; (fem IfSc + Eb; tib IfSc + ScW)	41/41
Khanduja et al (IV)[48]	2006	29 (21-47)	19 (100)	66 (24-110)	PCL/PLC	SB/TT	Variable grafts; (fem/tib IfSc)	19/19
Wang et al (IV)[49]	2002	28 (17-55)	25 (100)	40 (32-60)	PCL/PLC	SB/TT	Variable grafts	19/25

All follow-up periods minimum 24 mo.

30 patients with 31 knees.

Ac indicates Achilles tendon graft; ACL, anterior cruciate ligament; Al, allograft; Au, autograft; DB, double budle; Eb, endobutton, HT, hamstring tendon (number preceding denotes number of graft strands); IfSc, interference screw; MCL, medial collateral ligament; NR, not reported; P, plate; PCL, posterior cruciate ligament; PLC, posterolateral corner; Pr, preservation of PCL remnant; PT, Bone-patellar tendon-Bone; PW, post + washer; QT, quadriceps tendon graft; SB, single bundle; Sc, screw; ScW, screw and washer; St, staples; Su, sutures; TA, tibialis anterior tendon graft; TT, transtibial drilling technique.

TABLE 3. PCL Graft Failure (Failure Defined as >10 mm Increase in Posterior Tibial Displacement, Displacement of Medial Tibial Plateau Posterior to Femoral Condyle, Grade III Posterior Drawer Test, and/or PCL Revision Reconstruction)

Study	Sample Size (N)	Graft Failure (No. Patients) (%)	Failure Description
Isolated PCL Reconstruction Studies			
Chan et al[39]	20	1 (5)	Grade III posterior drawer test, 11-15 mm increase in posterior tibial displacement
Wong et al[23]	55	10 (18.2)	5 in each group met IKDC criteria of severely abnormal ligament laxity (> 10 mm)
MacGillivray et al[30]	20	6 (30)	Grade C posterior drawer test (defined as posterior displacement of tibia relative to femoral condyles)
Mariani et al[29]	24	2 (8.3)	Manual posterior drawer test with > 10 mm post displacement
Wu et al [22]	22	2 (9.1%)	Grade III posterior drawer test, 11-15 mm increase in posterior tibial displacement
Zhao et al[20]	43	1 (2.3)	Grade III posterior drawer test in 4-strand hamstring tendon autograft group
Combined PCL Reconstruction Studies			
Mariani et al[42]	15	1 (7.1)	Patient underwent revision surgery in another hospital for severe postoperative residual laxity.
Strobel et al[44]	17	2 (11.8)	Grade III posterior drawer test
Totals	215	25 (11.6)	

an outcome was 25 out of 215 PCL reconstructions (11.6%).

Knee Range of Motion (Table 4)

All but 9 studies, in some fashion, reported on range of motion deficits at final follow-up (Table 4). One study compared SB HT versus DB HT reconstructions and found no significant difference between the 2 groups for mean knee range of motion (ROM).[26] In a study comparing 4-strand HT versus allograft Ac tendon, one patient in the Ac allograft group required a manipulation under anesthesia (MUA) at 5 months for arthrofibrosis.[40] The highest rates of knees requiring MUA and/ or arthroscopic lysis of adhesions (LOA) postoperatively were seen in the combined PCL studies. In 1 study evaluating ROM after combined ACL/PCL reconstruction, with the PCL being reconstructed using 6-8-strand HT autografts, there were 8 out of 12 patients total (66.7%) that required MUA at 3 months postoperatively. None of the Level III retrospective comparative studies found any significant differences in knee ROM between groups compared.

Activity Level and Functional Assessments (Tables 5, 6)

As shown in Table 6, the majority of the studies used the Tegner activity scale for follow-up assessments. Only 8 of these studies reported Tegner activity scores for preinjury assessments as well. Other studies simply reported a percentage of patients that were able to return to preinjury activity level or to competitive sports. In a study by Hermans et al,[35] a significant negative difference was found between preinjury and latest follow-up mean activity levels (7.2 vs. 5.7, $P < 0.001$) in their study of SB PCL reconstructions. Zhao et al[20] found that a significantly higher percentage of patients in their 7-strand HT autograft group were able to return to preinjury activity level when compared to their 4-strand HT autograft group (82% vs. 76%, $P < 0.01$). No other comparative studies of isolated PCL reconstructions noted significant differences with regard to patient return to activity. In the combined PCL studies, return to preinjury activity level ranged from 19 to 68%. Table 6 contains the data on standardized functional outcome assessments for each of the studies. No significant differences in functional outcomes (Lysholm mean score and IKDC % normal and % nearly normal) were noted in any of the level II or III comparative studies.

