Clinical Sports Medicine Update

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

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Background: Comprehensive studies evaluating quadriceps tendon (QT) autograft for anterior cruciate ligament (ACL) reconstruction are lacking. The optimal choice of graft between bone–patellar tendon–bone (BPTB), hamstring tendon (HT), and QT is still debatable.

Hypothesis: The current literature supports the use of QT as a strong autograft with good outcomes when used in ACL reconstruction.

Study Design: Meta-analysis; Level of evidence, 2.

Methods: A systematic search of the literature was performed in PubMed, MEDLINE, Cochrane, and Ovid databases to identify published articles on clinical studies relevant to ACL reconstruction with QT autograft and studies comparing QT autograft versus BPTB and HT autografts. The results of the eligible studies were analyzed in terms of instrumented laxity measurements, Lachman test, pivot-shift test, Lysholm score, objective and subjective International Knee Documentation committee (IKDC) scores, donor-site pain, and graft failure.

Results: Twenty-seven clinical studies including 2856 patients with ACL reconstruction met the inclusion criteria. Comparison of 581 QT versus 514 BPTB autografts showed no significant differences in terms of instrumented mean side-to-side difference (P = .45), Lachman test (P = .76), pivot-shift test grade 0 (P = .23), pivot-shift test grade 0 or 1 (P = .85), mean Lysholm score (P = .1), mean subjective IKDC score (P = .36), or graft failure (P = .50). However, outcomes in favor of QT were found in terms of less donor-site pain (risk ratio for QT vs BPTB groups, 0.25; 95% CI, 0.18-0.36; $P < .00001$). Comparison of 181 QT versus 176 HT autografts showed no significant differences in terms of instrumented mean side-to-side difference (P = .75), Lachman test (P = .41), pivot-shift test grade 0 (P = .53), Lysholm score less than 84 (P = .53), mean subjective IKDC score (P = .13), donor-site pain (P = .40), or graft failure (P = .46). However, outcomes in favor of QT were found in terms of mean Lysholm score (mean difference between QT and HT groups, 3.81; 95% CI, 0.45-7.17; P = .03).

Conclusion: QT autograft had comparable clinical and functional outcomes and graft survival rate compared with BPTB and HT autografts. However, QT autograft showed significantly less harvest site pain compared with BPTB autograft and better functional outcome scores compared with HT autograft.

Keywords: anterior cruciate ligament; quadriceps tendon; hamstring tendon; bone–patellar tendon–bone

Anterior cruciate ligament (ACL) injury is one of the most common knee injuries, with an estimated incidence of 1 in 3000 in the United States.[8] Several types of grafts have been used for ACL reconstruction to restore knee stability; however, the optimal graft source remains a topic of controversy.

Some orthopaedic surgeons still consider the bone–patellar tendon–bone (BPTP) graft to be the standard for ACL reconstruction,[52] despite the well-documented morbidities including postoperative anterior knee pain,[4] difficulty kneeling, and possible patellar fracture and patellar tendon rupture.[52] Proponents of hamstring tendon (HT) autograft have reported less donor-site morbidity compared with BPTB graft in terms of anterior knee pain[12] and the incidence of mid- and long-term osteoarthritis.[42] However, weakness in hip extension and terminal knee flexion,[9] graft laxity, higher infection rate,[14] increased

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objective laxity in female patients over time,[33] tendon truncation during harvest, and variable sizes and lengths of grafts remain problematic.[52]

The desire to avoid complications and reduce the incidence of postoperative morbidity with BPTB and HT autografts has prompted a search for alternative graft sources. Recently, the quadriceps tendon (QT) autograft has been discussed as a potential alternative graft for ACL reconstruction, even though it was first advocated by Marshall et al[39] in 1979 and Blauth[4] in 1984. Although the QT autograft is the least studied and least used autograft, its use is expected to increase.[35] In 2010, 2.5% of all anatomic ACL reconstructions were performed with QT autograft.[56] This number increased to 11% in 2014, according to data collected from 35 surgeons from more than 20 countries at an international summit on anatomic ACL reconstructions.[40] Biomechanical characteristics of this graft showed an obvious advantage, as it provided a thicker graft with more favorable tensile properties compared with BPTB and HT grafts.[19,20,50,54,55] Stäubli et al[54,55] reported that a 10 mm–wide QT had a significantly greater mean cross-sectional area than a BPTB graft of the same width (64.6 vs 36.8 mm^2, respectively). This large cross-sectional area is desirable to reduce the bungee and windshield wiper effects as well as tunnel-graft mismatch, which is believed to cause inflow of synovial fluid and cytokines with subsequent bone resorption and tunnel widening.[17,20] Furthermore, Shani et al[50] reported that the cross-sectional area of the QT was nearly twice that of the BPTB (91 vs 48 mm^2, respectively). Ultimate load to failure (2186 vs 1581 N) and stiffness (466 vs 278 N/mm) were significantly higher for the QT graft compared with BPTB, respectively. Harris et al[19] showed that the thickness of the QT was 1.8 times greater than that of the BPTB. In their work on the strength of the QT, Harris et al[19] found that the load to failure of the QT was 1.36 times higher than that of a BPTB graft of comparable width. They explained this high strength after harvesting 20 cadaveric specimens of QT and patellar tendon. The investigators found that the QT contains 20% more collagen, has a higher fibril-interstitial ratio, and demonstrates a higher fibroblast density.

