Systematic Review

Quadriceps Tendon Autograft in Anterior Cruciate Ligament Reconstruction: A Systematic Review

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Purpose: To systematically review the current evidence to ascertain whether quadriceps tendon autograft (QT) is a viable option in anterior cruciate ligament reconstruction. **Methods:** A literature review was conducted in accordance with Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines. Cohort studies comparing QT with bone−patellar tendon−bone autograft (BPTB) or hamstring tendon autograft (HT) were included. Clinical outcomes were compared, with all statistical analyses performed using IBM SPSS Statistics for Windows, version 22.0, with $P < .05$ being considered statistically significant. **Results:** We identified 15 clinical trials with 1,910 patients. In all included studies, QT resulted in lower rates of anterior knee pain than BPTB. There was no difference in the rate of graft rupture between QT and BPTB or HT in any of the studies reporting this. One study found that QT resulted in greater knee stability than BPTB, and another study found increased stability compared with HT. One study found that QT resulted in improved functional outcomes compared with BPTB, and another found improved outcomes compared with HT, but one study found worse outcomes compared with BPTB. **Conclusions:** Current literature suggests QT is a viable option in anterior cruciate ligament reconstruction, with published literature showing comparable knee stability, functional outcomes, donor-site morbidity, and rerupture rates compared with BPTB and HT. **Level of Evidence:** Level III, systematic review of Level I, II, and III studies.

Anterior cruciate ligament (ACL) rupture is a common sporting injury, with an estimated 100,000 to 200,000 ACL ruptures every year in the United States alone.[1] The mechanism of injury classically involves noncontact deceleration or sudden changes in direction, but this injury may also occur as a result of physical contact in certain sports such as rugby union.[2] ACL reconstruction remains the standard of care to limit instability and prevent further cartilage and/or meniscal damage in the physically active population and athletes. The choice of graft used is multifactorial and largely dependent on surgeon preference, patient activity level, concomitant injuries, perceived functional outcome, age, sex, and donor-site morbidity.[3] Graft selection can be divided into 3 broad categories: autograft, allograft, and synthetic graft.[4] Bone−patellar tendon−bone autograft (BPTB) and hamstring tendon autograft (HT) are the most commonly used, but quadriceps tendon autograft (QT) has become increasingly popular.[5-7]

BPTB historically has been considered the gold-standard graft for many surgeons and is still the most popular graft choice in young high-level athletes despite developments in ACL reconstruction.[8] BPTB has the advantages of excellent strength, ease of harvesting, and consistency of graft size.[9] Concerns include harvest-site complications such as anterior knee pain and pain when kneeling, as well as patellar tendon rupture and increased long-term risk of osteoarthritis.[10-15] HT use was introduced in the 1980s, with the technique gaining popularity in recent years, especially across much of Europe and Australia.[16-18] Studies have shown that although harvest-site morbidity is still a concern, there is a lower rate of anterior knee pain and pain on kneeling associated with HT versus BPTB.[19] However, some studies have suggested there may be a higher rerupture rate and knee instability associated with HT.[20,21]

QT use in ACL reconstruction was first described by Marshall et al.[22] in 1979. Concerns were expressed

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The authors report that they have no conflicts of interest in the authorship and publication of this article. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

Received August 30, 2017; accepted January 15, 2018.

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0749-8063/171072/$36.00
https://doi.org/10.1016/j.arthro.2018.01.046

initially regarding postoperative quadriceps muscle weakness.[23] Although quadriceps tendon grafts have primarily been used in the revision setting, they have benefited from clinical interest because they have been shown to be an effective alternative graft that has the potential to reduce donor-site morbidity.[24,25] Morphometric and biomechanical evaluation has suggested that the quadriceps tendon is an anatomically viable alternative to the bone—patellar tendon—bone graft.[4]

Currently, there are only 2 systematic reviews of outcomes after QT,[26,27] but no systematic review of cohort studies comparing QT with other grafts in ACL reconstruction exists. Therefore, the purpose of this study was to systematically review the current evidence comparing QT with BPTB and HT to ascertain whether QT is a viable option in ACL reconstruction. Our hypothesis was that current literature would suggest QT is a viable option in ACL reconstruction, showing comparable knee stability, functional outcomes, donor-site morbidity, and rerupture rates compared with BPTB and HT.

