Graft Failure in Pediatric Patients After Bone–Patellar Tendon–Bone, Hamstring Tendon, or Quadriceps Tendon Autograft ACLR

A Systematic Review and Meta-analysis

Camryn B. Petit,*†‡§ BS, Zaamin B. Hussain,‡ MD, EdM, April McPherson,*†‡∥ PhD,
Erich J. Petushek,¶ PhD [ORCID], Alicia M. Montalvo,*# PhD, MPH, ATC, Mia S. White,** MILS, AHIP,
Harris S. Slone,†† MD, Joseph D. Lamplot,*‡ MD, John W. Xerogeanes,*†‡ MD,
and Gregory D. Myer,*†‡§§∥∥¶¶##a PhD [ORCID]
Investigation performed at Department of Orthopaedics, Emory University School of Medicine, Atlanta, Georgia, USA

Background: Anterior cruciate ligament (ACL) reinjury risk is high in young athletes, with graft failure rates as high as 23%. The optimal autograft choice to minimize reinjury risk in this population is unclear.

Purpose: To compare graft failure rates between bone–patellar tendon–bone (BPTB), hamstring tendon (HT), and quadriceps tendon (QT) autografts in patients aged ≤18 years with a minimum follow-up (FU) of 24 months.

Study Design: Systematic review; Level of evidence, 4.

Methods: A systematic review of the literature between database inception and March 2022 encompassed PubMed/MEDLINE, Cochrane CENTRAL, Embase, and Web of Science Core Collection databases. Studies on autograft ACL reconstruction (ACLR) using HT, QT, or BPTB autograft in patients ≤18 years old with a minimum FU of 2 years were included. Graft failure rates were pooled and estimated using random-effects models via the inverse variance method and logit transformations. Meta-analyses were used to estimate failure rates and pairwise comparisons were conducted by autograft type when appropriate.

Results: A total of 24 studies comprising 2299 patients (HT: n = 1237, 44.8% female, 59.1-month mean FU; BPTB: n = 913, 67.3% female, 79.9-month mean FU; QT: n = 149, 36.4% female, 35.3-month mean FU) were included. HT exhibited the highest failure rate at 11.8% (95% CI, 9.0%-15.4%); failure rates for BPTB and QT were 7.9% (95% CI, 6.2%-10.0%) and 2.7% (95% CI, 1.0%-7.5%), respectively. HT had a significantly higher failure rate than both BPTB (Q = 5.01; P = .025) and QT (Q = 7.70; P = .006); BPTB had a significantly higher failure rate than QT (Q = 4.01; P = .045). Male patients were less likely than their female counterparts to experience graft failure after HT ACLR (odds ratio, 0.48; 95% CI, 0.25-0.95).

Conclusion: While the HT remains a common choice for ACLR, the current aggregate data indicate that BPTB and QT demonstrated significantly lower failure rates than HT ACLR in adolescent athletes ≤18 years old. The QT demonstrated the lowest failure rate in adolescents but also the lowest proportion of patients represented due to a paucity of published QT data, indicating a need for future studies with larger sample sizes that include QT autografts, reduced risk of bias, and consistent reporting on skeletal maturity and surgical technique to better determine the ideal autograft for active athletic populations ≤18 years old.

Keywords: knee; ACL; adolescent; athlete; graft failure

In the United States alone, an estimated 100,000 to 200,000 anterior cruciate ligament (ACL) injuries occur each year, corresponding to an estimated 64,000 to 100,000 ACL reconstructions (ACLRs).[8,9,40] ACL injury

rates are highest in young athletes due to participation in high-risk sports such as soccer, basketball, and football that involve cutting and pivoting motions with corresponding deceleration and valgus knee moments.[6,9] ACL injuries in pediatric athletes continue to rise, likely attributable to increased youth sport participation and early single-sport specialization.[16,19,47] ACL injuries result in significant time lost from sport, increase the risk of developing early-onset knee osteoarthritis, and alter the quality of life for young athletes.[1,36] ACLR is the standard-of-care for treatment in young ACL-injured athletes to restore mechanical stability of the knee, irrespective of skeletal maturity.[16] Graft type surgical technique, management of concomitant meniscal pathology, and graft fixation strategy may contribute to postoperative outcomes.[24,67]

Optimal graft type for ACLR remains a source of debate and active research.[24] Despite efforts to determine optimal return-to-sport timing and requirements, graft failure continues to be a major burden, particularly among young athletes. Patients <25 years old have graft failure rates as high as 23%[66] and are 6 times more likely to reinjure their knee within 2 years of returning to sport participation compared with athletes who have no history of ACL injury.[45] These outcomes prompted exhaustive investigation into risk factors for secondary ACL injury in this population, leading to identification of young age, high activity level, sex, and allograft use as contributors.[2,3,23,44,45,61,66] As surgeons have recognized the important role of the meniscus as a secondary knee stabilizer, propensity for meniscal repair alongside ACLR has increased.[26,53]

Notably, given the risk of growth disturbance, ACLR in skeletally immature patients provides a unique challenge, due to the open distal femoral and proximal tibial physes. No single graft type has been determined to be most appropriate for this skeletally immature population.[67] Hamstring tendon (HT) remains a common graft type for young patients outside of North America due to reduced risk of patellar fracture, anterior knee pain, and quadriceps inhibition.[30] HT autograft has become the most commonly selected autograft among surgeons worldwide, with bone–patellar tendon–bone (BPTB) the second most used but significantly less common choice for ACLR.[28,58] However, HT has been questioned for use in younger athletic populations due to the potential for undersizing in small patients, tunnel widening, and evidence indicating higher failure rates for HT autografts compared with BPTB autografts in young patients.[2,24,26,30,43,52,37] BPTB has been considered the gold standard for ACLR in the United States due to high rates of return to sport and lower rates of failure.[15,48] Over the past decade, the quadriceps tendon (QT) autograft has received increased interest for use in ACLR in pediatric patient populations due to increased size and strength of the graft and outcomes of reduced postoperative anterior knee pain.[30] However, few studies have compared failure rates using QT with those of other autograft types in these patients.[26] Due to a paucity of published data on the QT autograft, its widespread adoption for ACLR has been limited.

While graft type is an identified risk factor for ACL graft failure, the rising rates of primary ACL injury among young patients underscore a need to understand how graft selection and subsequent failure rates vary in this age group.[16] Therefore, the purpose of this review was to compare graft failure rates between BPTB, HT, and QT autografts in patients aged ≤18 years with a minimum follow-up (FU) of 24 months. The secondary aim of this review was to stratify graft failure rates by sex, skeletal maturity, and concomitant meniscal surgery. We hypothesized that BPTB would demonstrate reduced failure relative to QT and HT autografts.

METHODS

Search Strategy

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement was used as the guideline for performing this review. The protocol for the

[a]Address correspondence to Gregory D. Myer, PhD, Emory Orthopaedics and Spine Center, 4450 Falcon Parkway, Flowery Branch, GA 30097, USA (email: greg.myer@emory.edu) (Twitter/X: @gregmyer11).