Several clinical studies evaluating outcomes of QT encourage its use as an autograft for ACL reconstruction, showing good clinical results with minimal donor-site morbidity.[42,52] However, understanding the literature has its difficulties, especially in comparing outcomes between the grafts. A paucity of trials have directly compared clinical results of QT with those of BPTB and HT; hence, no study quantitatively summarizes the results. The aim of this study was to carry out a meta-analysis based on the available data regarding outcomes of QT autograft and on clinical studies comparing QT autograft versus BPTB and HT autografts in ACL reconstruction for stability outcomes, functional outcomes, donor-site pain, and graft survival. Our hypothesis was that the current literature supports the use of QT as a strong autograft with good outcomes when used in ACL reconstruction.

METHODS

Identification and Selection of Studies

A comprehensive search of the published literature in PubMed, MEDLINE, Cochrane, and Ovid databases was performed based on PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.[41] References from primary and review articles and major orthopaedic texts were cross-referenced to identify any additional articles that met the inclusion criteria and were not located in the original search. The following terms were used as keywords: "quadriceps tendon autograft" and "quadriceps graft," in combination with the terms "anterior cruciate ligament reconstruction" or "ACL reconstruction." All articles published up to May 1, 2018, were included, including articles published online.

Inclusion and Exclusion Criteria

This study included all original articles reporting on (1) clinical studies on ACL reconstruction using QT autograft, single- or double-bundle reconstruction, with or without bone block (bone plug–free quadriceps autograft); (2) studies directly comparing outcomes of QT versus BPTB; and (3) studies directly comparing outcomes of QT versus HT, using either semitendinosus-gracilis or semitendinosus alone, 3 or 4 strands. All procedures were primary ligament reconstructions performed for symptomatic acute or chronic ACL deficiency, with or without meniscal injury, except for the Häner et al[18] study, which compared QT and HT in revision ACL reconstructions.

We excluded irrelevant articles and studies that failed to meet inclusion criteria, such as reviews, articles not available in the French or English language, studies with less than 12 months of follow-up, and studies investigating outcomes after reconstruction of other ligaments.

Data Extraction and Analysis

Papers identified in searches were reviewed by 2 authors (D.M., E.C.). Data extraction was performed independently, and any conflict was resolved before final analysis. In

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clinical and comparative series, the outcome measures were collected. When the data were not provided, authors were contacted by email. Statistical analysis was feasible after summarizing homogeneous and comparable outcomes between the studies. Parameters analyzed in this meta-analysis were (1) knee stability, including mean side-to-side difference and percentage of side-to-side difference greater than 3 mm (using KT-1000/2000 or Rolimeter arthrometer), Lachman test grade 0 and grade 0 or 1, and pivot-shift test grade 0 and grade 0 or 1; (2) functional outcomes, including mean Lysholm score, percentage of Lysholm score greater than 84 (corresponding to good to excellent results), percentage of objective International Knee Documentation Committee (IKDC) grade A or B (corresponding to normal or nearly normal knee), and mean IKDC subjective score; (3) graft site pain; and (4) graft failure rate.

Statistical Analysis

Studies' results were tabulated with number of events and total number of patients in QT versus HT or BPTB groups (for KT-1000/2000 arthrometer findings >3 mm, Lachman = 0, Lachman = 0 or 1, pivot shift = 0, pivot shift = 0 or 1, Lysholm >84, IKDC = A or B, anterior knee pain, and graft failure). Studies' results were tabulated with mean and SD together with total number of patients in QT versus HT or BPTB groups for continuous endpoints (KT-1000/2000 arthrometer, Lysholm, and IKDC). Missing SDs were assessed according to the sample size and means from reported P values.[11] For the description of QT results, we calculated the frequency of event or the weighted mean (of continuous endpoint) together with 95% CI. We calculated the risk ratio of event for QT versus HT or BPTB according to the inverse variance approach with their 95% CIs. When number of events was equal to zero in each group, it was imputed to 1 to estimate the risk ratio. We estimated the mean differences between QT versus HT or BPTB for continuous endpoints according to the inverse variance approach with their 95% CIs. To assess heterogeneity across studies, we used forest plots as well as the Cochran heterogeneity statistic and Higgins I^2 coefficient.[21] A P value less than .1 or I^2 greater than 50% was considered suggestive of statistical heterogeneity, prompting random effects modeling. We produced funnel plots to assess small-study effects.[43] Funnel plots did not show evidence of small-study bias. For analyses, we used the Review Manager 5.2 analysis software (Cochrane Collaboration).

