Clinical Sports Medicine Update

Analysis of Graft Types Augmented With an Internal Brace for ACL Reconstruction

CME

A Systematic Review

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Background: New techniques are being developed to decrease the failure rate of anterior cruciate ligament (ACL) grafts and prevent revision surgery. One such technique involves high-strength suture tape (ST), also referred to as internal bracing. Recent literature has highlighted the use of ST for ACL reconstruction, but no study has compared ST augmentation between graft types.

Purpose: To compare the use of ST augmentation for ACL reconstruction based on the type of graft used (ie, bone–patellar tendon–bone [BPTB], quadriceps, hamstring).

Study Design: Systematic review; Level of evidence, 5.

Methods: An online search of multiple databases was performed according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines and was completed April 2022 to identify studies related to ST augmentation of ACL grafts.

Results: Of 926 studies identified, 10 met inclusion criteria. Five studies (50%) used hamstring tendon (HT), 3 (30%) used quadriceps tendon (QT), 1 (10%) used BPTB, and 1 (10%) used both HT and QT grafts. HT autografts augmented with ST had decreased dynamic and peak elongation (15%-56%), increased load to failure, and increased initial and final dynamic stiffness compared with controls. There was no significant difference in postoperative physical examination findings (range of motion, Lachman, pivot shift), except that ST-augmented grafts had significantly less laxity after surgery compared with HT alone (0.8 vs 1.9 mm; $P < .05$). QT allografts with ST augmentation showed increased graft strength. Human QT autograft studies showed higher Knee injury and Osteoarthritis Outcome Score scores compared with controls. BPTB allografts with ST augmentation had decreased cyclic displacement by 31% ($P = .015$) and increased load (758 ± 128 N; $P < .001$) and stiffness (156 ± 23 N/mm; $P = .003$) compared with nonaugmented groups. The complication rate was low or showed no increase in the ST augmentation groups compared with control groups.

Conclusion: HT, QT, and BPTB grafts augmented with ST demonstrate an effective method for ACL reconstruction. All graft types with ST augmentation showed no evidence of clinical disadvantage, with some studies indicating significant biomechanical or clinical advantages compared with conventional ACL reconstruction.

Keywords: ACL; allograft; internal brace; suture tape augmentation

It is estimated that 100,000 to 150,000 anterior cruciate ligament (ACL) reconstructions are performed annually in the United States, and the incidence of ACL injuries has continued to steadily increase over the past 2 decades.[20,38] ACL injuries account for 25% to 50% of ligamentous knee injuries. The standard treatment for an ACL injury in athletes and active individuals is ACL reconstruction (ACLR).[19] Although this has historically been the preferred operative management, the success rates of ACLR are variable.[11] Many studies have demonstrated an increased failure rate in younger patients, and there are additional concerns regarding graft elongation from suspensory fixation and the stability of fixation.[3,4,21] However, new techniques have evolved that use high-strength suture tape (ST) to protect the graft from excessive stretching and unpredictable loads during the ligamentization period.[1]

One of these new techniques involves augmenting the ACL graft with an ultra–high molecular weight polyethylene/polyester tape that is coated in collagen, also known as

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internal bracing. This allows increased graft strength and limits elongation during the ligamentization period.[16,17] The use of ST has been described in various ligament augmentations in sports medicine. For example, both ulnar collateral ligament reconstruction and subscapularis repair with ST augmentation demonstrated greater load to failure than nonaugmented groups.[23,42] Furthermore, Gould et al[8] showed that patellar tendon repair with ST augmentation has significantly less displacement than standard repair. Smith and Bley[33] discussed a technique for ACLR with anterior tibialis allograft augmented with ST that provides the advantage of added protection during the revascularization and remodeling phase. In theory, this approach is beneficial for allografts as biologic incorporation of allograft tissue has been shown to be slower than with autograft.[32] Although this procedure offers many benefits, a common concern is overconstraining the joint and stress shielding of the graft; however, these complications can be avoided by fixing the graft to the tibia with the knee in full extension and securing the ST to the tibia separately from primary graft fixation.[29,33,41]