*Emory Sports Performance And Research Center (SPARC), Flowery Branch, Georgia, USA.
[†]Emory Sports Medicine Center, Atlanta, Georgia, USA.
[‡]Department of Orthopaedics, Emory University School of Medicine, Atlanta, Georgia, USA.
[§]Medical College of Georgia, Augusta, Georgia, USA.
[||]Department of Orthopaedics, The Ohio State University Wexner Medical Center, Columbus, Ohio, USA.
[¶]Department of Psychology and Human Factors, Michigan Technical University, Houghton, Michigan, USA.
[#]College of Health Solutions, Arizona State University, Phoenix, Arizona, USA.
[**]Emory University Woodruff Health Sciences Center Library, Atlanta, Georgia, USA.
[††]Department of Orthopaedics and Physical Medicine, Medical University of South Carolina, Charleston, South Carolina, USA.
[‡‡]Campbell Clinic Orthopaedics, Germantown, Tennessee, USA.
[§§]Sports Medicine Division, Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio, USA.
[||||]Wallace H. Coulter Department of Biomedical Engineering, Georgia Institute of Technology & Emory University, Atlanta, Georgia, USA.
[¶¶]The Micheli Center for Sports Injury Prevention, Waltham, Massachusetts, USA.
[##]Youth Physical Development Centre, Cardiff Metropolitan University, Cardiff, Wales, UK.
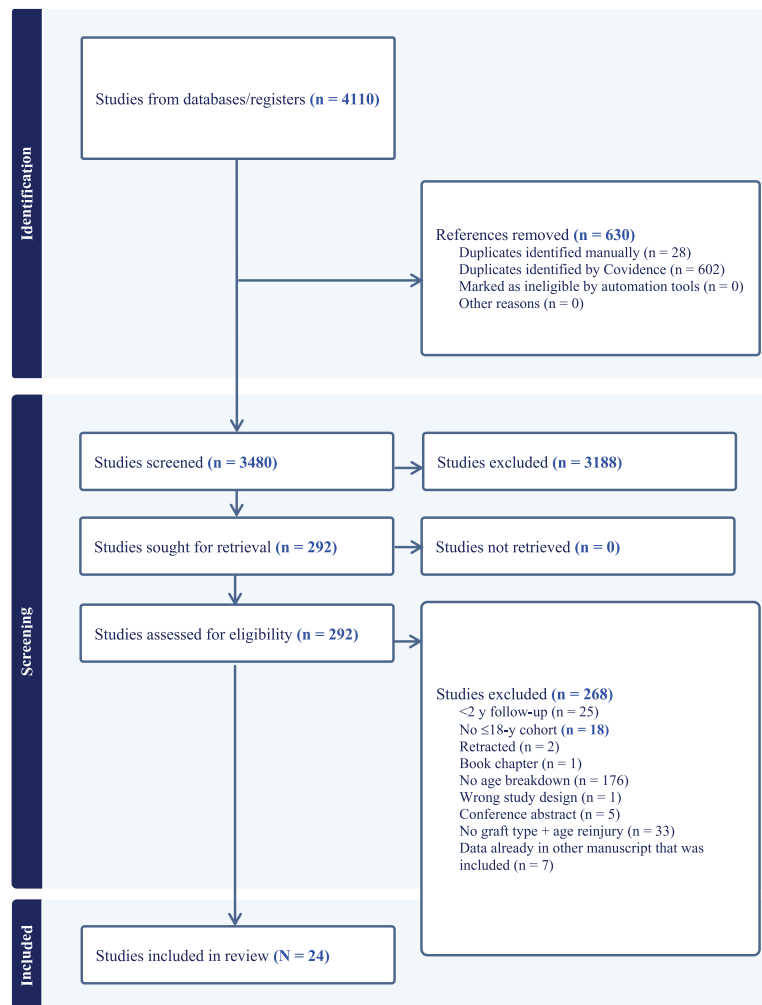Final revision submitted April 7, 2024; accepted April 18, 2024.

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart for inclusion and exclusion of articles.

review was not registered. An information specialist/librarian (M.S.W.) searched PubMed/MEDLINE (National Library of Medicine: 1946-), Embase (Elsevier: 1966-), Cochrane CENTRAL (Cochrane Library 1996-), and Web of Science Core Collection (Clarivate: 1900-) between origin of database and March 3, 2022. A combination of controlled vocabulary and text words related to autografts was combined with the Boolean operator "AND" with controlled vocabulary and text words associated with ligaments, tendons, and bone grafts related to the patella (Appendix Table A1). Language was limited to English, and the following types of studies were excluded: case reports, comment, commentary, editorial, any type of review, or letter. Age filters were not added to the searches to avoid inadvertent exclusion of relevant records.

Data Extraction

In total, 6220 records were retrieved and imported into the citation manager EndNote 20.[62] EndNote's "find duplicates" feature was used to remove 2110 duplicates, and

4110 records were uploaded to Covidence (Veritas Health Innovation; www.covidence.org). Covidence removed an additional 602 duplicates; thus, along with 28 records removed manually, a total of 3480 records were advanced for the initial title/abstract screening. Of 3480 records reviewed, 3188 studies were deemed irrelevant or out of scope. Team members (C.B.P., Z.B.H.) reviewed the records; for any records that were disputed, 3 additional team members (J.D.L., A.M., G.D.M.) provided conflict resolution. A total of 292 studies were determined to be eligible for full-text review, and ultimately 24 papers were included for this study (Figure 1).[b]

Selection Criteria

Included studies covered autograft ACLR using HT, QT (comprising a combination of quadriceps tendon–bone [QTB] and all–soft tissue quadriceps tendon [ASTQT]), or

---

[b]References 5, 7, 11, 12, 13, 17, 18, 20, 25, 27, 29, 32, 33, 35, 38, 41, 42, 46, 49, 50, 51, 54, 57, 63.

TABLE 1
Inclusion/Exclusion Criteria[a]

Inclusion	Exclusion
Proportions of graft used and graft failures by graft type and age	No proportion of grafts and graft failures for younger population (age ≤18 years)
All ages permitted in study, but study must include the proportion of grafts and graft failures for younger population (age ≤18 years)	Revision ACLR
Patient underwent ACLR using autograft (hamstring tendon, quadriceps tendon–bone, all–soft tissue quadriceps tendon, or bone–patellar tendon–bone)	ACLR using allograft
Rates of clinical failure (grade 2+ or worse Lachman, grade 2+ or worse pivot shift, overall IKDC grade C or D, instrumented laxity with side-to-side difference of >5 mm)	ACLR with concomitant lateral extra-articular tenodesis
Observational study	Multiligament knee injury (MCL, LCL, PLC, and/or PCL repaired or reconstructed)
Therapeutic intervention	Concomitant cartilage repair or restoration surgery
Human study	Minimum follow-up <2 years
Peer-reviewed literature, articles published in scientific journals	Laboratory or animal study
Origin of database—date search was performed	Reviews without original data
English language	Non–peer reviewed study
	General/systematic reviews, meta-analyses, case reports, editorials, conference abstracts, book chapters
	Non-English language
	Data already reported in a separate, included manuscript

[a]ACLR, anterior cruciate ligament reconstruction; IKDC, International Knee Documentation Committee; LCL, lateral collateral ligament; MCL, medial collateral ligament; PCL, posterior cruciate ligament; PLC, posterolateral corner.

BPTB autograft in patients ≤18 years old with a minimum FU of 2 years. Included studies also had to report ACL graft failure rates (indicated by revision ACLR, grade 2+ or worse Lachman, grade 2+ or worse pivot shift, overall International Knee Documentation Committee grade C or D, instrumented laxity with side-to-side difference of >5 mm)[14] in patients ≤18 years old. Studies on outcomes of revision ACLR, allograft, and/or allograft augmentation ACLR; ACLR with concomitant lateral extra-articular tenodesis; and studies without graft failure rates reported by both graft type and young age (≤18 years) were excluded. If >1 study reported outcomes on the same patient population, only the study with complete outcome data was included in the meta-analysis. Inclusion and exclusion criteria are also detailed in Table 1.