RESULTS

Literature Search, Study Selection, and Study Characteristics

The search of the literature through different databases identified 324 articles. A total of 267 articles were evaluated after duplicates from each database were excluded. After screening of titles and abstracts, 78 articles were included and full texts were assessed for eligibility. A total of 27 articles met our eligibility criteria: 15 articles reporting on outcomes of ACL reconstruction treated by QT autograft,[¶] 7 articles comparing outcomes of QT autograft versus those of BPTB autograft,[14,15,17,25,27,28,36] and 5 articles comparing outcomes of QT autograft versus those of HT autograft[6,18,31,46,53]; a total of 2856 patients were included in this meta-analysis. Descriptive study characteristics are shown in Appendix Table A1 (available in the online version of the article). A flowchart of the literature search is provided in Figure 1.

QT Outcomes Analysis

In total, 2166 QT autografts used in ACL reconstruction were analyzed, including 1404 QT autografts from articles reporting on QT outcomes, 581 QT autografts from articles comparing QT versus BPTB autografts, and 181 QT autografts from articles comparing QT versus HT autografts (Appendix Table A2, available online). Outcome measures are summarized in Table 1.

Stability Outcome. In 24 studies, 1645 patients treated with QT autograft were evaluated by use of KT-1000/2000 or Rolimeter arthrometer. Weighted mean side-to-side difference in anterior tibial translation was 1.72 mm (95% CI, 1.69-1.75 mm). In 20 studies, 1277 patients were examined for anterior tibial translation greater than 3 mm. Side-to-side difference greater than 3 mm was found in 23.7% of cases (95% CI, 21.4%-26.1%).

In 14 studies, 926 patients were evaluated for Lachman test grade 0. Negative Lachman test (grade 0) was found in 81.2% of cases (95% CI, 78.7%-83.7%). Moreover, 14 studies evaluated 1029 patients for Lachman test grade 0 or 1, which was found in 96.1% of cases (95% CI, 94.9%-97.3%).

In 15 studies, 918 patients were evaluated for pivot-shift test grade 0. Negative pivot-shift test (grade 0) was found in 84.8% of cases (95% CI, 82.4%-87.1%). Moreover, 15 studies evaluated 940 patients for pivot-shift test grade 0 or 1, which was found in 97.0% of cases (95% CI, 95.9%-98.1%).

Functional Outcome. In 19 studies, 1482 patients were evaluated for Lysholm score. Weighted mean Lysholm score was 90.7 (95% CI, 90.6-90.9). In 9 studies, 455 patients were evaluated for Lysholm score greater than 84 (good to excellent results), which was found in 87.9% (95% CI, 84.9%-90.9%).

In 17 studies, objective IKDC was evaluated in 1414 patients treated with QT autograft. Objective IKDC grade A or B was found in 87.1% (95% CI, 85.4%-88.9%). Weighted mean subjective IKDC was evaluated in 8 studies for 467 patients and was 83.1 (95% CI, 82.6-83.7).

Donor-Site Pain. Graft site pain was evaluated in 20 studies in 1448 patients and was found in 6.1% of cases (95% CI, 4.9%-7.3%).

[¶]References 2, 3, 7, 9, 13, 16, 26, 29, 30, 32-34, 38, 49, 51.

