Systematic Review

Suture Tape Augmentation of Posterior Cruciate Ligament Reconstruction Shows Improved Biomechanical Stability With Equivalent Outcome and Complication Rates: A Scoping Review

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Purpose: To assess the current literature surrounding suture tape augmentation (STA) of posterior cruciate ligament reconstruction (PCLR) with additional evaluation of PCLR+STA in clinical practice. **Methods:** A systematic search of 3 databases (PubMed, EMBASE, and Web of Science Core Collection) was performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines and was completed in April 2023 to identify studies related to PCLR+STA. Surgical technique, animal, biomechanical, and clinical studies were included for review with quality appraisal conducted according to study design. **Results:** A total of 380 articles were identified in the search, 6 of which met inclusion criteria. Biomechanical studies showed a significant reduction in posterior tibial translation with STA of PCLR in multiple studies. STA was found to decrease total elongation by 45% to 58% in multiple studies; increased load to failure was seen with STA as well in 1 study. Clinical studies showed equivalent or improved patient-reported outcomes with STA of PCLR compared with PCLR alone. **Conclusions:** Biomechanical studies offer evidence showing the beneficial load-sharing properties of STA such as increased strength and ultimate load with decreased elongation of the graft, especially with larger forces. Clinical evidence illustrates improved or equivalent patient-reported outcomes to standard PCLR with no difference in complication rate. **Clinical Relevance:** STA of PCLR offers an opportunity to improve initial graft stability during the early healing phase through load sharing between the augmentation and the graft.

The posterior cruciate ligament (PCL) serves the primary function of limiting posterior tibial translation (PTT) and accounts for up to 20% of ligament injuries around the knee.[1] Isolated grade 1 to 2 PCL injuries often are treated nonoperatively because of the self-healing capacity of the ligament, whereas isolated grade 3 PCL tear treatment is controversial.[2,3] Nonoperative treatment has been associated with increased rates of subsequent meniscus tears and 6-fold greater rates of symptomatic arthritis. PCL injuries have been reported to occur in up to 79% of multiligament knee injuries, which commonly include the anterior cruciate ligament (ACL), medial collateral ligament (MCL), and posterolateral corner (PLC).[4] Posterior cruciate ligament reconstruction (PCLR) is the gold standard of care in multiligament knee injuries along with failed nonoperative management of isolated PCL tears.

Knee laxity after PCLR is common, with up to 11.6% of patients experiencing graft failure or needing to undergo PCL revision.[5,6] Suture tape augmentation (STA), also referred to as internal bracing, involves using ultra-high-molecular-weight collagen-coated polyethylene/polyester tape to augment grafts and act as a secondary stabilizer. Mackay et al. described the use of a synthetic suture tape (FiberTape; Arthrex, Naples, FL) as a reinforcing adjunct for primary ACL repair and reconstructions, but it also has been used in chronic ankle instability, ulnar collateral ligament elbow stabilization, and acromioclavicular joint stabilization.[7-10] PCL repair with STA was first described by Hopper

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et al.[11] in 2018, as it promotes natural healing and allows early mobilization of the knee.

Studies have shown improved biomechanical characteristics of PCLR grafts on cadaveric and bone model knees, such as decreased total graft elongation and increased ultimate strength.[12,13] Several PCLR techniques have been described in the literature (autograft vs allograft, single vs double bundle, arthroscopic transtibial [TT] vs open inlay tibial), and clinical data have indicated no significant differences.[14-19] Internal bracing offers another opportunity to improve graft stability during healing, reduce graft laxity while increasing knee stability, and decrease rates of graft failure. Therefore, the purpose of this study is to assess the current literature surrounding STA of PCLR with additional evaluation of PCLR+STA in clinical practice. Our hypothesis was that STA of PCLR would show improved load sharing of grafts in biomechanical studies and noninferior clinical outcomes in clinical studies compared with PCLR alone.

Methods

A scoping review was conducted according to the Preferred Reporting for Systematic Review and Meta-Analyses guidelines for scoping reviews.[20]

Search Strategy

Three databases (PubMed, EMBASE, and Web of Science Core Collection) were searched on April 7, 2023, from the inception of the databases by a single contributor. Search terms included the controlled vocabulary of each database, if available, subheadings, key words, and appropriate abbreviations. This consisted of dividing the search into 2 main categories: "PCL reconstruction" and "suture tape augmentation." The first category would include "posterior cruciate ligament reconstruction" and "PCLR," whereas the second category included "suture tape augmentation," "internal brac*," and "fibertape." Search strategies can be found in Figure 1. Search terms, strategies, and Boolean operators were customized to each database.

Study Selection and Quality Assessment

All identified articles were imported into the Rayyan Intelligent Systematic Review tool. Articles were independently screened by title and abstract by 2 authors (C.R. and M.B.). Inclusion criteria included all studies focusing on the use of STA for PCL reconstruction procedures using autografts or allografts of all types. Because of the limited studies regarding this novel topic, nonrandomized studies were included such as technique papers, biomechanical studies, and clinical studies (cohort, case series, etc). Exclusion criteria included studies that only evaluate PCL repair with internal bracing and studies including PCLR revision cases. After initial screening, discrepancies were resolved by a third author (M.S.). The remaining studies were screened using the full text of each article. Disagreements of inclusion or exclusion after full-text review were discussed by the group until a consensus was reached. Quality assessment was conducted for all including studies using the Quality Appraisal for Cadaveric Studies score for biomechanical/cadaveric studies and the Risk of Bias in Nonrandomized Studies of Interventions tool for nonrandomized clinical studies.[21,22]

Data Extraction

All included studies were recorded into a data-extraction template. Data measures included author(s), publication year, country, number of subjects (n), biomechanical study measures (load to failure,

Fig 1. Example search strategy.