Posterior Knee Laxity (Table 7)

Many of the studies included in this review included instrumented-laxity testing as an objective outcome measure in addition to the manually performed posterior drawer test. As seen in Table 7, there was one study by Zhao et al[20] that found a significant difference in the mean posterior drawer test side-to-side difference (STSD) between the 4-strand HT and 7-strand HT groups (3.7 mm vs. 1.7 mm, $P < 0.05$). No other significant findings were noted in the comparison of different graft options or surgical techniques. Importantly, no significant differences were noted by Wang et al[25] in the comparison of SB and DB reconstructions using HT autograft (mean instrumented STSD 2.3 mm vs. 3.1 mm, respectively). In evaluating the combined PCL reconstruction studies, mean corrected STSD on instrumented-laxity testing ranged from 2 to 4.2 mm. Two studies showed that no patients were "normal" on posterior drawer test at final follow-up.[43,44] The remainder of the combined PCL studies showed from 37% to 70% with normal posterior drawer test at final follow-up.

DISCUSSION

There are few prospective comparative studies and even fewer randomized controlled trials from which to guide treatment decisions after PCL injury. Watsend et al[51] have shown that the methodological quality of studies focused on isolated PCL injury is low and warn that caution is required when interpreting results after management of injury to the PCL. From this systematic review, since 1997, there have been 21 studies after isolated PCL reconstruction and 10 studies after combined PCL reconstruction that met our inclusion criteria. Of the 21 studies evaluating outcomes after isolated PCL reconstruction, only 1 was a prospective study, 7 were retrospective comparative studies and the remaining were retrospective case series. All 10 studies meeting our inclusion criteria for

TABLE 4. Knee range of Motion Deficits at Final Follow-up

Study	Extension Loss [No. patients (%)] < 3°	3-5°	Flexion Loss [No. patients (%)] ≤5°	> 5°	Mean Extension Loss (°) (Range)	Mean Flexion Loss (°) (Range)	Mean ROM (°)	Comments
Combined PCL Studies								
Lo et al[41]	—	1 (9)	—	2 (18)	—	—	—	
Mariani et al[42]	0		—		—	—	—	Mean knee flexion 118° (range, 105-135)
Shi et al[43]	—		—		1.5 (0-4)	3 (0-10)	144	
Strobel et al[44]	—		—	2 (11.7)	—	—	—	
Zhao et al[45]	None		—		—	—	—	Mean knee flexion 143° (range, 130-150); 8 patients required MUA at 3 mo
Zhao et al[46]	None		4 (19)	1 (4.7)	—	—	—	
Fanelli et al[47]	None		—		—	—	—	3 patients required LOA and MUA
Khanduja et al[48]	—		—		—	—	—	2 patients required MUA at 6 wk
Wang et al[49]	—		—		—	—	—	2 knees required LOA and MUA
Isolated PCL Studies								
Ahn et al[40]	—		—		—	—	—	1 patient in allograft group required MUA at 5 mo
Chan et al[39]	—	1 (5)	—	2 (10)	—	—	—	
Chen and Gao[38]	—	1 (5.3)	—	2 (10.5)	—	—	—	
Chen et al[37]	—		—		—	—	—	QT group 95% Nml/NN; HT group 96% Nml/NN
Garofalo et al[36]	—		—	4 (26.4)	—	—	—	
Hermans et al[35]	—		—		—	8	—	1 patient required open capsular release
Kim et al[33]	—		—		—	10 (5-20)	—	2 patients required LOA and MUA
Kim et al[32]	—		—		—	3.4	—	NS
MacGillivray et al[30]	—		—		—	—	—	Reported NS differences between groups
Mariani et al[29]	—	2 (8)	—		—	(6-15)	—	None required MUA
Nyland et al[28]	1 (5.5)	—	—		—	—	—	
Wang et al[26]	—		—		—	—	126 (SB) vs. 124 (DB)	NS
Wang et al[25]	—		—		—	—	125 (Au) vs. 127 (Al)	NS
Wu et al[22]	—	1 (4.5)	—	1 (4.5)	—	—	—	1 patient had > 5° extension loss; 1 patient required LOA and MUA
Zhao et al[21]	—		3 (7)	—	—	—	—	NS
Zhao et al[20]	—		2 (11)	—	—	—	—	