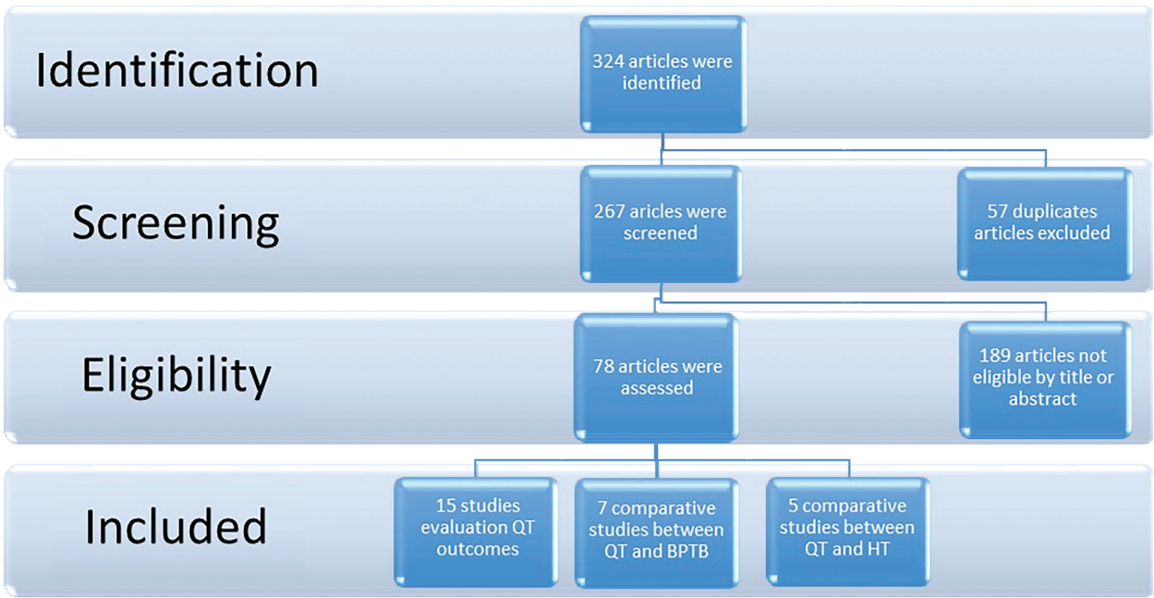

Figure 1. PRISMA (Preferred Reporting Items for Systematic Meta-Analyses) study selection flow diagram. BPTB, bone–patellar tendon–bone autograft; HT, hamstring autograft; QT, quadriceps tendon autograft.

TABLE 1
Outcome Measures Analyzed From Quadriceps Tendon Autografts[a]

	n	% (95% CI)
Side-to-side difference, weighted mean, mm	1645	1.72 (1.69-1.75)
Side-to-side difference >3 mm	1277	23.7 (21.4-26.1)
Lachman grade 0	926	81.2 (78.7-83.7)
Lachman grade 0 or 1	1029	96.1 (94.9-97.3)
Pivot-shift grade 0	918	84.8 (82.4-87.1)
Pivot-shift grade 0 or 1	940	97.0 (95.9-98.1)
Lysholm score, weighted mean	1482	90.7 (90.6-90.9)
Lysholm score >84	455	87.9 (84.9-90.9)
Objective IKDC A or B	1414	87.1 (85.4-88.9)
Subjective IKDC, weighted mean	467	83.1 (82.6-83.7)
Donor-site pain	1448	6.1 (4.9-7.3)
Graft failure	1554	2.1 (1.4-2.8)

[a]IKDC, International Knee Documentation Committee.

Graft Survival. An analysis of graft survival in 1554 patients treated with QT autograft from 21 studies showed a graft failure rate of 2.1% (95% CI, 1.4%-2.8%).

QT Versus BPTB Outcomes Analysis

In total, outcomes of 581 QT versus 514 BPTB autografts were statistically analyzed. Outcome measures are provided in Table 2.

Stability Outcome. Four studies evaluated mean side-to-side difference in anterior tibial translation between the operated and the contralateral knee using KT arthrometer in 248 patients treated with QT autograft versus 311 patients treated with BPTB autograft. No significant difference was demonstrated between the 2 groups (mean difference between QT and BPTB groups, –0.18; 95% CI, –0.65 to 0.29; P = .45) (Appendix Figure A1, available online). Six studies compared the percentage of patients with side-to-side difference greater than 3 mm in 518 patients treated with QT and 413 patients treated with BPTB. No significant difference was demonstrated between the 2 groups (risk ratio for QT vs BPTB group, 0.77; 95% CI, 0.49-1.18; P = .23) (Appendix Figure A1, available online).

Four studies compared the Lachman test grade between 390 patients treated with QT autograft and 316 patients treated with BPTB autograft. No significant difference was demonstrated in the rate of negative Lachman test (grade 0) (risk ratio for QT vs BPTB group, 1.02; 95% CI, 0.91-1.14; P = .76) (Appendix Figure A2, available online) or in the rate of Lachman test grade 0 or 1 (risk ratio for QT vs BPTB group, 1.00; 95% CI, 0.97-1.03; P = .79) (Appendix Figure A2, available online).

Five studies compared pivot-shift test grade 0 at last follow-up between 416 patients treated with QT autograft and 341 patients treated with BPTB autograft. No significant difference was found between the 2 groups (risk ratio for QT vs BPTB group, 1.04; 95% CI, 0.98-1.10; P = .23) (Appendix Figure A3, available online). Moreover, 4 studies compared pivot-shift test grade 0 or 1 at last follow-up between 390 patients treated with QT autograft and 316 patients treated with BPTB autograft. Similarly, no significant difference was found between the 2 groups (risk ratio for QT vs BPTB group, 1.00; 95% CI, 0.97-1.02; P = .85) (Appendix Figure A3, available online).

Functional Outcome. Five studies evaluated Lysholm score in 357 patients treated with QT autograft and 459 patients treated with BPTB autograft. No significant difference was found between the 2 groups, but the mean

TABLE 2
Outcome Measures Analyzed From Quadriceps Tendon (QT) Versus Bone–Patellar Tendon–Bone (BPTB) Autograft Studies[a]

	nQT:BPTB	Mean difference (95% CI)QT – BPTB	Risk ratio (95% CI)QT:BPTB	*P* value
Side-to-side difference, mean	248:311	–0.18 (–0.65 to 0.29)		0.45
Side-to-side difference >3 mm	518:413		0.77 (0.49 to 1.18)	.23
Lachman grade 0	390:316		1.02 (0.91 to 1.14)	.76
Lachman grade 0 or 1	390:316		1.00 (0.97 to 1.03)	.79
Pivot-shift grade 0	416:341		1.04 (0.98 to 1.1)	.23
Pivot-shift grade 0 or 1	390:316		1.00 (0.97 to 1.02)	.85
Lysholm score, mean	357:459	–0.81 (–1.77 to 0.15)		.10
Objective IKDC A or B	328:427		0.97 (0.92 to 1.02)	.20
Subjective IKDC, mean	168:252	2.08 (–2.38 to 6.55)		.36
Donor-site pain	439:287		**0.25 (0.18 to 0.36)**	**<.00001**
Graft failure	439:287		0.72 (0.28 to 1.84	.50

[a]IKDC, International Knee Documentation Committee. Bolded values indicate significant difference.