Other methods are described in the literature to decrease primary ACL graft failure. The double-bundle reconstruction technique has been shown to decrease anterolateral instability by providing sufficient contact between the graft and bone tunnel wall, a significantly better technique than single-bundle reconstruction.[12] It has also been noted that large graft diameter reduces failure rate and is one of the most important factors in predicting revision rates in ACLR.[36] Furthermore, ACLR with lateral extra-articular tenodesis was found to reduce anterolateral instability, failure rate, and return to sport time.[7,44]

Augmenting grafts for ACLR with ST could affect the rehabilitation process and decrease failure rate in patients. Recent literature has highlighted the use of ST for ACLR, but no study has compared ST augmentation among graft types. The purpose of this study was to compare the use of ST augmentation for ACLR based on the type of graft used (ie, bone–patellar tendon–bone [BPTB], quadriceps, hamstring).

METHODS

This systematic review was conducted according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.[28]

Data Sources, Search Strategies, and Study Eligibilit

Six databases or registries were searched in April 2022 to gather published literature: MEDLINE (Ovid), Embase, Scopus, Web of Science Core Collection, clinicaltrials.gov, and the Cochrane Central Register of Controlled Trials (CENTER). Searches were limited to studies that were published in English from 2000 to April 2022. Search terms included the controlled vocabulary of each database—if available, subheadings, keywords, and appropriate abbreviations. These terms included *anterior cruciate ligament graft*, *anterior cruciate ligament reconstruction*, *anterior cruciate ligament brace*, *orthopedic fixation devices*, *internal fixators*, *internal brace*, *allografts*, and *autografts*. Example search strategies can be found in Table 1. Search terms, strategies, and Boolean operators were customized to each database.

Studies focusing on ACLR with internal fixation were retrieved. Studies were included if they met the following criteria: animal/biomechanical model, all levels of evidence, reported in the English language, and male or female patients who had an ACL injury and subsequently underwent ACLR with ST augmentation. Studies were excluded if ACL repair was performed rather than ACLR, patients had additional ligamentous injuries, patients underwent revision surgery, or if the study was a systematic or narrative review. Published abstracts were also excluded.

Study Selection and Quality Assessment

All identified articles were imported into the Rayyan tool.[26] Two of the authors (C.M., C.R.) independently screened the studies by title and abstract. The remaining studies were screened using the full text of each article. Differences were discussed between the same 2 authors, and consensus was reached regarding inclusion and exclusion of studies. A quality assessment of the methodologic rigor of reviewed studies was performed using the Risk of Bias in Nonrandomized Studies–Interventions (ROBINS-I) tool.[39]

Data Extraction, Analysis, and Synthesis

Two authors (C.M., C.R.) independently reviewed and recorded study data into an extraction template. Extracted data included the author(s), publication year, country, treatment protocol, inclusion criteria, exclusion criteria,

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TABLE 1
Example Search Strategies

No.	Query Results	Results
Embase Session Results		
#9.	#4 AND #6 AND [2000-2022]/py AND [english]/lim	363
#8.	#4 AND #6 AND [2000-2022]/py	373
#7.	#4 AND #6	394
#6.	#1 OR #2 OR #3 OR #5	2942
#5.	'anterior cruciate ligament graft'/exp OR 'acl graft'	1040
#4.	'graft'/exp OR 'autograft'/exp OR 'allograft'/exp	65,392
#3.	('anterior cruciate ligament'/exp OR 'acl') AND ('internal fixator'/exp OR 'orthopedic fixation device'/exp OR 'internal brace'/exp)	1952
#2.	('anterior cruciate ligament reconstruction'/exp OR 'acl reconstruction') AND ('internal fixator'/exp OR 'internal brace'/exp)	336
#1.	'anterior cruciate ligament brace'/exp OR 'acl brace'	58
Ovid MEDLINE ALL <1946 to March 30, 2022>		
1	anterior cruciate ligament.mp. or Anterior Cruciate Ligament/ or ACL.mp.	29,219
2	Anterior Cruciate Ligament Reconstruction/ or ACL reconstruction.mp.	10,729
3	(Anterior Cruciate Ligament brace or acl brace).mp.	13
4	(anterior cruciate ligament graft or ACL graft).mp.	1018
5	orthopedic fixation devices/ or internal fixators/ or internal brace.mp.	11,711
6	allografts/ or autografts/ or graft.mp.	320,590
7	1 or 2 or 3 or 4	29,219
8	5 and 6 and 7	159
9	limit 8 to (english language and yr = "2000-Current")	136