Methods

Study Selection

Two independent reviewers (E.T.H., M.C-G.) performed a literature search based on Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines and reviewed the search results, with a third author (D.W.) arbitrating in the event of a disagreement.[28] The title and abstract were reviewed for all search results, and potentially eligible studies received a full-text review. In addition, the reference lists of all included studies and all literature reviews found in the search results were manually screened for additional articles that met the inclusion criteria.

Search Strategy

The following search terms were used in the MEDLINE, Embase, and The Cochrane Library databases on January 1, 2018, as the search algorithm: (quadriceps autograft OR quadriceps tendon autograft) AND (ACL OR anterior cruciate ligament OR ACL reconstruction OR anterior cruciate ligament reconstruction). No time limit was given for publication date.

Eligibility Criteria

The inclusion criteria were as follows: (1) clinical studies comparing QT in ACL reconstruction with either BPTB or HT, (2) publication in a peer-reviewed journal, (3) publication in English, and (4) full text of studies available. The exclusion criteria were (1) case series, (2) review studies, (3) cadaveric studies, (4) biomechanical studies, and (5) abstract only.

Data Extraction and Analysis

All relevant information regarding the study were collected by 2 independent reviewers (E.T.H., M.C-G.) using a predetermined data sheet. When required information was not available in the text, the study authors were contacted. The methodologic quality of the evidence was assessed using the Newcastle-Ottawa Scale,[29] a 9-point scale that identifies studies receiving 7 to 9 points, 5 to 6 points, 4 points, and 0 to 3 points as very good, good, satisfactory, and unsatisfactory, respectively. Outcomes analyzed were (1) donor-site morbidity, including anterior knee pain and numbness; (2) graft rupture; (3) knee stability, including the Lachman test, pivot-shift test, and anterior laxity (using a KT arthrometer; MEDmetric, San Diego, CA); (4) functional outcomes, including the International Knee Documentation Committee (IKDC) score and Lysholm score; and (5) range of motion, including extension loss, flexion loss, isokinetic extension strength, and isokinetic flexion strength.

Statistics

Statistical analysis was performed using IBM SPSS Statistics for Windows (version 22.0 [2013 release]; IBM, Armonk, NY). Qualitative analysis was performed for each study. $P < .05$ was considered statistically significant.

Results

Literature Search

The initial literature search resulted in 446 total studies. Once duplicates were removed and the articles were screened for inclusion and exclusion criteria, 274 studies were included and full texts were assessed for eligibility. We included 15 clinical trials with 1,910 patients in this review (Fig 1).

Study Characteristics

There were 15 studies included (level of evidence [LOE] I in 1, LOE II in 5, and LOE III in 9).[30-44] There were 7 studies (LOE II in 3 and LOE III in 4) comparing 593 patients with QT and 542 patients with BPTB, with a mean follow-up time of 36 months.[33-35,38-40,42] There were 10 studies (LOE I in 1, LOE II in 4, and LOE III in 5) comparing 446 patients with QT and 369 patients with HT, with a mean follow-up time of 24 months.[30-32,36-38,40,42-44] There was no significant difference between the cohorts in terms of age, sex, concomitant cartilage injuries, or other reported baseline characteristic in most of the included studies. However, Geib et al.[33] found that patients treated with BPTB were significantly younger, and Fischer et al.[32] reported a significantly higher proportion of male