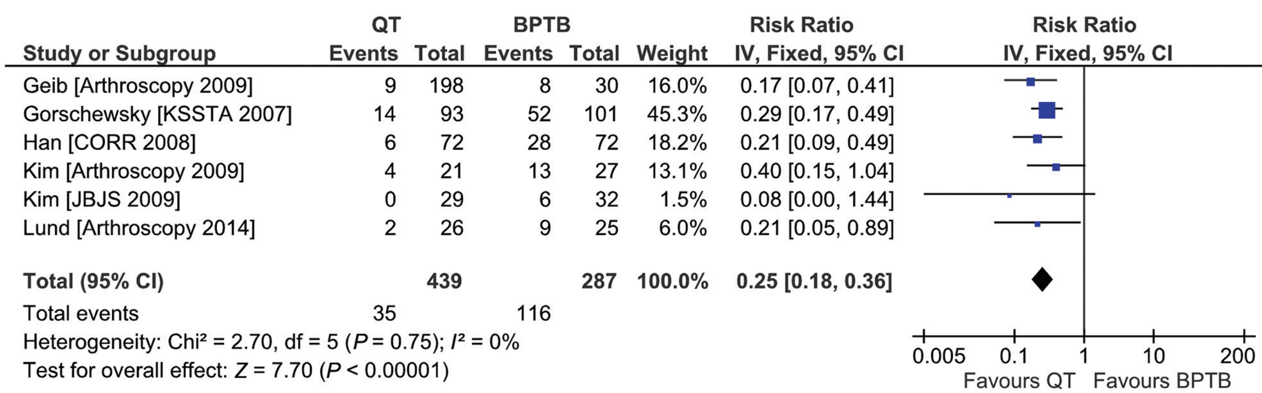

Figure 2. Forest plot showing risk ratio of the presence of donor-site pain for the quadriceps tendon (QT) versus bone–patellar tendon–bone (BPTB) autograft.

score tended to be in favor of BPTB autograft without reaching the threshold of significance (mean difference between QT and BPTB groups, –0.81; 95% CI, –1.77 to 0.15; P = .10) (Appendix Figure A4, available online).

Four studies compared objective IKDC score grade A or B between 328 patients treated with QT and 427 patients treated with BPTB. No significant difference was found between the 2 groups (risk ratio for QT vs BPTB group, 0.97; 95% CI, 0.92-1.02; P = .20) (Appendix Figure A4, available online).

Two studies compared mean subjective IKDC score between 168 patients treated with QT and 252 patients treated with BPTB. Similarly, no significant difference was found between the 2 groups' scores (mean difference between QT and BPTB groups, 2.08; 95% CI, –2.38 to 6.55; P = .36) (Appendix Figure A4, available online).

Donor-Site Pain. Six studies compared donor-site pain between 439 patients treated with QT autograft and 287 patients treated with BPTB autograft. A significant difference was found in favor of QT autograft (risk ratio for QT vs BPTB group, 0.25; 95% CI, 0.18-0.36; P < .00001) (Figure 2).

Graft Survival. Six studies compared the rate of graft rupture in 439 patients treated with QT autograft and 287 patients treated with BPTB autograft. No significant difference was found between the QT and BPTB groups (risk ratio for QT vs BPTB group, 0.72; 95% CI, 0.28-1.84; P = .50) (Appendix Figure A5, available online).

QT Versus HT Outcomes Analysis

In total, outcomes of 181 QT autografts and 176 HT autografts were statistically analyzed. Outcome measures are provided in Table 3.

Stability Outcome. Four studies compared mean side-to-side difference in anterior tibial translation between the operated and the contralateral knee using KT arthrometer in 140 patients treated with QT autograft versus 134 patients treated with HT autograft. No significant difference was found between the 2 groups (mean difference between QT and HT groups, –0.29; 95% CI, –2.12 to 1.53; P = .75) (Appendix Figure A6, available online). Two studies compared percentage of patients with side-to-side difference greater than 3 mm in 67 patients treated with