method of analysis, number of patients, treatment outcome, limitations, quality assessment, and outcome measures. Data extraction was independently reviewed for accuracy by different team members.

RESULTS

A total of 1231 studies were identified in the initial search, and after removal of duplicates, 926 underwent review. After title and abstract screening, 31 studies were assessed in full text, 10 (32%) of which met the criteria to be included in the systematic review (Figure 1). The studies included 7 animal/biomechanical studies and 3 human studies, which were assigned levels of evidence (Table 2).

The ROBINS-I tool was used to assess the risk of bias in the 3 human nonrandomized studies (Table 3). Overall, these 3 studies showed low risk of bias. Lavender et al[14] received a moderate risk of bias in selection of participants into the study because of the low number of overall participants (n = 16; n = 11 followed up over 2 years), as well as moderate risk of bias in measurement of outcomes and selection of the reported result.

Hamstring Tendon Autograft

Animal/Biomechanical Studies. Four of the 10 studies (40%) assessed the effect of ST augmentation on hamstring tendon (HT) autografts in animal or biomechanical models.[2,13,24,37] Three of the 4 studies (75%) used bovine flexor or extensor tendons, which share a similar structure and viscoelastic properties with human HT.[6] Bachmaier et al[2] and Noonan et al[24] found no significant differences ($P \geq .05$) for any outcome measure when comparing the 2 reinforced groups, with complete findings in Appendix Table A5 (available in the online version of this article). When comparing ST groups with their respective controls, they found decreased dynamic and total elongation by 15% to 56% and increased ultimate failure load for all ST augmented groups ($P = .066$ for smaller diameter graft at 250 N in Bachmeir et al; $P < .05$ for all other groups). The ST groups showed increased initial and final dynamic stiffness at 250 N and 400 N load testing ($P < .05$).[2,24]

These findings differ from those of Lai et al,[13] who found no significant difference between intact graft alone and intact graft with ST augmentation for any measurement in both the single suspensory construct and double suspensory construct techniques, whereas the resected graft with ST augmentation group showed increased ultimate load, increased yield strength, and decreased cyclic displacement compared with the resected graft–only group for the single and double suspensory construct techniques ($P < .001$ for all outcomes). The double suspensory construct technique also had significantly increased stiffness with ST augmentation compared with resected graft alone ($P < .022$). In addition, significant differences were found in the mechanism of graft failure between the groups. In the single suspensory construct technique group, 8 of the 10 (80%) intact graft with reinforcement failures were