Database	Search #	Query	Results (4.7.23)
PubMed	1	("Posterior Cruciate Ligament" [mh] OR "posterior cruciate ligament reconstruction" [mh] OR "posterior cruciate ligament*" [tiab] OR "PCL" [tiab] OR "posterior cruciate ligament reconstruction*" [tiab] OR "PCLR" [tiab] OR "PCLR+IB" [tiab] OR "PCL reconstruction*" [tiab] OR "knee ligament reconstruction*" [tiab])	18,940
	2	("braces" [mh] OR "sutures" [mh] OR internal brac* [tiab] OR IB [tiab] OR brac* [tiab] OR augment* [tiab] OR suture tape* [tiab] OR ST [tiab] OR suture tape reinforcement* [tiab] OR sutur* [tiab] OR suture tape augment* [tiab])	577,829
	3	(fibre* [tiab] OR fiber* [tiab] OR fiber tape* [tiab] OR fibre tape* [tiab])	397,794
	4	(Internal brac* [tiab] OR suture tape* [tiab] OR ST [tiab] OR suturetape reinforcement* [tiab] OR suture tape augment* [tiab] OR fiber tape* [tiab] OR fibre tape* [tiab] OR fibertape* [tiab] OR suturetape* [tiab])	130,328
	5	#1 AND #2 AND #3	112
	6	#1 AND #4	71
	7	#5 OR #6	171

cyclic loading, dynamic elongation, etc), patient-reported outcomes (Knee Injury and Osteoarthritis Outcome Score scores, Tegner scores, visual analog scale for pain and satisfaction scores, etc), physical examination markers (posterior drawer, knee laxity/instability, degrees of flexion and extension, etc), and any other outcome variables assessed by included studies. For technique papers, a description of the surgical technique with an emphasis on the role of the STA was recorded. Because of the heterogeneity of included studies, meta-analysis was not possible, and results for all study types are presented in narrative and tabular formats.

Results

A total of 649 results were obtained with the literature search, which resulted in 380 articles for screening after duplicate removal (Fig 2). After title and abstract review, 18 studies were assessed for full-text and citation review. No additional studies were included based on citation searching, and 12 studies were excluded upon full-text review. Six studies were included in the final review, including 1 technical note, 3 biomechanical studies, and 2 clinical studies.[12,13,23-26]

The Risk of Bias in Nonrandomized Studies of Interventions tool assessed the 2 clinical studies included in this review, with results shown in Table 1. The study by Zhao et al.[26] was found to have a moderate risk of bias in participant selection because of small numbers ($n = 31$ participants) with no control/comparison group, as well as a moderate risk of bias for outcome measures and reported results for similar reasoning. The study by Therrien et al.[25] showed a moderate risk of bias in confounding and outcome measurement as the result of the significant difference in follow-up time between the STA (34.6 ± 2.0) and the comparison group (60.0 ± 3.9; $P < .001$).

Surgical Techniques

There was one surgical technique paper in which Yasen et al.[23] used a FiberTape (Arthrex)-reinforced