TABLE 3
Outcome Measures Analyzed From Quadriceps Tendon (QT) Versus Hamstring Tendon (HT) Autograft Studies[a]

	nQT:HT	Mean Difference (95% CI)QT – HT	Risk Ratio (96% CI)QT:HT	*P* value
Side-to-side difference, mean	140:134	–0.29 (–2.12 to 1.53)		.75
Side-to-side difference >3 mm	67:60		1.03 (0.04 to 24.97)	.99
Lachman grade 0	92:87		1.37 (0.65 to 2.89)	.41
Lachman grade 0 or 1	92:87		1.04 (0.94 to 1.16)	.42
Pivot-shift grade 0	92:87		1.16 (0.73 to 1.82)	.53
Pivot-shift grade 0 or 1	92:87		1.04 (0.94 to 1.15)	.44
Lysholm score, mean	157:153	**3.81 (0.45 to 7.17)**		**.03**
Lysholm score >84	107:100		1.08 (0.85 to 1.38)	.53
Subjective IKDC, mean	92:87	2.84 (–0.86 to 6.53)		.13
Donor-site pain	136:135		0.82 (0.51 to 1.31)	.40
Graft failure	110:107		0.55 (0.12 to 2.62)	.46

[a]IKDC, International Knee Documentation Committee. Bolded values indicate significant difference.

	QT			HT				Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**
Cavaignac [AJSM 2017]	89	6.9	44	83.1	5.3	39	35.0%	5.90 [3.27, 8.53]
Haner [Arthroscopy 2016]	82.5	18	25	73.8	19	26	8.8%	8.70 [-1.45, 18.85]
Lee JK [AJSM 2016]	92.1	8.7	48	88.4	11.9	48	26.4%	3.70 [-0.47, 7.87]
Runer [ESSKA 2018]	93.4	7.5	40	93.4	8.7	40	29.7%	0.00 [-3.56, 3.56]
Total (95% CI)			**157**			**153**	**100.0%**	**3.81 [0.45, 7.17]**

Heterogeneity: Tau² = 6.58; Chi² = 7.69, df = 3 (*P* = 0.05); *I*² = 61%
Test for overall effect: *Z* = 2.22 (*P* = 0.03)

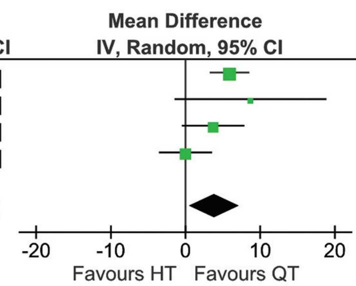

Figure 3. Forest plot showing mean difference in Lysholm scores between the quadriceps tendon (QT) and hamstring tendon (HT) autografts.

QT and 60 patients treated with HT. Similarly, no significant difference was found between the 2 groups (risk ratio for QT vs HT group, 1.03; 95% CI, 0.04-24.97; *P* = .99) (Appendix Figure A6, available online).

Two studies compared Lachman test grade 0 and grade 0 or 1 between 92 patients treated with QT autograft and 87 patients treated with HT autograft. No significant difference was found in the percentage of patients with negative or grade 0 Lachman test (risk ratio for QT vs HT group, 1.37; 95% CI, 0.65-2.89; *P* = .41) (Appendix Figure A7, available online) or in the percentage of patients with grade 0 or 1 (risk ratio for QT vs HT group, 1.04; 95% CI, 0.94-1.16; *P* = .42) (Appendix Figure A7, available online).

Two studies compared pivot-shift test grade 0 and grade 0 or 1 between 92 patients treated with QT autograft and 87 patients treated with HT autograft. No significant difference was found in the percentage of patients with negative or grade 0 pivot-shift test (risk ratio for QT vs HT group, 1.16; 95% CI, 0.73-1.82; *P* = .53) (Appendix Figure A8, available online) or in the percentage of patients with grade 0 or 1 (risk ratio for QT vs HT group, 1.04; 95% CI, 0.94-1.15; *P* = .44) (Appendix Figure A8, available online).

Functional Outcome. Four studies evaluated mean Lysholm score in 157 patients treated with QT autograft and 153 patients treated with HT autograft. Significant difference was found in the mean Lysholm score in favor of QT autograft (mean difference between QT and HT groups, 3.81; 95% CI, 0.45-7.17; *P* = .03) (Figure 3).

Three studies evaluated percentage of Lysholm score greater than 84 between 107 patients treated with QT autograft and 100 patients treated with HT autograft. No significant difference was found between QT and HT groups (risk ratio for QT vs HT group, 1.08; 95% CI, 0.85-1.38; *P* = .53) (Appendix Figure A9, available online).

Two studies compared mean subjective IKDC score between 92 patients treated with QT autograft and 87 patients treated with HT autograft. No significant difference was found between the 2 grafts, but the mean score tended to be in favor of QT autograft without reaching the threshold of significance (mean difference between QT and HT groups, 2.84; 95% CI, –0.86 to 6.53) (Appendix Figure A9, available online).

Donor-Site Pain. Four studies compared donor-site pain between 136 patients treated with QT autograft and 135 patients treated with HT autograft. No significant difference was demonstrated in terms of anterior knee pain between QT and HT groups (risk ratio for QT vs HT group, 0.82; 95% CI, 0.51-1.31; *P* = .40) (Appendix Figure A10, available online).