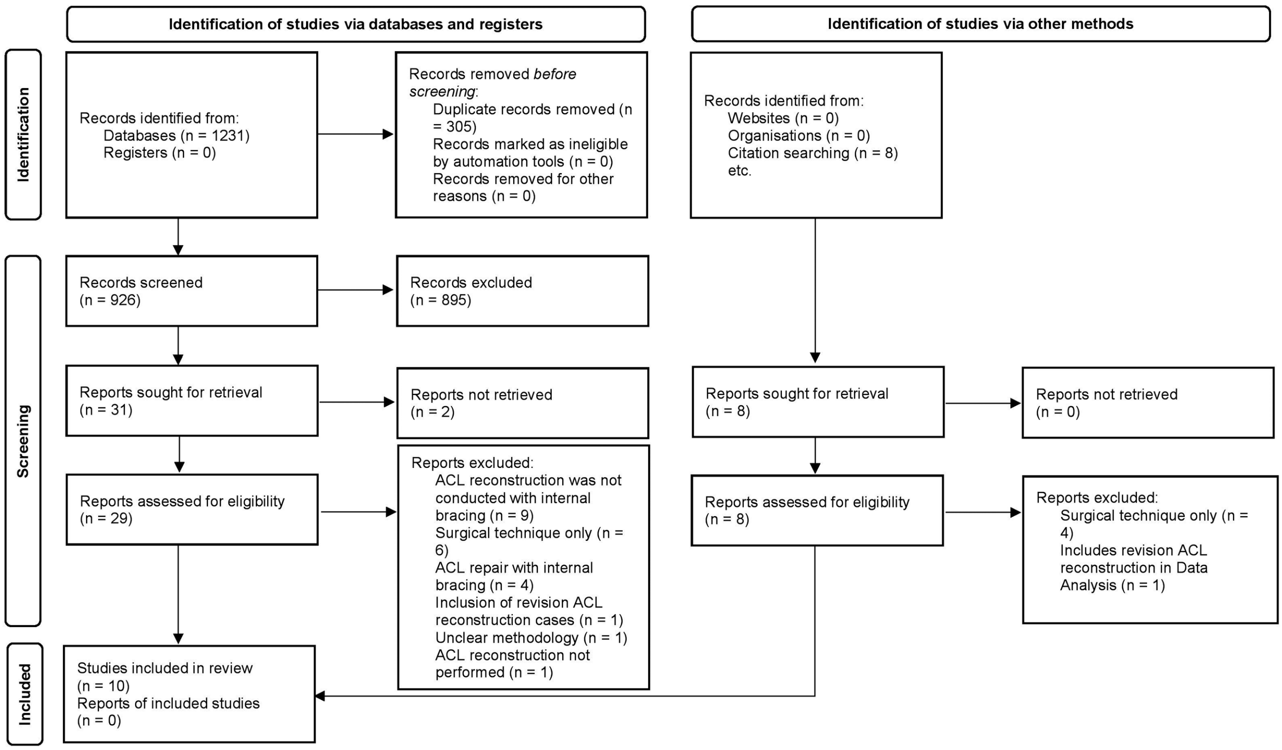

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram. ACL, anterior cruciate ligament.

due to the button breaking through the cortex, while 8 of the 10 (80%) intact graft failures were due to the graft slipping past the interference screw on the tibia (*P* = .023).[13] However, in the double suspensory construct technique group, 5 of the 10 (50%) resected graft with reinforcement failures were due to breaking of the tibial button, while 10 of the 10 (100%) resected graft failures were due to stretching of the graft (*P* = .033).[13]

Soreide et al[37] used a rabbit model with methods and outcome measures detailed in Appendix Table A6 (available online) showing no significant differences between the ST alone and autograft + ST groups. Biomechanical assessment showed higher ultimate load to failure (60.3 N; 46.1 N; *P* = .035) and higher energy absorption capabilities (103.5 N·mm; 82.7 N·mm; *P* = .022) in ST alone and ST + autograft, respectively, compared with autograft alone, which showed 26.4 N and 31.0 N·mm of ultimate load and energy absorption, respectively. In addition, the autograft alone (9.2 mm) showed increased elongation compared with the autograft + ST group (6.6 mm; *P* = .006). Micro–computed tomography assessment demonstrated no evidence of osteoarthritis, fracture, or heterotopic ossification in any of the groups, with a significant increase in bone mineral density in the tibial bone tunnel of the ST alone compared with the ST + autograft and autograft alone groups (*P* = .039). In addition, histologic assessment showed integration of the graft with secondary bone formation and fibrocartilage tissue in all 3 groups with limited signs of inflammation overall. Long-term inflammation assessed by quantitative polymerase chain reaction was also minimal in all 3 groups.[37]