Assessment of Level of Evidence

Two independent reviewers (C.B.P., Z.B.H.) evaluated each study and created a classification based on the level of evidence reflecting published criteria.[31]

Methodological Quality Assessment

To assess the methodological quality and risk of bias of the included studies, the Risk of Bias in Non-Randomized Studies of Interventions (ROBINS-I) tool was utilized.[60] ROBINS-I tool criteria assessed by the 2 independent reviewers (C.B.P., Z.B.H.) were biases (1) due to confounding, (2) in selection of participants into the study, (3) in classification of interventions, (4) due to deviations from

intended interventions, (5) due to missing data, (6) in measurement of outcomes, and (7) in selection of the reported result. Each criterion was rated as low risk, moderate risk, serious risk, critical risk, or no information in accordance with the ROBINS-I tool.[60]

Statistical Analysis

Graft failure rates were pooled and estimated using random-effects models via the inverse variance method and logit transformations.[4,55] For cells with zero counts, a continuity correction of 0.5 was applied.[65] The metaprop function within the metafor package in the statistical software environment (RStudio, Posit Software, PBC) was used to estimate the failure rates.[64] Subgroup analysis and pairwise comparisons were conducted by graft type. The metabin function was used to estimate the risk rates based on sex and odds ratio (OR) for the HT versus BPTB comparison.[64] Due to the small sample size, QT was not included in the OR comparison/estimation. Moderator analysis was conducted using the metareg function with between-study variance estimated using restricted maximum likelihood. Sensitivity analysis was conducted to assess if the rate estimates were similar utilizing only 2-arm studies. Statistical significance was set at $P < .05$. Where applicable, 95% CIs were reported.

RESULTS

Demographic Characteristics

Across all 24 included studies, there were 1237 patients who underwent primary ACLR using HT (17 studies);

913, BPTB (8 studies); and 149, QT (109 with QTB [3 studies][20,51,63] and 40 with ASTQT [2 studies][25,46]). Mean ages of patients by graft type were 14.2 years (range, 11.0-18.6 years) for HT, 15.6 years (range, 11.5-18.7 years) for BPTB, and 14.6 years (SD, 10.0-18.0 years) for QT. Mean FU duration was 59.1 months (range, 24.0-246.0 months) for patients who underwent HT ACLR, 79.9 months (range, 24.0-246.0 months) for BPTB autograft ACLR, and 35.3 months (range, 24.0-116.4 months) for QT autograft ACLR. On average, according to graft type, the proportion of patients completing FU was 88.2% for patients who underwent HT ACLR, 71.4% for patients who underwent BPTB ACLR, and 92.0% for patients who underwent QT ACLR. On average, according to graft type, 44.8% of HT, 67.3% of BPTB, and 36.4% of QT were in female patients (Table 2). Four percent of patients receiving QT had concomitant meniscal surgery, compared with 50% of patients receiving HT and 56% receiving BPTB.

All 24 included studies reported graft failure data; 11 studies included graft failure data according to sex,[c] 6 included mean time to graft failure,[7,17,35,42,46,49] 16 included skeletal maturity (open/closed physes) data,[d] 7 studies directly compared 2 graft types,[5,12,38,41,46,51,54] and 6 included concomitant meniscal surgery data.[7,11,12,18,20,49] There were no level 1 studies, 1 level 2 study,[57] 7 level 3 studies,[17,18,29,41,46,51,54] and 16 level 4 studies.[e]

Methodological Quality Assessment

For each study, risk of bias levels for each bias category using the ROBINS-I tool[60] are displayed in Table 3 and Figure 2.[34] In total, 21 (87.5%) studies had "serious" risk of bias due to confounding factors. The other bias categories were rated on average as low or moderate risk of bias.

Meta-analysis

Chi-Square Test for Overall Proportion of Patients for Each Graft Type

There was a significant difference in the proportion of patients undergoing QT, HT, and BPTB ACLR ($\chi^2 = 814.5$; $df = 2$; $P < .01$), with HT consisting of the most data/patients (n = 1237), followed by BPTB (n = 913), then QT (n = 149). All differences in pairwise comparisons were significant ($P < .001$).

Overall Graft Failure Rates

Pooled failure rates for each graft type were 11.8% for HT autografts (95% CI, 9.0%-15.4%) (Figure 3), 7.9% for BPTB autografts (95% CI, 6.2%-10.0%), and 2.7% for QT autografts (95% CI, 1.0%-7.5%). There was a significant difference between group failure rates ($\chi^2 = 10.5$; $P < .01$).

[c]References 5, 12, 17, 20, 25, 27, 41, 49, 50, 57, 63.
[d]References 5, 7, 11-13, 17, 25, 27, 29, 32, 33, 35, 41, 42, 46, 50.
[e]References 5, 7, 11-13, 20, 25, 27, 32, 33, 35, 38, 42, 49, 50, 63.

Pairwise Graft Failure Comparisons

HT demonstrated significantly increased failure rates relative to BPTB ACLR (Q = 5.01; $P = .025$) and QT ACLR (Q = 7.70; $P = .006$). BPTB had significantly increased graft failure rates relative to QT ACLR (Q = 4.01; $P = .045$), indicating QT demonstrated the overall lowest graft failure rates in the current data set of pediatric patients.

Graft Failure by Sex

Male patients were less likely than their female counterparts to experience graft failure after ACLR with HT (OR, 0.48; 95% CI, 0.25-0.95) (Figure 4). In contrast, there were no differences in risk of graft failure by sex after BPTB ACLR. There were insufficient data to evaluate sex differences in graft failure after QT ACLR.

Sensitivity Analyses

Other Potential Moderators. There were no differences between graft types with regard to mean FU (Q = 0.620; $P = .431$), mean time to graft failure (Q = 0.242; $P = .623$), mean age (Q = 0.571; $P = .450$), and sex by proportion of female patients (Q = 0.017; $P = .897$). There was a statistical influence between concomitant meniscal surgery and graft type (Q = 7.843; $P = .005$). The proportion of patients receiving concomitant meniscal surgery with QT reported less meniscal pathology than BPTB and HT ACLR.

DISCUSSION

This study yielded several important findings, most notably that HT autograft provides a significantly higher graft failure rate than BPTB autograft in pediatric patients. However, the data did not support our hypothesis that BPTB would demonstrate reduced failure relative to QT autografts after ACLR in patients ≤18 years old. Specifically, despite limited available data, QT autografts were associated with significantly lower graft failure rates than BPTB autografts. In addition, male patients were significantly less likely than female patients to experience graft failure after ACLR, specifically with HT grafts. Interestingly, there was an unequal proportion of patients ≤18 years old that underwent HT, BPTB, and QT ACLR. The highest proportion of patients underwent HT ACLR, followed by BPTB ACLR, and last, QT ACLR. However, an increased sample size of patients with QT ACLR in addition to more consistent reporting on skeletal maturity and surgical technique are needed to better determine the ideal graft for adolescent athletes.

The meta-analysis indicated that QT autografts comprised the lowest proportion of patients ≤18 years old who underwent ACLR. Despite growing interest in the QT autograft due to its increased size and biomechanical strength, a paucity of QT ACLR patient-reported outcome measures in the literature has prevented its widespread adoption. Although the QT data were limited, the meta-analysis found that QT autografts had significantly lower failure rates than both BPTB and HT autografts. This finding aligns with previous work, in which a meta-analysis of

TABLE 2
Study Demographics[a]