Graft Survival. Three studies compared the rate of graft rupture in 110 patients treated with QT autograft and 107 patients treated with HT autograft. No significant difference was found between QT and HT groups (risk ratio for QT vs HT group, 0.55; 95% CI, 0.12-2.62; P = .46) (Appendix Figure A11, available online).

DISCUSSION

The analysis of clinical studies documenting QT autograft showed satisfactory outcomes for ACL reconstruction, providing a stable and functional knee with low morbidity rate and graft failure rate. The analysis of comparative studies showed knee stability outcome and graft survival rate comparable with both BPTB and HT autografts, with QT autograft showing significantly less harvest site pain compared with BPTB autograft and better functional outcome scores (Lysholm) compared with HT autograft. This meta-analysis showed that QT seems to be a suitable graft and supports its use as an alternative graft choice for ACL reconstruction, confirming our hypothesis.

Overall, our meta-analysis in 2166 patients treated with QT autograft was in line with a meta-analysis of results following BPTP or HT autograft.[12] In terms of knee stability, in our study, postoperative mean side-to-side laxity was 1.72 mm with 23.7% side-to-side difference greater than 3 mm. Similarly, in the meta-analysis by Freedman et al,[12] 21% of 1153 BPTB grafts and 26.2% of 562 HT grafts were reported to have side-to-side laxity greater than 3 mm. In our study, Lachman test and pivot-shift test were negative (grade 0) in 81.2% and 84.8%, respectively, and were grade 0 or 1 in 96.1% and 97.0%, respectively. Functional outcomes were satisfactory in 87.9% of cases with good to excellent results (Lysholm score >84). Mean postoperative Lysholm score was 90.7, objective IKDC grade A or B was 87.1%, and mean subjective IKDC score was 83.1. Anterior knee pain was reported in only 6.1% of cases in our study, whereas Freedman et al[12] reported anterior knee pain in 17.4% of 972 patients treated with BPTB autograft and in 11.5% of 390 patients treated with HT autograft. Graft failure, which is a devastating complication for a patient, especially a young athlete hoping to return to athletic competition, was shown in only 2.1% of cases in our study.

We found 7 articles directly comparing QT and BPTB autografts in the literature. A significantly higher rate of anterior knee pain (P < .00001) was found in the BTPB group than the QT group. The reduction in anterior knee pain supports that QT autograft may be more appropriate for patients who sit for a long time or have occupations requiring them to kneel. In addition, the use of QT autograft resulted in patients' earlier return to activity and more satisfaction.[47] Comparable outcomes with no significant difference were found for stability outcomes (mean side-to-side difference, side-to-side difference >3 mm, Lachman test, or pivot-shift test), functional outcomes (mean Lysholm score, IKDC objective or subjective score), and rate of graft failure.

Regarding direct comparison of QT and HT autografts, 5 studies were found in the literature. No significant difference was found in terms of knee stability outcomes (mean side-to-side difference, side-to-side difference >3 mm, Lachman test, or pivot-shift test), anterior knee pain, or graft failure between 181 QT and 176 HT autografts. In contrast, a significantly higher mean Lysholm score was found in the QT group (P = .03). In addition, the subjective IKDC mean score tended to be in favor of QT autograft without reaching the threshold of significance.

QT harvest does not seem to be as detrimental to the extensor mechanism as it was previously believed. The quadriceps strength deficit in countermovement jumps and leg press exercises was reported to be statistically lower in patients operated with QT in comparison with that verified in a patellar tendon group after 6 months of follow-up.[44] Han et al[17] found that QT and BPTB autografts resulted in statistically similar levels with respect to quadriceps isokinetic strength at 1 year postoperatively as evaluated by peak torque ratio determined by Cybex isokinetic testing. When compared with HT autograft, QT autograft resulted in an equivalent level of muscle recovery and knee stability at 1 year after surgery.[23] No differences were found in recovered extensor muscle strength during isokinetic testing between QT and HT autografts evaluated with a Cybex II isokinetic testing device[31] or with a Con-Trex Multi Joint System[6]; however, flexor muscle strength recovery was better in the quadriceps group, indicating a potential advantage of the QT autograft.[6,31] In contrast, Fischer et al[10] found significantly greater extensor muscle strength in HT graft patients, whereas QT patients showed significantly greater values for flexor muscle strength at both time points of isokinetic testing during the first months postoperatively, with normal thigh strength restored over time. Lee et al[34] also found excellent stability with QT autograft and muscle recovery of 80% to 82% at 1 year and 89% at 2 years after surgery. Looking at laboratory studies evaluating the extensor mechanism, Adams et al[1] compared the extensor mechanism strength after harvesting of 10 mm–wide central free tendon grafts from the quadriceps and patellar tendons. Interestingly, the investigators found that harvesting of a central quadriceps free tendon graft leaves a stronger extensor mechanism (2430 ± 680 N) than harvesting of a patellar tendon graft (1920 ± 330 N), which may explain the clinical findings discussed previously.