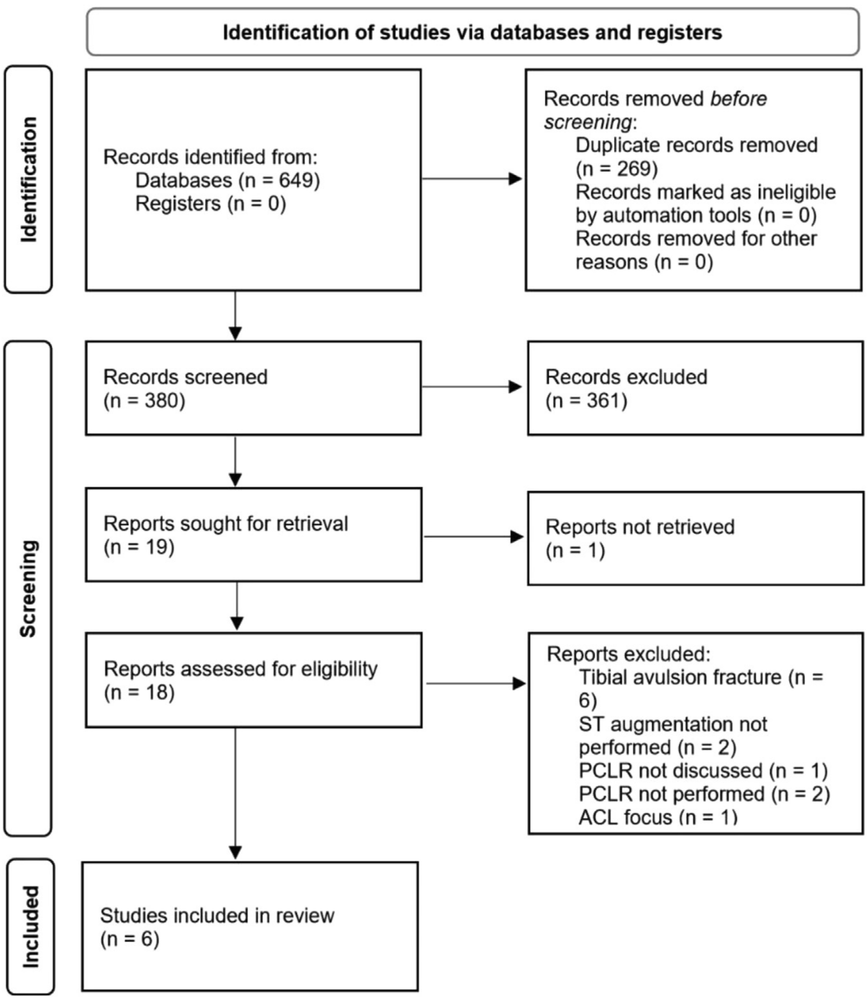

Fig 2. PRISMA flow diagram. (ACL, anterior cruciate ligament; PCLR, posterior cruciate ligament reconstruction; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; ST, suture tape.)

Table 1. Risk of Bias in Nonrandomized Studies of Interventions (ROBINS-I)

Lead Author (Year)	LOE	D1	D2	D3	D4	D5	D6	D7
Zhao et al.[26] (2022)	IV	● low	● moderate	● low	● low	● no information	● moderate	● moderate
Therrien et al.[25] (2022)	III	● moderate	● low	● low	● low	● low	● moderate	● low

NOTE. Assigned to each study is a low ● moderate ●, or high ● risk of bias for the associated categories. No information ● is assigned if not applicable.
LOE, level of evidence.
Domains:
D1: Bias caused by confounding.
D2: Bias in selection of participants into study.
D3: Bias in classification of interventions.
D4: Bias caused by deviations from intended interventions.
D5: Bias caused by missing data.
D6: Bias in measurement of outcomes.
D7: Bias in selection of the reported result.

peroneus longus allograft for PCLR. The technique is described in Table 2 with description of ST fixation.[23]

Biomechanical Studies

Three biomechanical studies were found to assess PCLR with STA, with outcome measures included in Table 3.[12,13,24] Grotting et al.[12] conducted PCLR on 11 cadaveric knees (5 male, 6 female) with a mean age of 63 years (range 51-72 years) using either all-inside (AI) or TT single-bundle techniques with STA. The AI group used a quadrupled tibialis anterior or peroneus longus allograft whereas the TT group used an Achilles tendon allograft. Both groups used FiberTape (Arthrex) for STA. Testing was performed with a 200-N load on the quadriceps and rigid security of the femur, whereas tibial hooks provided directional force (100 N for posterior drawer, 5 Nm for varus/valgus, internal/external rotation). Each knee was evaluated in the following states: intact PCL, PCL-deficient, AI PCLR with and without STA, and TT PCLR with and without STA. AI PCLR without STA was found to have significantly greater PTT compared with the intact PCL at 90° flexion ($P < .05$), but the addition of ST further reduced PTT to a value that was not significantly different than the intact PCL at all angles of flexion (P value not provided).[12] Similar findings were seen with TT PCLR, as STA showed a significant reduction in PTT compared with TT alone, with 60° flexions being significant ($P = .047$).[12] Numerical values were not reported, as these quantitative data were presented graphically only in the study. No other significant differences were found between ST-augmented grafts and non−ST-augmented grafts with assessment of internal/external rotation, varus/valgus rotation, and patellofemoral joint pressure.[12]

Trasolini et al.[24] used 10 cadaver knees to perform single-bundle PCLR using an outside-in technique with a tripled tibialis anterior allograft. Ten knees were evaluated at baseline with intact PCL then divided based on STA (PCLR+IB) and no STA (PCLR alone). PCLR+IB showed significantly less PTT compared with PCLR alone (6.59 mm vs 8.83 mm at 45 N, $P = .05$; 8.44 mm vs 10.84 mm at 90 N, $P = .035$; 10.23 mm vs 12.80 mm at 134 N, $P = .023$).[24] Significantly decreased graft lengthening was seen in PCLR+IB compared with PCLR alone after cyclic loading at 90 N ($P = .037$), but no significant differences were seen between groups at 45 N and 134 N. Intact PCL was found to have significantly increased stiffness compared with both groups ($P < .01$), but no significant difference in stiffness was found between PCLR+IB and PCLR alone at any load.[24]

Levy et al.[13] used porcine bone models that underwent PCLR using bovine extensor tendons. Two techniques were performed: (1) an AI method with adjustable loop devices (ALDs) in the tibia and femur (ALD-ALD), and (2) a method using an interference screw in the tibia an ALD in the femur (screw-ALD). Both groups were then separated into with or without STA (n = 8 per group; 4 total groups). STA was found to decrease total elongation from 4.77 ± 1.43 mm with ALD-ALD group to 2.60 ± 0.97 mm (45%) for ALD-ALD ST group ($P = .077$) and from 6.06 ± 1.28 mm with screw-ALD group to 2.50 ± 1.28 mm (58%) for screw-ALD ST group ($P = .018$).[13] In addition, elongation increased more rapidly at greater loads for non-ST groups compared with STA groups. The ALD-ALD ST group showed a mean stiffness closest to that of the native PCL (156.3 ± 16.1 vs 198.9 ± 33.5 N/mm, $P = .192$) along with the greatest ultimate failure load (1,505 ± 87 N), which was statistically significantly greater than all other groups ($P < .012$ for all other groups).[13]