Study (Year)	Patients, N	Mean Age, y (Range)	Sex (% Female)	Mean Follow-up, mo (Range)	Follow-up Completion (%)	Level of Evidence	Study Design
Bone–patellar tendon–bone autograft							
Britt et al (2020)[5]	41	15.4 (NR-18)	100	37.4 (24-NR)	78.9	4	Retrospective case series
Ellis et al (2012)[17]	59	16 (14-18)	NR	50.4 (24-135.6)	84.3	3	Retrospective cohort study
McCarroll et al (1994)[33]	60	14.2 (13-17)	51.7	50.4 (24-84)	NR	4	Retrospective case series
Morgan et al (2016)[38]	48	16 (13-18)	NR	198 (180-246)	84.0	4	Retrospective case series
Nelson et al (2016)[41]	55	15.2 (11.5-16.9)	54.5	34.8 (24-NR)	NR	3	Retrospective cohort study
Rauck et al (2021)[49]	53	16.6 (14.2-18.7)	71.7	45.36 (31.2-59.3)	37.0	4	Retrospective case series
Schilaty et al (2017)[54]	69	NR (NR-18)	NR	163.2 (24-NR)	66.0	3	Retrospective case series
Shelbourne et al (2009)[57]	528	NR (14-18)	58.7	60 (60-NR)	78.0	2	Retrospective cohort study
Hamstring tendon autograft							
Britt et al (2020)[5]	30	15.4 (NR-18)	100	46.1 (24-NR)	78.9	4	Retrospective case series
Calvo et al (2015)[7]	27	13 (12-16)	40.7	127.2 (120-156)	100.0	4	Retrospective case series
Cohen et al (2009)[11]	26	13.3 (11-15)	57.7	45 (24-84)	NR	4	Retrospective case series
Cordasco et al (2019)[12]	66	14.3 (12-17)	NR	36.6 (24-84)	97.6	4	Retrospective case series
Cordasco et al (2019)[12] (physeal sparing cohort)	49	12 (8-16)	NR	41.4 (24-84)	97.6	4	Retrospective case series
Courvoisier et al (2011)[13]	37	14 (11-15)	54.1	36 (24-48)	100.0	4	Retrospective case series
Engelman et al (2014)[18]	35	15.6 (12.7-18.6)	34.3	50.9 (24-NR)	65.0	3	Retrospective case series
Larson et al (2016)[27]	22	14.4 (12.3-16)	59.1	48 (24-84)	NR	4	Retrospective case series
Mariscalco et al (2013)[29]	85	NR (13-18)	NR	24 (24-NR)	82.2	3	Retrospective cohort study
Matava and Siegel (1997)[32]	8	14.4 (11.8-15.6)	25	32 (27-44)	100.0	4	Retrospective case series
McIntosh et al (2006)[35]	16	13.6 (11.2-14.9)	31	41.1 (24-112)	NR	4	Retrospective case series
Morgan et al (2016)[38]	194	16 (13-18)	NR	198 (180-246)	84.0	4	Retrospective case series
Nelson et al (2016)[41]	388	14.8 (11.5-16.9)	31.7	34.8 (24-NR)	NR	3	Retrospective cohort study
Nikolaou et al (2011)[42]	94	13.7 (11.6-15.9)	40	38 (24-60)	NR	4	Retrospective case series
Pennock et al (2019)[46]	56	14.8 (NR-18)	31	34.8 (24-NR)	92.0	3	Retrospective cohort study
Redler et al (2012)[50]	18	14.2 (NR-18)	33.3	43.4 (24-86.6)	94.7	4	Retrospective case series
Runer et al (2020)[51]	51	NR (NR-15)	NR	24 (24-NR)	NR	3	Retrospective cohort study
Schilaty et al (2017)[54]	35	NR (NR-18)	NR	163.2 (24-NR)	66.0	3	Retrospective case series
Quadriceps tendon autograft							
Gagliardi et al (2020)[20]	81	15.9 (10-18)	48.1	37.2 (24-36)	84.0	4	Retrospective case series
Kohl et al (2014)[25]	13	12.8 (6.2-15.8)	15.4	52.9 (25.2-116.4)	NR	4	Retrospective case series
Pennock et al (2019)[46]	27	14.8 (NR-18)	32	28.8 (24-NR)	92.0	3	Retrospective cohort study
Runer et al (2020)[51]	6	NR (NR-15)	NR	24 (24-NR)	NR	3	Retrospective cohort study
Vaughn et al (2022)[63]	22	15 (12-17)	50	33.6 (24-60)	100.0	4	Retrospective case series

[a]NR, not reported.

21 studies reported a 2.1% graft failure rate for QT in patients of all ages.[39] In addition to lower failure rates, QT autografts offer clinical and biomechanical benefits over BPTB autografts, such as increased cross-sectional area, increased ultimate load to failure, and increased stiffness.[56] Moreover, histological analysis revealed that QT autografts have more collagen fibrils and fibroblasts per cross-sectional area than BPTB autografts.[22] QT autografts also confer a lower risk of donor-site morbidity and easier graft harvesting procedures, which can result in less tissue damage and pain.[10,59] However, previous research demonstrated equivalent patient-reported outcomes after ACLR with a QT autograft compared with BPTB and HT autografts.[10] Further, although the results of this meta-analysis support a benefit of QT autograft, it is important to note the smaller sample size representing QT in the included studies compared with those representing BPTB and HT autografts. Larger studies of QT ACLR

in high-risk patient populations are needed to resolve these findings.

ACLR in a pediatric population involves unique considerations including factors such as graft type, graft fixation, and skeletal maturity.[21,67] The current meta-analysis did not detect differences in graft type failure rates with respect to skeletal maturity. Specifically, there were no significant differences in failure rates between graft types for mean time to graft failure or patient age. However, conclusions should be tempered considering inconsistencies in how data were reported in the included studies. Limited available data on skeletal maturity prevented a comprehensive analysis of how this factor affects graft failure rates (chronologic age was similar between groups). While there was no statistical difference, soft tissue autografts (QT and HT) were used more commonly in younger patients. Future studies should report both skeletal maturity and graft failure rates to overcome the small sample

TABLE 3
Risk of Bias Assessments for Included Nonrandomized Studies Using the ROBINS-I[a]

Study (Year)	Confounding	Participant Selection	Classification of Interventions	Deviations for Intended Interventions	Missing Data	Outcome Measurements	Selection of Reported Results
Britt et al (2020)[5]	Serious	Moderate	Low	Low	Serious	Moderate	Low
Calvo et al (2015)[7]	Serious	Moderate	Low	Low	Moderate	Moderate	Moderate
Cohen et al (2009)[11]	Serious	Moderate	Low	Low	Moderate	Moderate	Moderate
Cordasco et al (2019)[12]	Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate
Courvoisier et al (2011)[13]	Serious	Moderate	Low	Moderate	Serious	Moderate	Serious
Ellis et al (2012)[17]	Serious	Moderate	Low	Low	Moderate	Moderate	Moderate
Engelman et al (2014)[18]	Moderate	Serious	Low	Low	Serious	Moderate	Moderate
Gagliardi et al (2020)[20]	Serious	Serious	Low	Low	Serious	Moderate	Serious
Kohl et al (2014)[25]	Serious	Moderate	Low	Low	Moderate	Moderate	Moderate
Larson et al (2016)[27]	Serious	Moderate	Low	Low	Moderate	Moderate	Serious
Mariscalco et al (2013)[29]	Serious	Moderate	Low	Moderate	Moderate	Serious	Serious
Matava and Siegel (1997)[32]	Serious	Serious	Low	Low	Moderate	Moderate	Moderate
McCarroll et al (1994)[33]	Serious	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
McIntosh et al (2006)[35]	Serious	Moderate	Low	Low	Moderate	Serious	Moderate
Morgan et al (2016)[38]	Serious	Serious	Low	Moderate	Serious	Moderate	Serious
Nelson et al (2016)[41]	Serious	Serious	Moderate	Moderate	Moderate	Serious	Moderate
Nikolaou et al (2011)[42]	Serious	Moderate	Low	Moderate	Serious	Moderate	Serious
Pennock et al (2019)[46]	Serious	Moderate	Low	Moderate	Moderate	Moderate	Moderate
Rauck et al (2021)[49]	Serious	Serious	Low	Moderate	Serious	Moderate	Moderate
Redler et al (2012)[50]	Serious	Moderate	Low	Low	Serious	Moderate	Serious
Runer et al (2020)[51]	Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate
Schilaty et al (2017)[54]	Serious	Moderate	Low	Moderate	Serious	Serious	Moderate
Shelbourne et al (2009)[57]	Serious	Moderate	Low	Low	Moderate	Moderate	Moderate
Vaughn et al (2022)[63]	Serious	Moderate	Low	Moderate	Moderate	Moderate	Serious

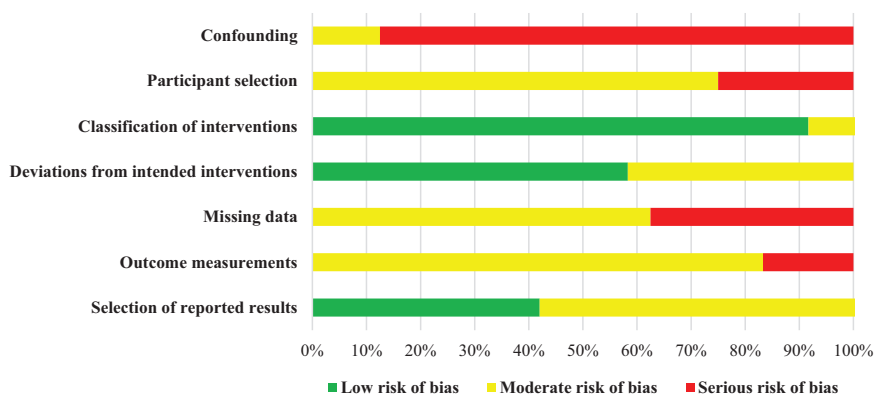[a]ROBINS-I, Risk of Bias in Non-Randomized Studies of Interventions.