— Unclear from presentation of data within the study, not reported, or categorized differently by study.
HT indicates hamstring tendon graft; LOA, lysis of adhesions; MUA, manipulation under anesthesia; Nml, IKDC Normal rating; NN, IKDC Nearly Normal rating; NS, no significant difference between groups compared within study; QT, quadriceps tendon graft.

outcomes following combined PCL reconstructions were retrospective case series.

Despite a number of graft options being available for PCL reconstruction, the most commonly used graft in North America for PCL reconstruction is the Achilles tendon allograft. We have seen good long-term results with use of this graft for combined PCL and posterolateral corner reconstructions as reported by Fanelli.[47] In their study, mean Lysholm score at latest follow-up (range 2 to 10 y) was 91.7 and mean Tegner activity score was 4.92 (there was no preinjury score as a comparison). Moreover 70% had a normal posterior drawer test at latest follow-up and grade I laxity was present in 27%. Shi et al[43] also showed good mid-term results with the use of this graft in the treatment of patients with combined ACL/PCL injuries and a mean follow-up of 38 months. Mean Lysholm score

TABLE 5. Pre-injury and Latest Follow-up Activity Levels After PCL Reconstruction

Study (Level of Evidence)	Scale	Pre-injury Activity Level*	Latest Follow-up Activity Level	P	Comments
Isolated PCL Studies					
Ahn et al (III)[40]	NR	NR	NR		
Chan et al[39]	Tegner	7 (1.5)†	6.3 (2.4)†	NR	
Chen and Garo[38]	Tegner	NR	6.3		
Chen CH et al[37]	IKDC I or II	77% vs. 82%	55% vs. 59%	NS	QT vs. HT groups
Garofalo et al[36]	Tegner	7.9 (1.06)†	6.2 (1.1)†	NS	No patients able to return to same preinjury level of sporting activities
Hermans et al[35]	Tegner	7.2 (1.8)†	5.7 (2)†	< 0.001	
Wong et al (II)[23]	Tegner	NR	4.4 (1.6)†vs. 5.1 (1.7)†	NS	Anteromedial vs. Anterolateral Tibial Tunnel drilling
Jung et al[34]	NR	NR	NR		
Kim et al[33]	Tegner	NR	6.4 vs. 6.5	NS	1-incision vs. 2-incision
Kim et al (III)[32]	NR	NR	NR		
Lim et al[31]	Tegner	7	6	NS	
MacGillivray et al[30]	Tegner	NR	6 vs. 6	NS	TI vs. TT techniques.
Mariani et al[29]	Tegner	7.4	5.4	NS	50% returned to preinjury scores; 50% decreased by 1 or more points
Nyland et al[28]	NR	NR	NR		
Seon et al (III)[27]	Tegner	NR	5.6 vs. 6.1	NS	TT/4HT vs. TI/PT techniques
Wang et al (III)[26]	Tegner	NR	4.5 vs. 5.2	NS	SB vs. DB reconstructions
Wang et al (III)[25]	Tegner	NR	4.73 (1.66)†vs. 4.70 (1.66)†	NS	Au vs. Al reconstructions
Wang et al[24]	Tegner	NR	4.5 (1)†	NR	80% able to participate in recreational sports such as cycling
Wu et al[22]	Tegner	7.2 (1.4)†	6.0 (2.6)†	NS	IKDC I or II: 82%
Zhao et al (III)[20]	NR	NR	NR		Return to former activity level: 76% (4HT) vs. 82% (7HT) → $P < 0.01$
Zhao et al[21]	Tegner	7.1	6.9	NS	
Combined PCL Studies					
Fanelli et al[4]	Tegner	NR	5.3		
Lo et al[41]	Tegner	7 (1.6)†	6.2 (2)†	NS	
Mariani et al[42]	NR	NR	NR		50% returned to preinjury level; 2 (14.3%) returned to competitive sports
Shi et al[43]	NR	NR	NR		
Strobel et al[44]	NR	NR	NR		
Zhao et al[45]	Tegner	6.8 (0.6)†	6.6 (0.8)†	NS	
Zhao et al[46]	Tegner	6.2 (1.8)†	5.0 (1.9)†	NS	Only 4 patients (19%) returned to preinjury activity level
Fanelli et al[47]	Tegner	NR	4.92		
Khanduja et al[48]	Tegner	NR	6.4		13 patients (68%) able to return to pre-injury level of activity
Wang et al[49]	Tegner	NR	3.72		