Human Studies. Two of the 10 (20%) studies examined HT autograft ACLR with ST reinforcement compared with ACLR without ST reinforcement, which can be found in Appendix Table A4 (available online).[29,41] Parkes et al[29] found no significant differences in patient-reported outcomes (PROs) such as Tegner activity score, Lysholm score, and International Knee Documentation Committee (IKDC) score, or physical examination findings between ST and control groups, with the exception of an increased postoperative Tegner activity score in the ST group (7.1) compared with the control group (6.4) (*P* = .026). von Essen et al[41] found that patients with ST augmentation of HT autograft had a significant deficit in flexion at 6 weeks (n = 11; 55%; *P* = .029) compared with the control group (n = 4; 20%), but this difference resolved at 6 months. However, patients with ST augmentation had significantly (*P* < .05) less laxity postoperatively (0.8 ± 0.8 mm) compared with the control group of HT alone (1.9 ± 1.9 mm).[41] The rate of complications, including graft failure, did not differ significantly between ST groups and their respective controls in both studies.[29,41]

Quadriceps Tendon Autograft/Allograft

Animal/Biomechanical Studies. Two animal studies had ACLR performed with quadriceps tendon (QT)

TABLE 2
Summary of Study Characteristics and Level of Evidence of Included Studies[a]

Lead Author (Year)	Subject	No. of Patients/Models ([M/F]; Animal Type if Applicable)	Graft Type (With Internal Brace/Without Internal Brace)	Outcome Measures	LOE
Bachmaier (2018)[2]	Animal study	32 (porcine bone model)	Bovine flexor tendon–HT autograft equivalent (16 HT + ST; 16 HT alone)	Cyclic displacement; LTF; stiffness	5
Noonan (2020)[24]	Animal study	32 (porcine bone model)	Bovine flexor tendon–HT autograft equivalent (16 HT + ST; 16 HT alone)	Cyclic displacement; LTF; stiffness	5
Lai (2021)[13]	Animal study	80 (porcine bone model)	Bovine extensor tendon–HT autograft equivalent (40 HT + ST; 40 HT alone)	Cyclic displacement; LTF; stiffness; yield strength	5
Soreide (2019)[37]	Animal study	18 (rabbits)	HT autograft (6 ST alone; 6 HT + ST; 6 HT alone)	Median elongation; median LTF; median stiffness; median energy absorption; histologic assessment; micro-CT assessment; qPCR	5
Parkes (2021)[29]	Human study	108 (75 M; 33 F)	HT autograft (36 HT + ST; 72 HT + ST)	RTS; time to RTS; Tegner activity score; Lysholm score; IKDC; complications/failure	3
von Essen (2022)[41]	Human study	80 (46 M; 34 F)	HT autograft (20 HT + ST; 20 HT alone); QT autograft (20 QT + ST; 20 QT alone)	Laxity; flexion (at 6 weeks, 6 months); pain; symptoms	3
Cook (2017)[5]	Animal study	20 (canines)	QT allograft (10 QT + ST; 10 QT alone)	Lameness; function; TPI; pain; effusion; CROM; anterior drawer; internal rotation	5
Smith (2020)[35]	Animal study	10 (canines)	QT allograft (5 QT + ST; 5 BPTB)	Lameness; function; TPI; pain; effusion; CROM; anterior drawer; internal rotation	5
Lavender (2021)[14]	Human study	11 (NR)	QT autograft or allograft (11 QT + ST)	Mean IKDC; mean Marx; complication; return to preoperative activity	4
Smith (2020)[34]	Animal study	30 (porcine bone model)	BPTB allograft (10 BPTB + ST; 20 BPTB alone)	Cyclic displacement; ultimate load; stiffness	5

[a]BPTB, bone–patellar tendon–bone; CROM, comfortable range of motion; CT, computed tomography; F, female; HT, hamstring tendon; IKDC, International Knee Documentation Committee; LOE, level of evidence; LTF, load to failure; M, male; NR, not reported; qPCR, quantitative polymerase chain reaction; QT, quadriceps tendon; RTS, return to sport; ST, suture tape augmentation; TPI, Total Pressure Index.