Clinical Studies

Two studies examined clinical outcomes of patients who underwent PCLR with STA, as described in Table 4.[25,26] ST was looped through the femoral button and independently tensioned and fixated through tibial anchor for both studies. Both studies used a suture anchor to secure the ST independently on the tibial side. Multiligamentous knee injuries and isolated PCL injuries were present in both studies, and no significant difference in concomitant injuries was present between PCLR+STA and PCLR alone for Therrien et al.[25]

Therrien et al.[25] assessed 50 patients (19 with STA+PCLR and 31 with PCLR alone) who underwent primary, AI allograft single-bundle PCLR, finding no differences in postoperative patient-reported outcomes (PROs) besides the visual analog scale for pain scores at rest, which was lower in the STA group ($P = .047$) compared with the PCLR alone group at minimum

Table 2. Technical Study

Author	Year (LOE)	Graft Type	Graft Fixation Description	ST Details	ST Fixation
Yasen et al.[23]	2017 (V)	Peroneus longus allograft reinforced with FiberTape fashioned into a Y-shaped "TriLink" construct to recreate the anterolateral and posteromedial femoral bundles	"With the femoral TightRope devices flipped and docked firmly against the medial femoral cortex, tensioning can commence. This is achieved by pulling the free ends of the TightRope back and forth to advance the TriLink graft into the retrograde sockets. The tensioning regimen reflects the tension profile of each bundle of the PCL during knee flexion. The AL bundle is tensioned at 90° of flexion (the position of greatest tension in the AL bundle physiologically) with concomitant anterior tibial translation applied by the surgical assistant. If insufficient tension in the AL bundle occurs because of the graft bottoming out within its femoral socket, this can be overcome by further tensioning of the tibial TightRope. It is imperative that no subsequent alterations to the tibial TightRope are made once the AL bundle is satisfactorily tensioned because this would either loosen or overconstrain the AL limb of the graft. After cycling of the knee, the PM bundle is tensioned at 30° of flexion (the position of maximum physiological tension). The knee is cycled several times through full range of movement before the TightRope button fixation is finalized. Before the tensioning sutures are cut, the posterior drawer test and arthroscopic visualization are used to verify satisfactory fixation and restoration of normal anteroposterior laxity. For TriLink constructs reinforced with FiberTape, as in our unit, the free ends of the FiberTape polymer loop are anchored distally in the tibia with a 4.75-mm anchor device (SwiveLock; Arthrex)"	FiberTape (Arthrex)	"For TriLink constructs reinforced with FiberTape, as in our unit, the free ends of the FiberTape polymer loop are anchored distally in the tibia with a 4.75mm anchor device (SwiveLock; Arthrex)."

AL, anterolateral; LOE, level of evidence; PCL, posterior cruciate ligament; PM, posteromedial; ST, suture tape.

Table 3. Biomechanical Studies

Author	Year (LOE)	QUACS Score	Specimen	Graft Type	Suture Tape	Groups	Subjects	Outcome measures	Results
Grotting et al.[12]	2020 (V)	13-Nov	Cadaver	a. All Inside= allograft (quadrupled tibialis anterior or peroneus longus) b. Transtibial= Achilles allograft	FiberTape (Arthrex)	a. All inside PCLR + ST b. Transtibial PCLR + ST c. Intact PCL d. PCL-deficient e. All-inside PCLR f. Transtibial PCLR	11 cadaveric lower limbs (5 male, 6 female). Mean age range 63 (51-72). Without evidence of prior injury	I. Posterior Tibial Translation II. Internal and external rotation III. Varus and Valgus rotation IV. Patellofemoral joint pressure All Outcome measures were tested at 30, 60, 90, 120 degrees of flexion	Results by Grotting et al. were presented graphically. Statistically significant results were shared in text and are described in the body of the article.
Levy et al.[13]	2021 (V)	13-Oct	Porcine bones and bovine tendons	Hamstring autograft	FiberTape (Arthrex)	a. All-inside PCLR using ALDs in tibia and femur + ST b. PCLR with interference screw on tibial side and ALD on femoral side + ST c. All-inside PCLR using ALDs in tibia and femur d. PCLR with interference screw on tibial side and ALD on femoral side	n=8/ group	I. Force Loss II. Dynamic Elongation (250 N) III. Dynamic Elongation (500 N) IV. Total Elongation V. Stiffness VI. Ultimate Failure Load	
Trasolini et al.[24]	2020 (V)	13-Nov	Cadaver	Tripled tibialis anterior allograft (length 75-80mm; diameter 10mm)	FiberTape (Arthrex)	a. Single bundle PCLR using outside in technique + ST b. Single bundle PCLR using outside in technique c. "Healthy control" established for each cadaveric knee before reconstruction	n= 10 fresh frozen cadaveric knees	I. Total Posterior Displacement (45N, 90N, 134N) at 1 and 30 cycles/load II. Construct lengthening after cyclic loading (mm) III. Stiffness (N/mm)	

Levy et al.[13] results:

	Force Loss (%±SD)		Dynamic Elongation (250 N) (mm±SD)		Dynamic Elongation (500 N) (mm±SD)		Total Elongation (mm±SD)		Stiffness (N/mm±SD)		Ultimate Failure Load (N±SD)
a.	10.1±3.2	a.	1.81±0.27	a.	2.78±0.66	a.	2.60±0.97	a.	156.3±16.1	a.	1505±87
b.	13.1±2.9	b.	1.62±0.22	b.	3.06±1.23	b.	2.50±1.28	b.	151.0±9.8	b.	1184±276
c.	17.8±5.3	c.	2.28±0.25	c.	4.46±1.16	c.	4.77±1.43	c.	136.1±7.2	c.	1167±125
d.	16.4±3.5	d.	1.67±0.18	d.	6.21±3.54	d.	6.06±3.60	d.	142.8±15.3	d.	1014±194