Figure 2. Risk-of-bias assessments for included studies using the Risk of Bias in Non-Randomized Studies of Interventions tool, with green representing low risk for a given criteria, yellow representing moderate risk, and red representing serious risk.

size limitation encountered in this analysis of the effect of skeletal maturity on graft failure rates in pediatric patients.

Applying the ROBINS-I tool in the present meta-analysis revealed that 91.7% of the studies had an overall serious risk of bias. The domain most consistently rated as a serious risk was bias due to confounding factors. This assessment suggests that future studies should carefully consider and attempt to mitigate potential confounding factors, such as sex, age, sport, and level of activity, to reduce bias and improve reproducibility.

Limitations

The results of this meta-analysis should be interpreted in the context of its limitations. Overall, this study's primary outcome of interest was graft failure, although it is known whether there are other factors, such as return to sport, contralateral ACL injury, anterior knee pain, and donor-site morbidity, that should be considered when determining the ideal autograft for pediatric patients. The unequal proportion of patients undergoing HT, BPTB, and QT ACLR could have influenced failure rate calculations,
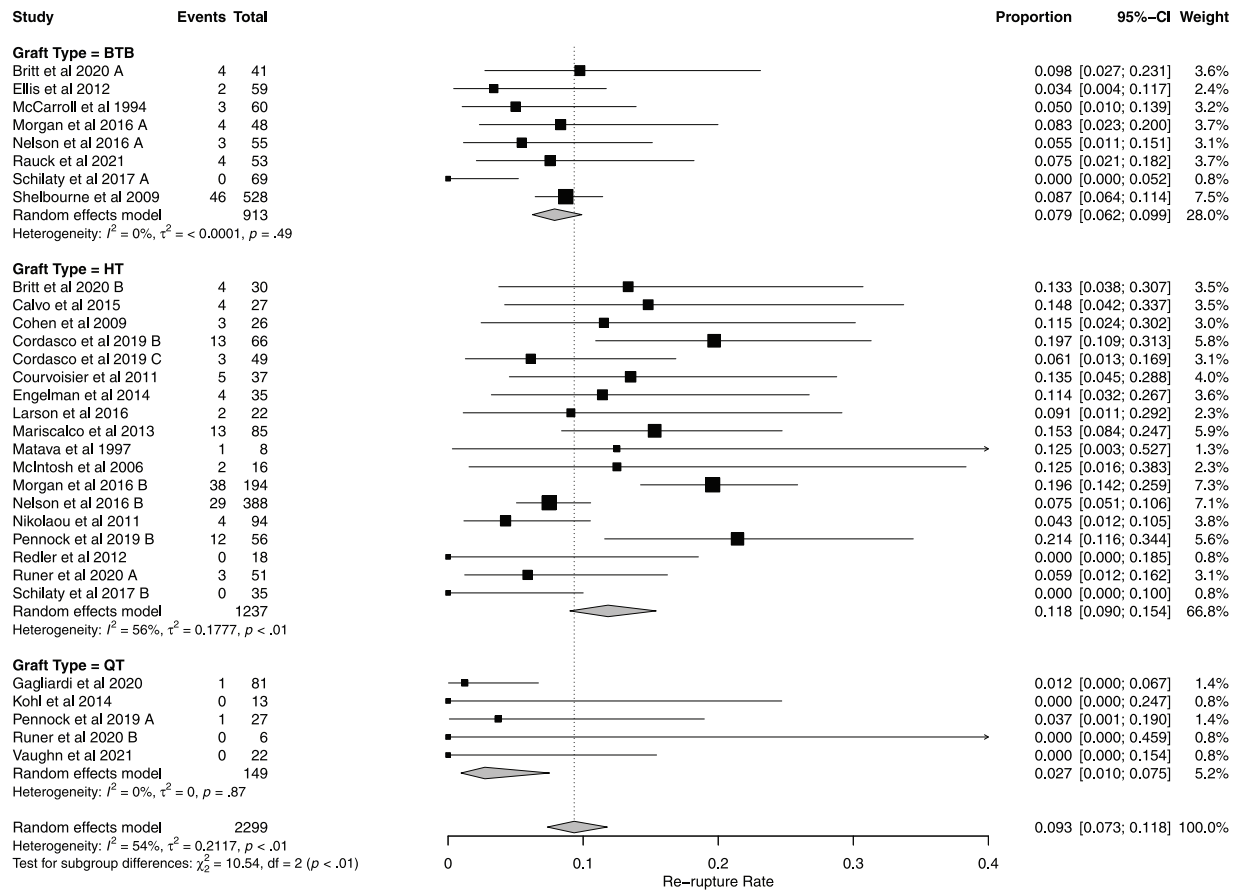
Figure 3. Pooled risk of graft failure by graft type for all included studies. BTB, bone–patellar tendon–bone; HT, hamstring tendon; QT, quadriceps tendon. A/B/C designations were added to author groups that included more than one autograft type in ther study in order to distinguish between graft type groups when performing statistical analysis.
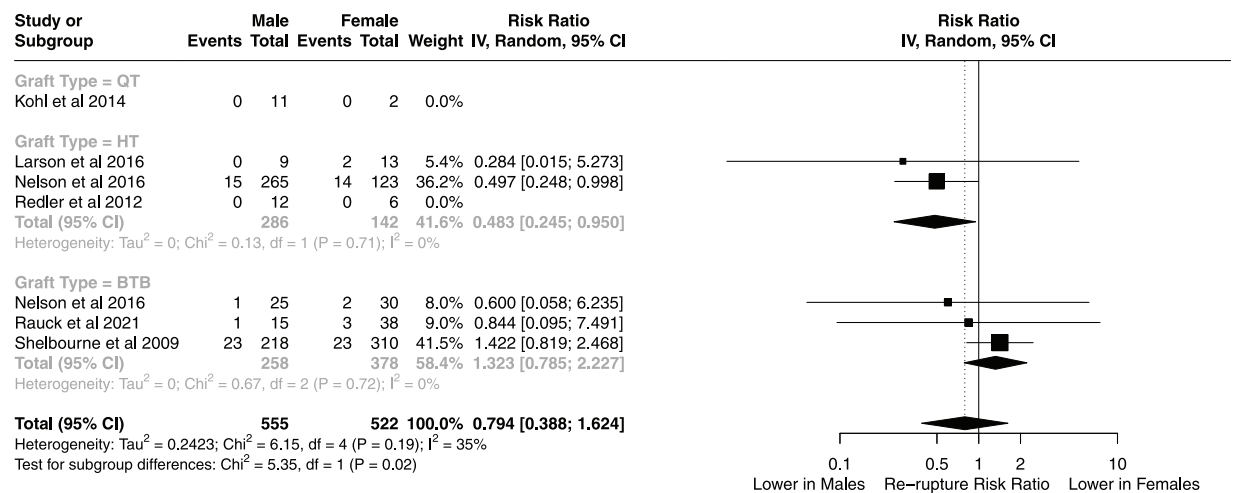