TABLE 3
Risk of Bias Assessment[a]

Lead Author (Year)	D1	D2	D3	D4	D5	D6	D7
Lavender (2021)[14]	L	M	L	L	N	M	M
Parkes (2021)[29]	L	L	L	L	L	L	L
von Essen (2022)[41]	L	L	L	L	L	L	L

[a]Assigned to each study is a low (L), moderate (M), or high (H) risk of bias for the associated categories. No information (N) is assigned if not applicable. Domains: D1, bias due to confounding; D2, bias in selection of participants into study; D3, bias in classification of interventions; D4, bias due to deviations from intended interventions; D5, bias due to missing data; D6, bias in measurement of outcomes; D7, bias in selection of the reported result.

allografts along with ST augmentation with outcome measure outlined in Appendix Table A6 (available online).[5,35] One of these studies was done by Cook et al,[5] who performed all-inside ACLR on 10 canines with a QT allograft and ST internal bracing (QTIB), with the control group being the native ACL of the contralateral knee. Cook et al[5] showed no differences in clinical outcome data at 6 months, as well as no evidence of widening at femoral or tibial sockets and no degenerative or osteoarthritic changes on radiographic imaging.[5] In the QTIB group, 8 of 10 knees (80%) showed mild effusion at 2 months while 4 of 10 (40%) showed mild effusion at 6 months on radiographic imaging.[5] Arthroscopic assessment revealed no apparent articular cartilage or meniscal pathology, as well as no osteophyte formation in any QTIB knees. Histologic assessment showed all QTIB grafts had direct bone attachment and 4-zone healing consisting of tendon, chondroid tissue, calcified cartilage, and bone with no evidence of necrosis, rejection, or infection. A similar study conducted by Smith et al[35] observed no significant differences between

QTIB and BPTB autograft groups. Mild effusion in 2 of 5 (40%) QTIB knees was noted at 6 months on radiographic imaging, with similar findings on arthroscopic and histologic assessment as Cook et al mentioned previously.[35]

Clinical Studies. Two studies included findings of patients who underwent ACLR with ST reinforcement of a QT autograft with findings included in Appendix Table A4 (available online).[14,41] Lavender et al[14] found that all patients had a negative Lachman and pivot-shift examination with no subjective instability. Seven of 11 (64%) patients reported their knee felt good and 4 (36%) reported their knee felt average, but the breakdown between autograft and allograft was not reported. Of the 9 of 11 (82%) patients who returned to normal preinjury activity level, 7 of 8 (87.5%) had an autograft, and 2 of 3 (67%) had a FlexiGraft GraftLink allograft (LifeNet). No retears or infections were reported, but 1 case of arthrofibrosis was reported at 6 weeks postoperatively and treated.[14]

von Essen et al[41] assessed ST augmentation of ACLR in the same study as mentioned previously. A significant deficit in flexion at 6 weeks was also seen in the QT + ST group (n = 10; 50%) compared with the control group (n = 4; 20%; $P = .046$), as seen with the HT + ST group, with this deficit resolving at 6 months as well. No other significant differences were found in physical examination findings between the 2 groups at any point postoperatively, along with no significant difference ($P > .05$) in side-to-side difference in displacement.[41] Knee injury and Osteoarthritis Outcome Score scores were not significantly different preoperatively or 12 months postoperatively between groups as well. The rate of subsequent surgery or graft rupture did not differ significantly compared with the control group, but 1 patient had a new trauma that resulted in tearing of the ST while the graft remained intact.[41]

BPTB Allograft

Smith et al[34] evaluated biomechanical properties of porcine bone models after ACLR with BPTB allograft, with results found in Appendix Table A5 (available online). The adjustable loop device on the femur with an interference screw (ALD-S) on the tibia with ST (ALD-S-ST) group had decreased cyclic displacement by 31% compared with the ALD-S ($P = .015$) and interference screw fixation on the tibia and femur (S-S) groups ($P = .017$). Construct stiffness and ultimate load to failure were significantly higher in both the ALD-S-ST (respectively, 156 ± 23 N/mm, $P = .003$; 758 ± 128 N, $P < .001$) and the ALD-S (respectively, 122 ± 28 N/mm, $P = .0042$; 628 ± 223 N, $P = .025$) groups compared with the S-S group (104 ± 40 N/mm; 416 ± 167 N), but a significant difference was not seen between the 2 ALD-S groups.[34]