		Force Loss	Dynamic Elongation (250 N)	Dynamic Elongation (500 N)	Total Elongation	Stiffness	Ultimate Failure Load
p-values	**a vs c**	p=0.004	p=0.004	p=0.127	p=0.077	p=0.250	p=0.010
	b vs d	p=0.380	p=0.667	p=0.015	p=0.018	p>0.999	p=0.267

Trasolini et al.[24] results:

Construct Lengthening (mm)$^{(*=p\text{-value}<0.05)}$

Load	**a**	**b**	**c**
45 N	-0.30±0.02	-0.29±0.01	-0.16±0.01
90 N	0.30±0.01	0.39±0.01^{*2}	0.15±0.01
134 N	0.72±0.08	0.80±0.03	0.34±0.02

Construct lengthening was the difference in length between first and last cycle for each load

Construct Lengthening (mm)$^{(*=p\text{-value}<0.05)}$

Load	**a**	**b**	**c**
45 N	-0.30±0.02	-0.29±0.01	-0.16±0.01
90 N	0.30±0.01	0.39±0.01^{*2}	0.15±0.01
134 N	0.72±0.08	0.80±0.03	0.34±0.02

Construct lengthening was the difference in length between first and last cycle for each load

Stiffness (N/mm)$^{(*=p\text{-value}<0.01)}$

Load	**a**	**c**
45 N	24.76^{*1}	33.37
90 N	38.46^{*1}	49.94
134 N	47.82^{*1}	58.55

Table 4. Clinical Studies

Author	Year (LOE)	Subjects (n)	Graft type	Intervention	Control Group	Follow-Up	Outcome Measures
Therrien et al.[25]	2022 (III)	50 patients (n=19 with suture tape; n=31 control group)	Allograft - quadrupled peroneus longus or tibialis anterior	ST looped through femoral button and independently tensioned and fixated through tibial anchor	All-inside PCLR with tibial and femoral suspensory fixation	> 2 years	IKDC, Lysholm, Tegner, VAS pain scale

Results

Tegner	Suture tape	Control	p-value
Preinjury	7.1±0.6	7.0±0.2	0.204
Final Follow-up	5.6±0.5	5.7±0.3	0.562

	Suture Tape	Control	p-value
Lysholm	87.5±2.4	84.3±2.9	0.828

	Suture Tape	Control	p-value
IKDC	79.3±3.5	79.6±3.0	0.779

VAS	Suture Tape	Control	p-value
Preinjury			
At rest--	2.2±0.4	2.1±0.4	0.526
With use--	4.9±0.6	3.8±0.4	0.173
Final Follow-up			
At rest--	0	0.4±0.2	0.047
With use--	2.3±0.7	2.2±0.4	0.949

Author	Year (LOE)	Subjects (n)	Graft type	Intervention	Control Group	Follow-Up	Outcome Measures
Zhao et al.[26]	2022 (IV)	33 patients (21 men, 12 women)	Hamstring autograft	ST looped through femoral button and independently tensioned and fixated through tibial anchor	Preoperative values	> 2 years	Mean side-to-side difference in laxity, IKDC, Lysholm, Tegner

Results

Mean side-to-side difference in laxity (mm)

	Pre-op	Post-op
Δ	12.13±2.66	1.87±0.56[1]

	Pre-op	Post-op
IKDC	51.65±12.35	84.52±6.42[1]

	Pre-op	Post-op
Lysholm	53.90±11.86	86.68±6.84[1]

	Pre-op	Post-op
Tegner	2.81±0.79	6.71±1.83[1]

(x)[1]=P<0.05 compared to preoperative values

2-year follow-up. No significant difference was seen with PCL laxity between the 2 groups, which had comparable results assessed via posterior drawer testing and side-to-side difference on bilateral kneeling stress radiographs. The complication rate was greater in the STA group, with 5 reoperations (26%), including 1 PCLR revision and 1 lysis of adhesion, compared with the control group, with 3 reoperations (10%), which had no PCLR revisions with 2 lysis of adhesions, although this finding was not statistically significant ($P = .232$).[25]

Zhao et al.[26] conducted a case series of 31 patients with combined or isolated grade 3 PCL tears who underwent TT single-bundle PCLR with hamstring autografts. Preoperative PROs were then compared with postoperative values at minimum 2-year follow-up. Additional ligament injuries were seen in 17 of 31 patients (55%), with isolated PCL injuries present in 14 of 31 patients. This study showed significantly increased PROs postoperatively, including increased International Knee Documentation Committee scores from 51.65 $\pm$ 12.35 to 84.52 $\pm$ 6.42, increased Lysholm score from 53.90 $\pm$ 11.86 to 85.68 $\pm$ 4.99, and increased Tegner score from 2.81 $\pm$ 0.79 to 6.71 $\pm$ 1.83 ($P < .05$ for all). No patients required PCL revision surgery, and 29 of 31 (93.5%) reported normal or near-normal range of motion and a return to normal daily exercise level. In terms of knee stability, posterior drawer was negative in 30 of 31 (96.8%) patients postoperatively along with decreased mean side-to-side difference in posterior laxity from 12.13 $\pm$ 2.66 mm preoperatively to 1.87 $\pm$ 0.56 mm postoperatively ($P < .05$).[26]