Figure 4. Risk of graft failure by sex for each graft type. BTB, bonepatellar tendonbone; HT, hamstring tendon; QT, quadriceps tendon.

with a greater proportion of HT autografts included leading to increased capture of graft failures and vice versa for QT autografts. Moreover, only 7 studies directly compared 2 different graft types, which makes definitive conclusions more difficult. Additionally, inconsistent reporting of skeletal maturity hindered the ability to accurately pool and assess the effect of skeletal maturity on graft failure. Future studies should more carefully assess and report skeletal maturity. With these data focused on a pediatric population, who are at most risk of graft failure, we acknowledge that there is likely some variance in physeal status of subsets of the data reported and that physeal sparing techniques may have been employed. These data were not commonly reported and thus not included in moderator analyses, and results should not be generalized to specific physeal status or physeal sparing techniques. However, given similar chronologic ages between groups, it is unlikely that significant differences exist with regard to physiologic ages for the entire population. Additionally, while this analysis investigated the effect of graft type and other associated risk factors on graft failure, return-to-sport and functional knee outcomes after ACLR before graft failure were not considered. Rehabilitation programs and return-to-sport guidelines that differ between studies could influence graft failure rates. Heterogeneity in the definitions of graft failure used by each study also complicated the graft failure comparisons. For our analysis, QTB and ASTQT were consolidated into a single QT autograft type, and the effects of bone plug on clinical and functional outcomes remain poorly understood.

Another important limitation of the current investigational results was the variance in FU reporting windows after ACLR. Longer FU time will likely result in a larger number of graft failures. While FU time was not statistically different, the BPTB group had generally longer FU times that may have influenced relative graft failure rates for the included studies.

Another consideration for graft failure rates is the presence or absence of concomitant procedures with ACLR. The percentage of patients that underwent concomitant meniscectomy and/or meniscal repair with ACLR demonstrated significant differences depending on graft type, most likely due to neglected meniscal pathology or lack of reported data. Only 4% of patients receiving QT had concomitant meniscal surgery, compared with 50% of patients receiving HT and 56% receiving BPTB. Further, concomitant meniscal surgery was related to significant differences in graft failure rate, but there were too few studies to better delineate this association. The low percentage of concomitant surgeries in the QT group likely reflects incomplete reporting, which suggests caution in interpreting the significant difference in failure rates. Further, the true prevalence of meniscal pathology is unknown since the extracted data included only the surgically treated meniscal pathology. Altogether, these data indicate that graft type and concomitant meniscal surgery may affect the risk of graft failure in pediatric patients undergoing ACLR. More research, and complete reporting on pathological/surgical data, is needed to evaluate the interaction between graft type and concomitant meniscal surgery on graft failure.

Finally, in the absence of high-quality evidence, excluding studies by level of evidence was not always appropriate or possible and should be considered. As such, this study is limited by quality of the available data and the scientific rigor underlying data collection. We therefore used the ROBINS-I tool to assess bias in these instances to evaluate these studies explicitly. The overall so-called "serious risk of bias" across 22 of 24 (92%) studies should not be dismissed. Finally, reporting heterogeneity limits the strength of conclusions that could be made.

CONCLUSION

While the HT remains a common choice for ACLR, the current aggregate data indicate that BPTB and QT demonstrated significantly lower failure rates than HT ACLR in adolescents ≤18 years old. The QT ACLR demonstrated the lowest failure rate in adolescents but also the lowest proportion of patients represented, indicating a need for future studies with larger sample sizes that include QT autografts, reduced risk of bias, and consistent reporting on skeletal maturity and surgical technique to better determine the ideal graft for highly active athletic populations ≤18 years of age.

ORCID iDs

Erich J. Petushek (iD) https://orcid.org/0000-0001-6837-5229
Gregory D. Myer (iD) https://orcid.org/0000-0002-9983-8422

REFERENCES

1. Aichroth PM, Patel DV, Zorrilla P. The natural history and treatment of rupture of the anterior cruciate ligament in children and adolescents: a prospective review. *J Bone Joint Surg Br*. 2002;84(1):38-41.
2. Barrett AM, Craft JA, Replogle WH, Hydrick JM, Barrett GR. Anterior cruciate ligament graft failure: a comparison of graft type based on age and Tegner activity level. *Am J Sports Med*. 2011;39(10):2194-2198.
3. Borchers JR, Pedroza A, Kaeding C. Activity level and graft type as risk factors for anterior cruciate ligament graft failure: a case-control study. *Am J Sports Med*. 2009;37(12):2362-2367.
4. Borenstein M, Hedges LV, Higgins JP, Rothstein HR. A basic introduction to fixed-effect and random-effects models for meta-analysis. *Res Synth Methods*. 2010;1(2):97-111.
5. Britt E, Ouillette R, Edmonds E, et al. The challenges of treating female soccer players with ACL injuries: hamstring versus bone–patellar tendon–bone autograft. *Orthop J Sports Med*. 2020;8(11):2325967120964884.
6. Brophy RH, Stepan JG, Silvers HJ, Mandelbaum BR. Defending puts the anterior cruciate ligament at risk during soccer: a gender-based analysis. *Sports Health*. 2015;7(3):244-249.
7. Calvo R, Figueroa D, Gili F, et al. Transphyseal anterior cruciate ligament reconstruction in patients with open physes: 10-year follow-up study. *Am J Sports Med*. 2015;43(2):289-294.
8. Cavanaugh JT, Powers M. ACL rehabilitation progression: where are we now? *Curr Rev Musculoskelet Med*. 2017;10(3):289-296.
9. Chen V, Hunter R, Woolf J. Anterior cruciate ligament injuries. *Ann Med Surg (London)*. 2020;60:509-514.
10. Clinger B, Xerogeanes J, Feller J, et al. Quadriceps tendon autograft for anterior cruciate ligament reconstruction: state of the art. *J ISAKOS*. 2022;7(6):162-172.

11. Cohen M, Ferretti M, Quarteiro M, et al. Transphyseal anterior cruciate ligament reconstruction in patients with open physes. *Arthroscopy*. 2009;25(8):831-838.

12. Cordasco FA, Black SR, Price M, et al. Return to sport and reoperation rates in patients under the age of 20 after primary anterior cruciate ligament reconstruction: risk profile comparing 3 patient groups predicated upon skeletal age. *Am J Sports Med*. 2019;47(3):628-639.

13. Courvoisier A, Grimaldi M, Plaweski S. Good surgical outcome of transphyseal ACL reconstruction in skeletally immature patients using four-strand hamstring graft. *Knee Surg Sports Traumatol Arthrosc*. 2011;19(4):588-591.

14. Crawford SN, Waterman BR, Lubowitz JH. Long-term failure of anterior cruciate ligament reconstruction. *Arthroscopy*. 2013;29(9):1566-1571.

15. DeFazio MW, Curry EJ, Gustin MJ, et al. Return to sport after ACL reconstruction with a BTB versus hamstring tendon autograft: a systematic review and meta-analysis. *Orthop J Sports Med*. 2020;8(12):2325967120964919.

16. Dodwell ER, Lamont LE, Green DW, Pan DJ, Marx RG, Lyman S. 20 years of pediatric anterior cruciate ligament reconstruction in New York State. *Am J Sports Med*. 2014;42(3):675-680.

17. Ellis HB, Matheny LM, Briggs KK, Pennock AT, Steadman JR. Outcomes and revision rate after bone-patellar tendon-bone allograft versus autograft anterior cruciate ligament reconstruction in patients aged 18 years or younger with closed physes. *Arthroscopy*. 2012;28(12):1819-1825.

18. Engelman GH, Carry PM, Hitt KG, Polousky JD, Vidal AF. Comparison of allograft versus autograft anterior cruciate ligament reconstruction graft survival in an active adolescent cohort. *Am J Sports Med*. 2014;42(10):2311-2318.

19. Field AE, Tepolt FA, Yang DS, Kocher MS. Injury risk associated with sports specialization and activity volume in youth. *Orthop J Sports Med*. 2019;7(9):2325967119870124.