*Tegner activity levels reported as means.
†Number in parentheses denotes standard deviation.
Ac indicates Achilles tendon graft; Al, allograft; Au, autograft; DB, double bundle; HT, hamstring tendon graft (number preceding denotes number of graft strands); NR, pre-injury activity level not reported; NS, no significant difference; PT, bone patellar tendon graft; QT, quadriceps tendon graft; SB, single bundle; TA, tibialis anterior tendon graft; TI, tibial inlay technique; TT, transtibial drilling technique.

at latest follow-up was 90% and 93% were rated as normal or nearly normal per IKDC grading. They did not report any patients with a normal posterior drawer test at latest follow-up; 86.7% had a Grade I and 13.3% Grade II posterior drawer test. In many other countries, hamstring autograft is the graft of choice. There are multiple reports using hamstring autograft with good results, although 4-strand HT autografts may show slightly inferior results to 6-8-strand HT autografts.[20,21,39,45]

A number of controversies still exist regarding the clinical and biomechanical superiority of various techniques used in reconstruction of the PCL. The literature has failed to show superiority of the double-bundle graft in PCL reconstruction to the single anterolateral bundle graft. Only one study comparing single-bundle and double-bundle reconstructions met our initial inclusion criteria. This level III study by Wang et al,[26] showed no significant differences in mean knee ROM (126° vs. 124°); mean Tegner activity level (4.5 vs. 5.2); mean Lysholm score (88 vs. 89); or in mean posterior tibial translation (1.16 mm vs. 1.13 mm) in single-bundle versus double-bundle reconstructions, respectively. Garofalo et al[36] reported his results on isolated grade III PCL injuries using a double-bundle technique (patellar tendon combined with 2-strand HT autograft). They reported that their results were not superior to single-bundle reconstruction; moreover, knee laxity was not normalized and no patient was able to return to the same preinjury level of sporting activities. Although there is no

TABLE 6. Functional Assessments at Latest Follow-up

Study (Level of Evidence)	IKDC (% "normal"/ "nearly normal")	Lysholm Score (Mean)	Comments
Isolated PCL Studies			
Ahn et al(III)[40]*	88.8 vs. 77.7	90.1 vs. 85.8	Lysholm % G/E: 83 vs. 78 ($P < 0.01$)
Chan et al[39]	85	93	Lysholm % G/E: 90
Chen and Garo[38]	94.7	92.5	Mean IKDC subjective score 92.5
Chen CH et al[37]†	82 vs. 81	—	Lysholm % G/E: 86 vs. 89
Garofalo et al[36]	60	87.5	Lysholm % G/E: 93; IKDC Subj mean 66.3
Hermans et al[35]	40.9	75	
Wong et al (II)[23]	67.9 vs. 66.6	88 vs. 91	NS
Jung et al[34]	100	—	
Kim et al[33]	—	90 vs. 90.6	NS
Kim et al (III)[32]	—	86.8 vs. 79.7 vs. 84.3	NS
Lim et al[31]	—	88	Lysholm % G/E: 90.9
MacGillivray et al[30]‡	—	81 vs 76	% satisfied: 92 vs. 86; NS
Mariani et al[29]	79.2	94	Lysholm % G/E: 91.7
Nyland et al[28]	89	—	Lysholm % G/E: 90
Seon et al (III)[27]	—	91.3 vs. 92.8	
Wang et al (III)[26]	57.9 vs. 81.3	88 vs. 89	
Wang et al (III)[25]	71.9 vs. 60.9	87.8 vs. 92.3	
Wang et al[24]	—	92	Lysholm % G/E: 77.4
Wu et al[22]	82	89	Lysholm % G/E: 86
Zhao et al (III)[20]	76.2 vs. 90.9	83 vs. 92	$P < 0.05$ for IKDC; $P < 0.001$ for Lysholm score
Zhao et al[21]	100	94.9	
Combined PCL Studies			
Fanelli et al[4]	—	35	Mean HSS score 86.8; NS between Au vs. Al for all scales or between Acute vs. Chronic
Lo et al[41]	82	88	
Mariani et al[42]	66.7	95.1	Mean HSS score 89.6
Shi et al[43]	93.3	90	
Strobel et al[44]	29.4	—	Mean Postoperative Subjective IKDC score 71.8
Zhao et al[45]	91.6	92.3	IKDC mean subjective score 92.4
Zhao et al[46]	95.2	91.9	IKDC mean subjective score 85.5
Fanelli et al[47]	—	91.7	
Khanduja et al[48]	89.5	76.5	
Wang et al[49]	—	86	