Discussion

Although the data are limited, this review shows improved graft strength overall in biomechanical studies with STA along with equivalent or improved patient outcomes in clinical studies. Biomechanical studies give a time-zero assessment of STA of PCLR and show a biomechanical advantage over standard PCLR in all 3 studies, including decreased PTT and graft elongation as well as increased graft strength and ultimate load. This may help protect the graft during the early remodeling phases of graft ligamentization, which is discussed more frequently regarding the ACL.[27] In contrast, the opposite could be true where STA creates stress shielding and prevents the graft from undergoing the histologic changes in collagen fibril size, cellularity, and vascularity that occur with ligamentization.[28] This lack of ligamentization would likely decrease the long-term biomechanical performance of the graft construct. Because of the time-zero nature of these biomechanical studies, a conclusion cannot be made without longitudinal studies. In addition, although stiffness was increased with STA, it was noted to be less than that of the native, intact PCL, indicating STA would likely not increase the risk of overconstraint of the knee, which is a theoretical complication of internal bracing with the ACL.[29]

Clinical studies show mixed results in terms of the efficacy of STA. Both studies showed positive results in PROs and functional data for the STA group. However, these studies have the high potential for a type II error as the result of their low power, which can affect the conclusions drawn from these data. Zhao et al.[26] demonstrated that STA for PCLR is clinically useful for PCL-deficient knees, but the study design lacked a control group. Although this demonstrates that STA for PCLR is an effective treatment strategy, the design indicates a moderate risk of bias because of the preoperative versus postoperative comparison of outcome measures for the same group. Therrien et al.[25] used a non-STA group as well, in which patient outcomes were equivalent to that of the STA group. There was also an increased complication rate in the STA group compared with the control group, although it was not significant. This was likely caused by the heterogeneity nonrandomization of the patient population used because of the small sample size. It is also worth noting that a majority of the complications in the STA group involved other structures of the knee besides the PCL, including 2 ACL, 1 MCL/posteromedial corner, 1 lateral collateral ligament/PLC, and 1 medial meniscus. These studies provide evidence that STA for PCLR is an effective addition to standard PCLR, but further research is necessary to understand the long-term effects. One issue with making such a conclusion is that both studies are inadequately powered because of the small sample size of each. The minimum follow-up period of 2 years is a relatively short time frame as well, making it difficult to assess long-term effects of STA. Although the mean follow-up time of STA groups for Zhao et al.[26] and Therrien et al.[25] were 45.35 $\pm$ 10.88 months and 34.6 months, respectively, longer-term and adequately powered study designs will help answer questions regarding the longevity of ST. Furthermore, both studies are retrospective in design, indicating the possibility of information bias and further emphasizing the need for prospective randomized studies.

The findings of this review are consistent with other reviews regarding STA of different ligaments. Mackenzie et al.[30] reported improved biomechanical advantages with STA for ACL reconstruction with equivalent clinical outcome data to non-ST groups. In addition, Wittig et al.[31] found significantly improved return to sport with the addition of ST to the Broström repair in the surgical treatment of chronic lateral ankle instability. ST has also been used for rotator cuff repair and has shown similar complication rates to standard repair, but it has not shown any clinical outcome advantages.[32] Although this review focuses on PCL reconstruction, PCL repair with STA is being evaluated as well. Although the technique by Hopper et al.[33] was mentioned previously, a case series was conducted as well. The ST group demonstrated statistically significant improvements in Knee Injury and Osteoarthritis Outcome Score values for pain, symptoms, and quality of life ($P < .05$), as well as significant improvements in Western Ontario and McMaster Universities Arthritis Index scores for pain, function, and stiffness ($P < .01$) for patients who underwent PCL repair with STA.[33] Ostrander et al.[34] conducted a biomechanical study showing PCL repair with STA did not have significantly increased PTT compared with the intact PCL ($P = .391$), whereas the non-STA group did have significantly increased PTT ($P = .005$).

Historically, intra-articular devices have been controversial in ligament reconstruction as the result of inflammatory response and rates of failure. Batty et al.[35] found rates of sterile effusion and synovitis in up to 27.6% of patients using earlier-generation synthetic devices with revision rates ranging from 2.6% to 11.8%. The Ligament Augmentation and Reconstruction System device was considered the most effective device with the fewest complications and initially showed positive results specifically with PCLR.[36] However, recent studies with longer-term follow-up have shown increased rates of failure and synovitis.[37,38] This further emphasizes the importance of longer-term follow-up studies for STA, as intra-articular devices can diminish the graft effectiveness over time. It is worth noting that both clinical studies reported low complication rates with no reports of sterile effusion or synovitis.[25,26]

STA has a few criticisms, including overconstraint of the knee leading to increased knee stiffness and stress shielding. However, Trasolini et al.[24] showed that the stiffness of the native, intact PCL exceeds that of the ST-augmented graft complex at all loads and therefore provides evidence against this criticism. Animal studies conducting ACL reconstruction with STA showed complete 4-zone healing between bone and graft with little to no evidence of necrosis, rejection, osteoarthritis, or inflammation (both acute and chronic) of the graft complex.[39,40] In addition, most techniques for ACL reconstruction with STA report ST fixation while the knee is in hyperextension, to theoretically avoid stress shielding of the graft. For PCLR the ST fixation occurs after graft tensioning with the knee in 90° of flexion. It would likely be of benefit to conduct similar animal studies for STA of PCLR as those seen with ACL reconstruction, to compare the differences that may be seen in terms of inflammation and neovascularization.