Other variable outcomes were not amenable to statistical analysis in our review because of the heterogeneity of the data measurement or because they were reported in only a few series. Two studies[6,18] compared the Knee injury and Osteoarthritis Outcome Score (KOOS) in patients with QT and HT. The first study found no significant difference,[18] and the second found a significantly better KOOS with QT.[6] Only 1 study[36] evaluated KOOS in QT versus BPTB groups, finding a significant difference in favor of QT. In terms of kneeling pain, 2 studies[17,27] contributed to the subjective assessment of moderate to severe kneeling pain between QT and BPTB, and both found significantly less kneeling pain for QT patients compared with BPTB patients. Therefore, QT should be considered for patients whose work requires them to kneel or who belong to ethnic groups in which kneeling is common culturally.[22] Three studies[14,17,27] compared the postoperative range of motion in patients with QT and BPTB autografts. Of those studies, 2 studies[17,27] found no significant difference in extension loss, and 1 study[14] found a significantly lower loss of extension with QT. No study evaluated loss of range of motion in comparative studies between QT and HT. Finally, Han et al[17] and Kim et al[27] found no differences regarding patient satisfaction between the BPTB and QT-bone groups.

Other advantages of QT autograft include less analgesic consumption and pain in the immediate postoperative period compared with the use of HT autograft and the achievement of complete knee extension sooner compared with the use of BPTB autograft.[5,24] In an anatomic and morphological evaluation using magnetic resonance imaging reconstruction, QT was shown to have the anatomic characteristics to produce a graft whose length and volume are both reproducible and predictable while yielding a graft with a significantly greater intra-articular volume than a BPTB graft of similar width.[57] In another magnetic resonance imaging evaluation, the signal-noise quotient was calculated to compare the difference between QT and HT autografts at 6 months after ACL reconstruction, and better maturity was found in QT grafts.[37] Recently, Sasaki et al[48] published a human cadaveric study in which a robotic/universal force-moment sensor testing system was used to evaluate knee biomechanics after ACL reconstruction with QT versus quadrupled HT. Both autografts restored anterior tibial translation to within 2.5 mm of the intact knee and in situ forces to within 20 N of the intact ACL, with no statistically significant differences between the 2 grafts.

As far as we know, 3 articles[22,42,52] have systematically reviewed the clinical studies of ACL reconstruction using QT autograft. Yet, these reviews only summarized the outcomes of the studies and did not perform statistical analysis or directly compare results between QT and other grafts. One meta-analysis was published recently in 806 patients with ACL reconstruction, including trials that directly compared QT and BPTB within the same study.[45] However, 2 new comparative studies[14,25] including 289 new patients were added in our meta-analysis, making the comparison between QT and BPTB more reliable. Our study is the first meta-analysis, with the largest number of ACL reconstructions using QT autograft, that statistically assesses outcomes of QT clinical series. In addition, an analysis of studies that compared QT, BPTB, and HT added strength to our findings, making them more inclusive. QT may offer surgeons a new option in graft choice or may become a routine choice.

Several limitations of this study warrant mention. First, the nonrandomized design of the included studies may have led to unrecognized differences in patient populations and demographic data (eg, mean age at time of surgery, baseline activity, sex) and in associated comorbidities (with or without meniscal injury, associated osteoarthritis). We know that these differences can affect subsequent clinical and functional outcomes as well as complication rates. Moreover, the studies involved substantially different surgical techniques (single- and double-bundle reconstruction, QT with or without bone block, HT with semitendinosus-gracilis or semitendinosus alone, 3 strands and 4 strands), different fixation methods (interference screw, endo-button, cross-pin fixation, press-fit fixation), and lack of standardized rehabilitation protocols. This heterogeneity of techniques makes comparison of graft choice difficult and may have obscured the reporting of differences between the grafts. Second, factors or scores frequently used to assess the outcomes of ACL reconstruction, such as timing of return to sports, one-legged hop test, Tegner score, and radiographic osteoarthritic changes, were not analyzed. Indeed, heterogeneity in the reporting of these data made the analysis of these variables impossible. If those data had been available, their analysis would have rendered the study more complete, but we think that the objective testing and scores analyzed in this study were sufficient to discuss ACL reconstruction outcomes. Third, all articles included were published in English, which may lead to a potential publication bias (nevertheless, funnel plots did not show evidence of bias). Fourth, follow-up time varied between the studies and thus may have influenced our results. Fifth, heterogeneity across studies was statistically significant for many of the outcomes evaluated. This may have lowered the power of the meta-analysis for nonsignificant outcomes. Nevertheless, we took into account statistical heterogeneity, prompting random effects modeling.

CONCLUSION

Clinical and functional outcomes and graft survival rate for QT autograft were comparable with those of BPTB and HT autografts. However, QT autograft had significantly less harvest site pain compared with BPTB autograft and better functional outcome scores (Lysholm) compared with HT autograft. Given these findings, QT autograft is certainly a suitable alternative graft choice for patients undergoing ACL reconstruction.

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