*4-strand hamstring tendon autograft group vs. Achilles tendon allograft group.
†Quadriceps tendon autograft vs. 4-strand hamstring tendon autograft.
‡transtibial vs. tibial inlay techniques.
— indicates Unclear from presentation of data within the study, not reported, or categorized differently by study; G/E, percent good/excellent results; NS, no significant difference; $P = P$ value.

clinical support for the superiority of double-bundle PCL reconstructions, Harner et al[52] reported that a double-bundle reconstruction more closely restores normal knee kinematics in the laboratory.

Similarly, both tibial inlay and transtibial tunnel techniques have been used and there are currently no clinical studies showing significant differences between these. The tibial inlay technique was first described by Berg.[53] The theory behind the technique is aimed at addressing the abnormal stresses placed on the graft as it makes an acute angle to gain entrance into the tibial tunnel. Bergfeld et al,[54] in a cadaveric study, showed that the tibial inlay technique results in less mechanical attenuation of the graft as compared with the transtibial technique after repetitive loading. They also reported less anterior-posterior translation in the tibial inlay group. Margheritini et al[55] also conducted a laboratory study and reported that both reconstruction techniques restored posterior tibial translations and that there were no significant differences between the grafts. Two level III studies meeting our inclusion criteria[27,32] compared transtibial and tibial inlay techniques in patients with isolated PCL injuries. Seon et al[27] reported no significant difference in Tegner activity score at latest follow-up. Neither study reported significant differences in mean Lysholm score or knee laxity nor were there any graft failures.

It has also been suggested that the acute angle of the graft on the posterior aspect of the tibia can be reduced by drilling from the anterolateral aspect of the tibia as opposed to the standard anteromedial drilling technique. Wong et al[23] compared these 2 techniques in a prospective study of isolated PCL reconstructions using HT autograft. No significant differences with regard to graft failure (5 in each group, 18.2%), mean Tegner activity score, mean Lysholm score or knee laxity were noted between groups.

In patients with grade II laxity, in which the remnant of the graft is still present, 3 studies meeting our inclusion criteria presented good results with preservation of the remnant and augmenting it with either HT or PT autografts.[21,23,34] There are no studies comparing preservation of the remnant versus debridement of the PCL remnant. In the study by Zhao et al[21] the investigators report a "sandwich" reconstruction of the PCL. This is a double-bundle PCL reconstruction using 8-strand HT