20. Gagliardi AG, Carry PM, Parikh HB, Albright JC. Outcomes of quadriceps tendon with patellar bone block anterior cruciate ligament reconstruction in adolescent patients with a minimum 2-year follow-up. *Am J Sports Med*. 2020;48(1):93-98.

21. Graziano J, Chiaia T, de Mille P, Nawabi DH, Green DW, Cordasco FA. Return to sport for skeletally immature athletes after ACL reconstruction: preventing a second injury using a quality of movement assessment and quantitative measures to address modifiable risk factors. *Orthop J Sports Med*. 2017;5(4):2325967117700599.

22. Hadjicostas PT, Soucacos PN, Berger I, Koleganova N, Paessler HH. Comparative analysis of the morphologic structure of quadriceps and patellar tendon: a descriptive laboratory study. *Arthroscopy*. 2007;23(7):744-750.

23. Hettrich CM, Dunn WR, Reinke EK, Spindler KP. The rate of subsequent surgery and predictors after anterior cruciate ligament reconstruction: two- and 6-year follow-up results from a multicenter cohort. *Am J Sports Med*. 2013;41(7):1534-1540.

24. Ho B, Edmonds EW, Chambers HG, Bastrom TP, Pennock AT. Risk factors for early ACL reconstruction failure in pediatric and adolescent patients: a review of 561 cases. *J Pediatr Orthop*. 2018;38(7):388-392.

25. Kohl S, Stutz C, Decker S, et al. Mid-term results of transphyseal anterior cruciate ligament reconstruction in children and adolescents. *Knee*. 2014;21(1):80-85.

26. Kooy CEVW, Jakobsen RB, Fenstad AM, et al. Major increase in incidence of pediatric ACL reconstructions from 2005 to 2021: a study from the Norwegian Knee Ligament Register. *Am J Sports Med*. 2023;51(11):2891-2899.

27. Larson CM, Heikes CS, Ellingson CI, et al. Allograft and autograft transphyseal anterior cruciate ligament reconstruction in skeletally immature patients: outcomes and complications. *Arthroscopy*. 2016;32(5):860-867.

28. Lee YHD, Kuroda R, Chan KM. Anterior cruciate ligament reconstruction: a 2015 global perspective of the Magellan Society. *Asia Pac J Sports Med Arthrosc Rehabil Technol*. 2015;2(4):122-128.

29. Mariscalco MW, Flanigan DC, Mitchell J, et al. The influence of hamstring autograft size on patient-reported outcomes and risk of revision after anterior cruciate ligament reconstruction: a Multicenter Orthopaedic Outcomes Network (MOON) cohort study. *Arthroscopy*. 2013;29(12):1948-1953.

30. Marx RG, Hsu J, Fink C, Eriksson K, Vincent A, van der Merwe WM. Graft choices for paediatric anterior cruciate ligament reconstruction: state of the art. *J ISAKOS*. 2023;8(3):145-152.

31. Marx RG, Wilson SM, Swiontkowski MF. Updating the assignment of levels of evidence. *J Bone Joint Surg Am*. 2015;97(1):1-2.

32. Matava MJ, Siegel MG. Arthroscopic reconstruction of the ACL with semitendinosus-gracilis autograft in skeletally immature adolescent patients. *Am J Knee Surg*. 1997;10(2):60-69.

33. McCarroll JR, Shelbourne KD, Porter DA, Rettig AC, Murray S. Patellar tendon graft reconstruction for midsubstance anterior cruciate ligament rupture in junior high school athletes: an algorithm for management. *Am J Sports Med*. 1994;22(4):478-484.

34. McGuinness LA, Higgins JPT. Risk-of-bias VISualization (ROBVIS): an R package and Shiny web app for visualizing risk-of-bias assessments. *Res Synth Methods*. 2021;12(1):55-61.

35. McIntosh AL, Dahm DL, Stuart MJ. Anterior cruciate ligament reconstruction in the skeletally immature patient. *Arthroscopy*. 2006;22(12):1325-1330.

36. Micheli LJ, Rask B, Gerberg L. Anterior cruciate ligament reconstruction in patients who are prepubescent. *Clin Orthop Relat Res*. 1999;364:40-47.

37. MOON Knee Group; Spindler KP, Huston LJ, Chagin KM, et al. Ten-year outcomes and risk factors after anterior cruciate ligament reconstruction: a MOON longitudinal prospective cohort study. *Am J Sports Med*. 2018;46(4):815-825.

38. Morgan MD, Salmon LJ, Waller A, Roe JP, Pinczewski LA. Fifteen-year survival of endoscopic anterior cruciate ligament reconstruction in patients aged 18 years and younger. *Am J Sports Med*. 2016;44(2):384-392.

39. Mouarbes D, Menetrey J, Marot V, Courtot L, Berard E, Cavaignac E. Anterior cruciate ligament reconstruction: a systematic review and meta-analysis of outcomes for quadriceps tendon autograft versus bone–patellar tendon–bone and hamstring-tendon autografts. *Am J Sports Med*. 2019;47(14):3531-3540.

40. Musahl V, Karlsson J. Anterior cruciate ligament tear. *N Engl J Med*. 2019;380(24):2341-2348.

41. Nelson IR, Chen J, Love R, Davis BR, Maletis GB, Funahashi TT. A comparison of revision and rerupture rates of ACL reconstruction between autografts and allografts in the skeletally immature. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(3):773-779.

42. Nikolaou P, Kalliakmanis A, Bousgas D, Zourntos S. Intraarticular stabilization following anterior cruciate ligament injury in children and adolescents. *Knee Surg Sports Traumatol Arthrosc*. 2011;19(5):801-805.

43. Paschos NK, Howell SM. Anterior cruciate ligament reconstruction: principles of treatment. *EFORT Open Rev*. 2016;1(11):398-408.

44. Paterno MV, Rauh MJ, Schmitt LC, Ford KR, Hewett TE. Incidence of contralateral and ipsilateral anterior cruciate ligament (ACL) injury after primary ACL reconstruction and return to sport. *Clin J Sport Med*. 2012;22(2):116-121.

45. Paterno MV, Rauh MJ, Schmitt LC, Ford KR, Hewett TE. Incidence of second ACL injuries 2 years after primary ACL reconstruction and return to sport. *Am J Sports Med*. 2014;42(7):1567-1573.

46. Pennock AT, Johnson KP, Turk RD, et al. Transphyseal anterior cruciate ligament reconstruction in the skeletally immature: quadriceps tendon autograft versus hamstring tendon autograft. *Orthop J Sports Med*. 2019;7(9):2325967119872450.

47. Post EG, Bell DR, Trigsted SM, et al. Association of competition volume, club sports, and sport specialization with sex and lower extremity injury history in high school athletes. *Sports Health*. 2017;9(6):518-523.

48. Rahardja R, Love H, Clatworthy MG, Monk AP, Young SW. Higher rate of return to preinjury activity levels after anterior cruciate ligament reconstruction with a bone–patellar tendon–bone versus

hamstring tendon autograft in high-activity patients: results from the New Zealand ACL Registry. *Am J Sports Med*. 2021;49(13):3488-3494.

49. Rauck RC, Apostolakos JM, Nwachukwu BU, et al; HSS ACL Registry Group. Return to sport after bone–patellar tendon–bone autograft ACL reconstruction in high school–aged athletes. *Orthop J Sports Med*. 2021;9(6):23259671211011510.

50. Redler LH, Brafman RT, Trentacosta N, Ahmad CS. Anterior cruciate ligament reconstruction in skeletally immature patients with transphyseal tunnels. *Arthroscopy*. 2012;28(11):1710-1717.

51. Runer A, Csapo R, Hepperger C, et al. Anterior cruciate ligament reconstructions with quadriceps tendon autograft result in lower graft rupture rates but similar patient-reported outcomes as compared with hamstring tendon autograft: a comparison of 875 patients. *Am J Sports Med*. 2020;48(9):2195-2204.