Limitations

The limitations of this study begin with the input literature, which limits all review studies. This study in particular lacks high-level clinical evidence because of the paucity in foundational literature that exists on this topic. The heterogeneity and inadequate powering resulting from small sample sizes of the included studies prevent meta-analysis, limiting the strength of the conclusions. The included biomechanical studies focused on time-zero, unidirectional movement of the graft, limiting the conclusions that can be drawn based on the multidirectional movement the graft will experience in a patient. The surgical technique article did not include a description of how to incorporate the ST into the graft complex but simply stated it could be used if there were concerns about a small or weak graft.[23] This limits the proper replication of STA for utilization of this technique.

Conclusions

Biomechanical studies offer evidence showing the beneficial load-sharing properties of STA such as increased strength and ultimate load with decreased elongation of the graft, especially with larger forces. Clinical evidence illustrates improved or equivalent PROs to standard PCLR with no difference in complication rate.

Disclosures

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: B.V. reports consultant or advisor for Artelon and Stryker Orthopaedics; equity or stocks from Carbon 22, Spinal Simplicity, and Altior; and board member of the American Orthopaedic Foot and Ankle Society. All other authors (C.R., M.B., M.S., J.R., R.L., T.M., M.V.) declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Spiridonov SI, Slinkard NJ, LaPrade RF. Isolated and combined grade-III posterior cruciate ligament tears treated with double-bundle reconstruction with use of endoscopically placed femoral tunnels and grafts: Operative technique and clinical outcomes. *J Bone Joint Surg Am* 2011;93:1773-1780.
2. Agolley D, Gabr A, Benjamin-Laing H, Haddad FS. Successful return to sports in athletes following non-operative management of acute isolated posterior cruciate ligament injuries: Medium-term follow-up. *Bone Joint J* 2017;99-b:774-778.
3. Shelbourne KD, Clark M, Gray T. Minimum 10-year follow-up of patients after an acute, isolated posterior cruciate ligament injury treated nonoperatively. *Am J Sports Med* 2013;41:1526-1533.
4. Becker EH, Watson JD, Dreese JC. Investigation of multiligamentous knee injury patterns with associated