TABLE 7. Objective Knee Stability Testing at Final Follow-up

Study (Level of Evidence)	KT-1000 Postoperative Mean STSD (mm) (range)	Posterior Drawer Test	Other Notes
Isolated PCL Studies			
Ahn et al (III)[40]	—	—	
Chan et al[39]	—	80% Grade I; 15% Grade II; 5% Grade III (1/20)	KT-1000 (89N): 0-2 mm in 50%, 3-5 mm in 35% and > 5 mm in 15%
Chen and Garo[38]	1.0	89.5% nml; 5.3% Grade I; 5.3% Grade II	Mean KT-1000 results: 1.0 mm (SD 1.0)
Chen CH et al[37]*	—	—	KT-1000: 32% vs. 29% 0-2 mm; 59% vs. 56% 3-5 mm; 9% vs. 15% 6-10 mm
Garofalo et al[36]	—	20% nml; 67% Grade I; 13% Grade II	
Hermans et al[35]	2.1 (SD 1.6)	9% nml; 68.2% Grade I; 22.7% Grade II	KT-1000 mean STSD performed at quadriceps neutral angle
Wong et al (II)[23]†	2.8 (1-6) vs. 3.3 (1-10); NS	—	PDT graded per IKDC criteria: 0-2 mm nml, 3-5 NN; 6-10 AB; > 10 SAb. Graded as 0-4 (0 = no laxity). Anteromedial tunnel drilling group mean grade 0.9; anterolateral tunnel drilling group mean grade 0.9
Jung et al[34]	1.8 (SD 1.2)	—	63.6% had < 3 mm increased displacement and 36.4% had 3-5 mm increased displacement
Kim et al[33]‡	2.1 (1-4) vs. 2.38 (0-6)	40% vs. 26.7% nml; 60% vs. 73.3% Grade I	KT-1000 or KT-2000 (testing done at 20-lb force); corrected posterior translation
Kim et al (III)[32]	—	—	Only measured mean posterior STSD with Telos stress radiographs: tibial inlay double bundle group 3.6 mm (SD 1.43) vs. transtibial single bundle group 5.6 mm (SD 2) ($P < 0.023$)
Lim et al[31]	—	—	KT-2000 mean STSD: 23% 0-2 mm; 68% 3-5 mm; 9% 6-10 mm.
MacGillivray et al[30]§	5.9 vs. 5.5	69.2% vs. 71.4% with Grade II or better PDT	4/13 (30.8%) vs. 2/7 (28.6%) Grade III PDT
Mariani et al[29]	4.08 (SD 2.09)	—	KT-2000 (89N, 70°); PDT: 0-2 mm 25%; 3-5 mm 54.2%; 6-10 mm 12.5%; > 10 mm 8.3% (2 patients)
Nyland et al[28]	—	—	PDT: 57.9% 0-2 mm; 42.1% 3-5 mm; KT-1000 (maximum manual) posterior displacement 2.4 mm (SD 2)
Seon et al (III)[27]‖	—	90.5% vs. 90.9% Grade I; 9.5% vs. 9.1% Grade II	
Wang et al (III)[26]¶	2.3 (1-6) vs. 3.1 (0-7) NS	—	PDT: single bundle group mean 1.16 mm (0-2 mm); double bundle group mean 1.13 mm (0-2 mm)
Wang et al (III)[25]#	3.16 (1-10) vs. 2.83 (1-6)	—	Mean PDT: Autograft group-0.94 mm (0-3 mm); Allograft group-0.61 mm (0-2 mm)
Wang et al[24]	—	52% nml	33.3% showed mild laxity (0-5 mm); 9.7% showed moderate laxity (5-10 mm)
Wu et al[22]	—	72.7% Grade I; 18.2% Grade II; 9.1% Grade III	KT-1000 (89N): 0-2 mm in 46%; 3-5 mm in 18%; 6-10 mm in 18.2%
Zhao et al (III)[20]**	3.7 (SD 1.6) vs. 1.7 (SD 1.4) ($P < .05$)	52.4% vs. 68.2% nml; 23.8% vs. 22.7% Grade I; 19% vs. 9.1% Grade II; 4.8% vs. 0% Grade III	$P < 0.05$ between groups
Zhao et al[21]	—	94.4% nml; 5.6% Grade I	KT-1000 at 90°, 30-lb; STSD < 3 mm in 94.4%; 5 mm in 5.6%
Combined PCL Studies			
Fanelli et al[4]	2.7 (0-7)	46% nml; 54% Grade I	
Lo et al[41]	2.6 (0-7)	55% nml; 45% Grade I	Mean postoperative corrected STSD 2.5 mm (range, 0-6.8)
Mariani et al[42]	—	—	Average posterior sag 2.07 mm (range, 3.9-1): 11 patients between 0-2 mm (grade A); 3 patients 3-5 mm (grade B)
Shi et al[43]	4.2 (−3.5 to 9)	86.7% Grade I; 13.3% Grade II	KT-1000 STSD at 70°
Strobel et al[44]	2 (−4 to 7)	88.2% Grade I or II	2 pts (11.8%) had Grade III PDT
Zhao et al[45]	—	—	Posterior sag at 70° STSD: 0-2 mm in 75%; 3-4 mm in 25%
Zhao et al[46]	—	—	KT-1000 STSD at 70°: 0-2 mm 16 patients; 3-5 mm 4; and 6-10 mm in 1