52. Runer A, Keeling L, Wagala N, et al. Current trends in graft choice for primary anterior cruciate ligament reconstruction—part II: in-vivo kinematics, patient reported outcomes, re-rupture rates, strength recovery, return to sports and complications. *J Exp Orthop*. 2023;10(1):40.

53. Salem HS, Huston LJ, Zajichek A, et al; MOON Knee Group. Anterior cruciate ligament reconstruction with concomitant meniscal repair: is graft choice predictive of meniscal repair success? *Orthop J Sports Med*. 2021;9(9):23259671211033584.

54. Schilaty ND, Bates NA, Sanders TL, Krych AJ, Stuart MJ, Hewett TE. Incidence of second anterior cruciate ligament tears (1990-2000) and associated factors in a specific geographic locale. *Am J Sports Med*. 2017;45(7):1567-1573.

55. Schwarzer G, Chemaitelly H, Abu-Raddad LJ, Rücker G. Seriously misleading results using inverse of Freeman-Tukey double arcsine transformation in meta-analysis of single proportions. *Res Synth Methods*. 2019;10(3):476-483.

56. Shani RH, Umpierez E, Nasert M, Hiza EA, Xerogeanes J. Biomechanical comparison of quadriceps and patellar tendon grafts in anterior cruciate ligament reconstruction. *Arthroscopy*. 2016;32(1):71-75.

57. Shelbourne KD, Gray T, Haro M. Incidence of subsequent injury to either knee within 5 years after anterior cruciate ligament reconstruction with patellar tendon autograft. *Am J Sports Med*. 2009;37(2):246-251.

58. Sherman SL, Calcei J, Ray T, et al. ACL Study Group presents the global trends in ACL reconstruction: biennial survey of the ACL Study Group. *J ISAKOS*. 2021;6(6):322-328.

59. Slone HS, Romine SE, Premkumar A, Xerogeanes JW. Quadriceps tendon autograft for anterior cruciate ligament reconstruction: a comprehensive review of current literature and systematic review of clinical results. *Arthroscopy*. 2015;31(3):541-554.

60. 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.

61. Tan SH, Lau BP, Khin LW, Lingaraj K. The importance of patient sex in the outcomes of anterior cruciate ligament reconstructions: a systematic review and meta-analysis. *Am J Sports Med*. 2016;44(1):242-254.

62. *EndNote* [Computer Software]. Version 20. Philidelphia, PA: Clarivate; 2013.

63. Vaughn NH, Dunleavy ML, Jackson T, Hennrikus W. The outcomes of quadriceps tendon autograft for anterior cruciate ligament reconstruction in adolescent athletes: a retrospective case series. *Eur J Orthop Surg Traumatol*. 2022;32(4):739-744.

64. Viechtbauer W. Conducting meta-analyses in R with the metafor package. *J Stat Softw*. 2010;36(3). doi:10.18637/jss.v036.i03

65. Weber F, Knapp G, Ickstadt K, Kundt G, Glass Ä. Zero-cell corrections in random-effects meta-analyses. *Res Synth Methods*. 2020;11(6):913-919.

66. Wiggins AJ, Grandhi RK, Schneider DK, Stanfield D, Webster KE, Myer JD. Risk of secondary injury in younger athletes after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. *Am J Sports Med*. 2016;44(7):1861-1876.

67. Wilson BR, Kocher MS. What's new in skeletally immature ACL? *Oper Tech Sports Med*. 2021;29(4):150834.

APPENDIX

APPENDIX TABLE A1
PubMed Search Query*ᵃ*

PubMed (NLM):

Dates searched: January 1, 1946-March 3, 2022

Filters: English

Filters: Use of Boolean "NOT" to exclude case reports, comments, reviews, letters, and editorials

1. ("hamstring tendons/transplantation"[MeSH] OR ("hamstring tendons"[MeSH] AND ("transplantation"[MeSH:noexp] OR transplant*[TW])) OR "hamstring tendons transplant*"[TW] OR "Semitendinosus Tendon"[TW] OR "semitendinosus gracilis"[TW]) AND ("autografts"[MeSH Terms:noexp] OR "Transplantation, Autologous"[MeSH] OR "Autologous Transplant*"[TW] OR "autograft*"[TW] OR "autologous repair"[TW] OR autotransplant*[TW])

2. ("Patellar Ligament/transplantation"[MeSH] OR ("patellar ligament"[TW] AND ("transplantation"[MeSH:noexp] OR transplant*[TW] OR graft*[TW])) OR ("patella"[MeSH] AND "ligaments"[MeSH] AND ("transplantation"[MeSH:noexp] OR transplant*[TW]))) AND ("autografts"[MeSH:noexp] OR "Transplantation, Autologous"[MeSH] OR "Autologous Transplant*"[TW] OR autograft*[TW] OR "autologous repair"[TW] OR autotransplant*[TW])

3. ("Bone-Patellar Tendon-Bone Grafts"[MeSH] OR (("BPTB"[TW] OR "Bone patellar tendon bone"[TW] OR "bone patellar bone"[TW] OR "bone tendon bone"[TW] OR "Tendon Bone Graft*"[TW] OR ("patella"[MeSH] AND "tendons"[MeSH:noexp]) OR "patellar tendon"[TW]) AND ("transplantation"[MeSH:noexp] OR transplant*[TW] OR graft*[TW]))) AND ("autografts"[MeSH:noexp] OR "Transplantation, Autologous"[MeSH] OR "Autologous Transplant*"[TW] OR autograft*[TW] OR "autologous repair"[TW] OR autotransplant*[TW])

4. ((("Quadriceps Muscle"[MeSH Terms] AND "Tendons"[MeSH Terms:noexp]) OR "bone quadriceps tendon"[TW]) AND ("autografts"[MeSH Terms:noexp] OR "Transplantation, Autologous"[MeSH] OR "Autologous Transplant*"[TW] OR "autograft*"[Text Word] OR "autologous repair"[TW] OR autotransplant*[TW])) OR "soft tissue quadriceps tendon autograft"[TW] OR "Quadriceps tendon autograft"[TW] OR "quad tendon autograft"[TW] OR "quad autograft"[TW] OR "quadriceps autograft"[TW] OR "Quadriceps tendon autograft"[TW] OR "quadriceps autograft"[TW]

5. "Anterior Cruciate Ligament Injuries/surgery"[MeSH] OR "Anterior Cruciate Ligament/surgery"[MeSH] OR "Anterior Cruciate Ligament Reconstruction"[MeSH] OR "anterior cruciate ligament*"[TW] OR ACLR[TW] OR ACL[TW] OR "Knee Joint/surgery"[MeSH] OR "knee injuries/surgery"[MeSH] OR ("knee joint"[TW] OR "knee injur*"[TW] AND (surg*[TW] OR repair[TW] OR reconstruct*[TW]))

6. (#1 OR #2 OR #3 OR #4) AND #5

7. (#6 AND English[LA]) NOT ("review"[PT] OR "systematic review"[PT] OR "systematic review"[TI] OR "meta-analysis"[PT] OR "meta analysis"[TI] OR "case reports"[PT] OR case report*[TI] OR "literature review"[TI] OR "narrative review"[TI] OR "scoping review"[TI] OR letter[PT] OR letter[TI] OR editorial[PT] OR editorial[TI] OR comment[PT] OR comment*[TI] OR booksdocs[Filter] OR preprint[PT])

ᵃ[MeSH]-Medical Subject Heading (Controlled vocabulary) in PubMed; [MeSH:noexp]- indicates do not explode the MeSH: do not search the more specific terms under the broad category; [TIAB]-search title and abstract; [PT]-publication type; [TI]-search title of article; [TW]-Text Word: all words and numbers in the title, abstract, other abstract, MeSH terms, MeSH Subheadings, Publication Types, Substance Names, Personal Name as Subject, Corporate Author, Secondary Source, Comment/Correction Notes, and Other Terms.