DISCUSSION

The findings of this review highlight the benefits of augmenting different grafts with ST for ACLR in both biomechanical and clinical settings. There were no studies assessing HT allografts, but HT autografts with ST augmentation resulted in increased strength and load to failure, decreased displacement, increased postoperative Tegner scores, decreased laxity, and no significant difference in other PROs compared with conventional ACLR.[2,13,24,29,37,41] QT allografts with ST augmentation showed no significant difference in clinical assessment data or abnormal findings on radiographic imaging and arthroscopic and histologic assessment in comparison with native ACLs in animal models.[5,35] QT allografts with ST augmentation performed well in clinical trials with a lack of concerning physical examination findings, positive PROs, and no reports of retears.[14] QT autografts with ST augmentation were proven to be equally effective as conventional ACLR in a clinical study. This procedure had no significant difference in physical examination findings, graft displacement, postoperative Knee injury and Osteoarthritis Outcome Score scores, and postoperative complications.[41] Furthermore, BPTB allograft with ST augmentation decreased displacement and increased load to failure and stiffness.[34]

Currently, no studies have analyzed the use of HT allografts with ST augmentation. Therefore, further research is required to determine if HT allografts are a practical option for ST augmentation, although 6 studies in our systematic review supported the use of HT autografts with ST augmentation for ACLR.[2,13,24,29,37,41] HT autografts with ST augmentation were shown to improve biomechanical outcome measures in comparison to grafts without augmentation.[2,13,24,37] Of note, 2 of the studies used tripled and quadrupled HT grafts, which likely increased the stability of the augmentation.[2,24] These biomechanical findings are consistent with a demonstration by Wicks et al,[43] which showed a significant increase in the yield and ultimate failure loads as well as a significant decrease in cyclic displacement in augmented ligament reconstructions compared with those without. Clinically, HT autograft with ST was shown to be similar to HT autograft alone in physical examination findings, PROs, isokinetic strength, and rate of subsequent surgery or graft rerupture, which indicates that this is a comparatively safe option for patients undergoing ACLR.[29,41] Further findings indicated an increase in postoperative Tegner activity scores and less laxity after surgery compared with HT alone.[29,41] Thus, HT with ST augmentation is a viable option for ACLR.

The most important findings regarding the use of QT allografts and allografts with ST augmentation is that it does not differ biomechanically or clinically from QT alone. From a clinical perspective, QT autografts with ST augmentation performed just as well as QT alone in terms of physical examination findings, PROs, and rate of subsequent surgery or graft rupture.[41] These findings are consistent with those of Saper,[31] who concluded that QT with ST for ACLR results in excellent clinical and PROs in adolescent athletes at the 12-month follow-up.

Findings in this review regarding QT auto-/allografts with ST augmentation were not directly comparable with the results of HT grafts with ST augmentation. This is because of few biomechanical studies involving QT auto-/allografts with ST augmentation measuring the same outcomes as the studies found on HT grafts. However, von Essen et al[41] is one of the only studies to directly compare

QT autografts with HT autografts with and without ST augmentation. Most important, the authors found there was significantly less laxity in the HT autograft with ST augmentation compared with HT autograft alone, while there was no difference in laxity between the QT autograft with ST augmentation and QT autograft–alone groups.[41] Previous literature states that QT autografts have less pivot-shift laxity and lower failure rates than HT autografts.[25] However, we do recognize that QT and HT autografts have both been shown to be comparably good for primary ACLR.[10] A randomized controlled trial by Horstmann et al[10] demonstrated that there was no significant difference in knee stability, IKDC score, Lysholm score, pivot-shift measurement, return to work or sport, strength of knee flexion and extension, or adverse events between the 2 groups for primary ACLR. In support of the previous study, Lind et al[15] concluded that QT autograft for ACLR did not result in inferior subjective outcome compared with HT autograft. There is no current literature that indicates HT auto-/allograft is more favorable than QT auto-/allograft for suture augmentation. Further studies will be required to directly evaluate QT versus HT auto-/allografts with ST augmentation.