TABLE 7. *(continued)*

Study (Level of Evidence)	KT-1000 Postoperative Mean STSD (mm) (range)	Posterior Drawer Test	Other Notes
Fanelli et al[47]	1.8 (−2.5 to 6.5)	70% nml; 27% Grade I; 2.4% Grade II	Mean corrected posterior STSD 2.11 mm (range, −2.5 to 7)
Khanduja et al[48]	—	37% nml; 58% Grade I; 5.3% Grade II	
Wang et al[49]	—	44% nml; 36% Grade I; 20% Grade II	

*Quadriceps tendon graft vs. hamstring tendon graft groups.
†Comparison of anteromedial tibial tunnel drilling vs. anterolateral tibial tunnel drilling.
‡Comparison of 2-incision vs. 1-incision groups.
§Comparison of transtibial vs. tibial inlay groups.
||Comparison of 4-strand hamstring tendon graft using transtibial technique vs. bone-patellar tendon-bone graft using tibial inlay technique.
¶Comparison of single bundle vs. double bundle techniques (both using autograft hamstring tendon).
#Comparison of Autograft vs. Allograft PCL reconstructions.
**Comparison of 4-strand hamstring tendon graft vs. 7-strand hamstring tendon graft groups.
AB indicates abnormal IKDC rating; N, newtons; nml, normal IKDC rating; NN, nearly normal IKDC rating; PDT, posterior drawer test; Sab, severely abnormal IKDC rating; SD, standard deviation; STSD, side-to-side difference.

autograft (4-strand HT for each bundle) and PCL remnant preservation. They reported results of 18 patients with isolated PCL injuries at a minimum 2-year follow-up. At latest follow-up they reported a mean Tegner score of 6.9, mean Lysholm score of 94.9 and 94.4% of patients had a normalized posterior drawer test.

Only 2 of the articles in the review presented here are of long-term outcomes. Hermans et al[35] published a 6 to 12-year follow-up (mean 9.1 y) study of single bundle PCL reconstruction. Twenty-two patients (88% follow-up) with isolated PCL injuries underwent reconstruction using PT autograft (n = 9), 4-strand HT (n = 7), 2-strand HT plus Achilles tendon allograft (n = 8), or Achilles tendon allograft alone (n = 1). There were no graft failures. At latest follow-up the mean Lysholm score was 75, the mean Tegner score was 5.7 and 40.9% had an IKDC rating of normal or nearly normal. There were no differences between grafts used. They indicated that results were inferior if cartilage damage was present at the time of reconstruction and recommended early reconstruction. Khanduja et al[48] reported 2 to 9-year follow-up of combined PCL/posterolateral corner reconstructions in 19 patients. They combined a single-bundle reconstruction of the PCL with a Larson-type tenodesis for the posterolateral corner. At latest follow-up the mean Tegner score was 6.4 and 13 patients (68%) were able to return to their preinjury level of activity. The mean Lysholm score was 76.5 and 89.5% had an IKDC rating of normal or nearly normal. Seven patients (37%) had a restoration of normal laxity on posterior drawer testing, 11 (58%) had a grade I and 1 (5.3%) had a grade II posterior drawer test. They concluded that although there was improvement at latest follow-up, normal stability was not restored.

In conclusion, firm recommendations on what treatment or technique to choose cannot be given based upon the available literature. There are many advances being made in PCL reconstruction and promising results are being shown in the laboratory. There is a need for higher-quality clinical studies and, ideally, randomized clinical trials to guide treatment. Unfortunately, randomized clinical trials are challenging to complete in this patient group owing to the infrequency and heterogeneity of these injuries. Generally good results are reported after PCL reconstruction, but the long-term studies available suggest that normal stability in the majority of patients is not restored.

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