injuries presenting at a level I trauma center. *J Orthop Trauma* 2013;27:226-231.
5. Hammoud S, Reinhardt KR, Marx RG. Outcomes of posterior cruciate ligament treatment: A review of the evidence. *Sports Med Arthrosc Rev* 2010;18:280-291.
6. Mygind-Klavsen B, Nielsen TG, Lind MC. Outcomes after posterior cruciate ligament (PCL) reconstruction in patients with isolated and combined PCL tears. *Orthop J Sports Med* 2017;5:2325967117700077.
7. Bodendorfer BM, Michaelson EM, Shu HT, et al. Suture augmented versus standard anterior cruciate ligament reconstruction: A matched comparative analysis. *Arthroscopy* 2019;35:2114-2122.
8. Cho BK, Park KJ, Kim SW, Lee HJ, Choi SM. Minimal invasive suture-tape augmentation for chronic ankle instability. *Foot Ankle Int* 2015;36:1330-1338.
9. Dugas JR, Walters BL, Beason DP, Fleisig GS, Chronister JE. Biomechanical comparison of ulnar collateral ligament repair with internal bracing versus modified Jobe reconstruction. *Am J Sports Med* 2016;44:735-741.
10. Mackay GM, Blyth MJ, Anthony I, Hopper GP, Ribbans WJ. A review of ligament augmentation with the InternalBrace™: The surgical principle is described for the lateral ankle ligament and ACL repair in particular, and a comprehensive review of other surgical applications and techniques is presented. *Surg Technol Int* 2015;26:239-255.
11. Hopper GP, Heusdens CHW, Dossche L, Mackay GM. Posterior cruciate ligament repair with suture tape augmentation. *Arthrosc Tech* 2019;8:e7-e10.
12. Grotting JA, Nelson TJ, Banffy MB, et al. Biomechanical evaluation of PCL reconstruction with suture augmentation. *Knee* 2020;27:375-383.
13. Levy BA, Piepenbrink M, Stuart MJ, Wijdicks CA. Posterior cruciate ligament reconstruction with independent suture tape reinforcement: An in vitro biomechanical full construct study. *Orthop J Sports Med* 2021;9.
14. Ansari AS, Dennis BB, Horner NS, et al. Influence of graft source on postoperative activity and joint laxity in posterior cruciate ligament reconstruction: A systematic review. *Arthroscopy* 2019;35:262-274.e266.
15. Belk JW, Kraeutler MJ, Purcell JM, McCarty EC. Autograft versus allograft for posterior cruciate ligament reconstruction: An updated systematic review and meta-analysis. *Am J Sports Med* 2018;46:1752-1757.
16. Hudgens JL, Gillette BP, Krych AJ, Stuart MJ, May JH, Levy BA. Allograft versus autograft in posterior cruciate ligament reconstruction: An evidence-based systematic review. *J Knee Surg* 2013;26:109-115.
17. Martin RK, Melugin HP, Freychet B, Krych AJ, Stuart MJ, Levy BA. Posterior cruciate ligament all-inside reconstruction. *Sports Med Arthrosc Rev* 2020;28:18-22.
18. Qi YS, Wang HJ, Wang SJ, Zhang ZZ, Huang AB, Yu JK. A systematic review of double-bundle versus single-bundle posterior cruciate ligament reconstruction. *BMC Musculoskelet Disord* 2016;17:45.
19. Shin YS, Kim HJ, Lee DH. No clinically important difference in knee scores or instability between transtibial and inlay techniques for PCL reconstruction: A systematic review. *Clin Orthop Relat Res* 2017;475:1239-1248.
20. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: Explanation and elaboration. *BMJ* 2009;339: b2700.
21. Wilke J, Krause F, Niederer D, et al. Appraising the methodological quality of cadaveric studies: Validation of the QUACS scale. *J Anat* 2015;226:440-446.
22. Sterne JA, Hernán MA, Reeves BC, et al. ROBINS-I: A tool for assessing risk of bias in non-randomised studies of interventions. *BMJ* 2016;355:i4919.
23. Yasen SK, Borton ZM, Britton EM, Palmer HC, Wilson AJ. Transmedial all-inside TriLink posterior cruciate ligament reconstruction. *Arthrosc Tech* 2017;6:e1871-e1877.
24. Trasolini NA, Hatch GF, Wright D, et al. Posterior cruciate ligament reconstruction with internal brace augmentation reduces posterior tibial translation under cyclic loading. *Orthopedics* 2021;44:235-240.
25. Therrien E, Pareek A, Song BM, et al. Comparison of posterior cruciate ligament reconstruction using an all-inside technique with and without independent suture tape reinforcement. *Orthop J Sports Med* 2022;10.
26. Zhao X, Duan MY, Chen SQ, et al. Posterior cruciate ligament reconstruction with independent internal brace reinforcement: Surgical technique and clinical outcomes with a minimum two year follow-up. *Int Orthop* 2022;46: 2019-2028.
27. Claes S, Verdonk P, Forsyth R, Bellemans J. The “ligamentization” process in anterior cruciate ligament reconstruction: What happens to the human graft? A systematic review of the literature. *Am J Sports Med* 2011;39:2476-2483.
28. Pauzenberger L, Syré S, Schurz M. "Ligamentization" in hamstring tendon grafts after anterior cruciate ligament reconstruction: A systematic review of the literature and a glimpse into the future. *Arthroscopy* 2013;29: 1712-1721.
29. Matava MJ, Koscso J, Melara L, Bogunovic L. Suture tape augmentation improves the biomechanical performance of bone-patellar tendon-bone grafts used for anterior cruciate ligament reconstruction. *Arthroscopy* 2021;37: 3335-3343.
30. Mackenzie CEA, Huntington LS, Tulloch S. Suture tape augmentation of anterior cruciate ligament reconstruction increases biomechanical stability: A scoping review of biomechanical, animal, and clinical studies. *Arthroscopy* 2022;38:2073-2089.
31. Wittig U, Hohenberger G, Ornig M, et al. Improved outcome and earlier return to activity after suture tape augmentation versus Broström repair for chronic lateral ankle instability? A systematic review. *Arthroscopy* 2022;38:597-608.
32. Boksh K, Haque A, Sharma A, Divall P, Singh H. Use of suture tapes versus conventional sutures for arthroscopic rotator cuff repairs: A systematic review and meta-analysis. *Am J Sports Med* 2022;50:264-272.
33. Hopper GP, Irfan A, Jenkins JM, Wilson WT, Mackay GM. Posterior cruciate ligament repair with suture tape augmentation: A case series with minimum 2-year follow-up. *J Exp Orthop* 2021;8:28.
34. Ostrander R, Jordan S, Konicek J, Baldwin W. Suture tape–augmented posterior cruciate ligament repair should be tensioned and fixed at approximately 100° knee

flexion to prevent loss of full flexion. *Arthrosc Sports Med Rehabil* 2021;3:e1811-e1818.

35. Batty LM, Norsworthy CJ, Lash NJ, Wasiak J, Richmond AK, Feller JA. Synthetic devices for reconstructive surgery of the cruciate ligaments: A systematic review. *Arthroscopy* 2015;31:957-968.
36. Smith C, Ajuied A, Wong F, Norris M, Back D, Davies A. The use of the ligament augmentation and reconstruction system (LARS) for posterior cruciate reconstruction. *Arthroscopy* 2014;30:111-120.
37. Tulloch SJ, Devitt BM, Norsworthy CJ, Mow C. Synovitis following anterior cruciate ligament reconstruction using the LARS device. *Knee Surg Sports Traumatol Arthrosc* 2019;27:2592-2598.
38. Tulloch SJ, Devitt BM, Porter T, et al. Primary ACL reconstruction using the LARS device is associated with a high failure rate at minimum of 6-year follow-up. *Knee Surg Sports Traumatol Arthrosc* 2019;27:3626-3632.
39. Cook JL, Smith P, Stannard JP, et al. A canine arthroscopic anterior cruciate ligament reconstruction model for study of synthetic augmentation of tendon allografts. *J Knee Surg* 2017;30:704-711.
40. Smith PA, Stannard JP, Bozynski CC, Kuroki K, Cook CR, Cook JL. Patellar bone—tendon—bone autografts versus quadriceps tendon allograft with synthetic augmentation in a canine model. *J Knee Surg* 2020;33:1256-1266.