Smith et al[34] was the only study to analyze BPTB allograft with ST augmentation for ACLR. Rather than using QT or HT grafts, this technique provided an alternative method for ACLR while producing promising biomechanical outcomes such as decreased cyclic displacement and increased ultimate load to failure and construct stiffness compared with ALD-S/S-S and S-S, respectively.[34] This construct involves an adjustable loop device, interference screw, and ST, which is different from the previous studies in this review. It is unclear whether the BPTB allograft with ST augmentation is biomechanically more favorable than either QT or HT auto-/allografts with ST augmentation. However, a systematic review and meta-analysis by Mouarbes et al[22] indicated that HT, QT, and BPTB autografts have comparable clinical and functional outcomes and graft survival rates for conventional ACLR. No current studies evaluate the clinical use of BPTB autografts with ST augmentation.

The findings of our study are similar to those of Mackenzie et al,[18] who in 2022 performed a systematic review assessing ST augmentation for ACLR in biomechanical, animal, and clinical studies. The previously mentioned study by Mackenzie et al found ST augmentation increased the strength of graft complex and reduced elongation in biomechanical studies, had no difference in graft maturation/healing and rates of intra-articular complications compared with no ST augmentation in animal studies, and had mixed PRO measures (IKDC scores and return to play) from significant and nonsignificant improvements as well as no difference in complications in clinical studies.[18] Although recent literature highlights the overall use of ST augmentation for ACLR, there are no reviews focusing on comparing graft types.

Limited clinical studies were found in the literature using ST for ACLR, but the use of ST has been effectively described clinically in other ligamentous injuries. Ozdag et al[27] demonstrated that lateral ulnar collateral ligament repair with ST augmentation results in acceptable functional outcomes and a reoperation rate comparable with other joint stabilization procedures. ST augmentation has also been shown to produce good short-term clinical outcomes with few complications when used for lateral ankle instability.[30] Last, Hinz et al[9] found that patellar tendon repair with ST augmentation led to good PROs and no postoperative complications. Therefore, ST augmentation is effective in various ligamentous injuries.

The cost of using ST augmentation can be a limitation for many clinicians and patients. The InternalBrace (Arthrex) ranges from $700 to $950 per box. Vannatta et al[40] looked at the total aggregate cost for lateral ankle ligament repair with suture anchors versus ST augmentation. Despite an upfront increase in ST cost of $900, the aggregate cost of the suture anchor group was $2219 more expensive than when augmenting with ST. The majority of savings occurred in decreases in number of physical therapy visits and faster return to work times. It is possible that the same outcomes could be seen with ACLR ST augmentation compared with traditional reconstruction, but further research is required.

Limitations

Limitations to this study should be noted. First, this study is a systematic review that is subject to the limitations of all systematic reviews, such as missing studies that should be included, risk of bias, random error, and inconsistency. Only 3 human studies were included in this systematic review, which were all retrospective studies. In 2 of the human studies, there was no randomization between groups, which makes them subject to bias.[29,41] Also, Parkes et al[29] noted that a post hoc power analysis revealed the total sample size needed to detect a difference would be 1290 patients, with 430 in the ST group, which was larger than the number in their study. Lavender et al[14] lacked a control group and had a small sample size (N = 16). In the current study, the 7 biomechanical studies on cadaveric tissue have limitations common to all biomechanical studies, such as not completely representative in vivo loads, use of nonhuman tissue, and varying graft sizes. Surgical techniques of graft and ST fixation varied throughout the included studies, and graft tension was not standardized. There are currently limited published data on ST for ACLR that includes human patients, which limited the material that could be included in the study. Because of these limited data, there are few studies directly comparing different graft types. Long-term data are lacking in the literature for the use of ST. Further research is required to better understand the clinical application of ST augmentation for ACLR.

CONCLUSION

HT, QT, and BPTB grafts augmented with ST demonstrate an effective method for ACLR. All graft types with ST augmentation showed no evidence of clinical disadvantage, with some studies indicating significant biomechanical or clinical advantages compared with conventional ACLR.

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