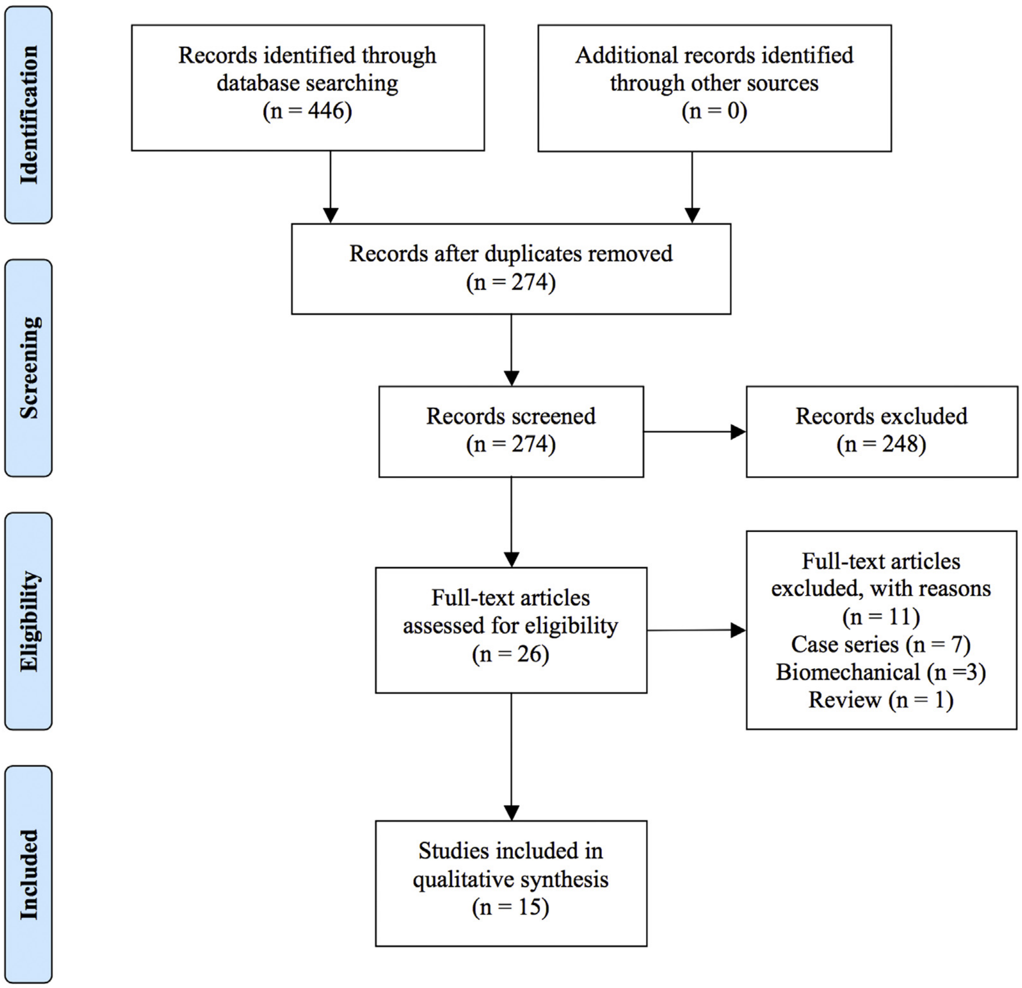

Fig 1. Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) study selection flow diagram.

patients in their HT group. Kim et al.,[40] Gorschewsky et al.,[34] and Joseph et al.[38] did not compare the baseline demographic characteristics of the groups. The study characteristics and patient demographic characteristics of QT versus BPTB and of QT versus HT are reported in Tables 1 and 2, respectively.

Clinical Outcomes of QT Versus BPTB

Donor-Site Morbidity. Five studies compared donor-site morbidity between patients treated with QT and BPTB[33-35,39,42] (Table 3). Five studies compared the rate of anterior knee pain in those with QT and

Table 1. Study Characteristics and Patient Demographic Characteristics of QT Versus BPTB

Authors	LOE	MQOE	n QT	n BPTB	Age, yr QT	Age, yr BPTB	M/F QT	M/F BPTB	Follow-up, mo
Geib et al.,[33] 2009	III	8	190	30	31.7 (NR)	25 (NR)	100/90	14/16	56.8 (minimum, 24)
Gorschewsky et al.,[34] 2007	III	6	124	136	NR		182/78		35 (minimum, 24)
Han et al.,[35] 2008	III	8	72	72	27.8 ± 9.0	27.8 ± 9.0	68/4	68/4	41 (24-124)
Joseph et al.,[38] 2006	II	6	18	25	NR				3 (NR)
Kim et al.,[39] 2009	III	8	21	27	27.1 ± 9.9	30.2 ± 8.3	18/3	18/8	26 (24-37)
Kim et al.,[40] 2013	II	6	142	227	NR		NR		Minimum, 24
Lund et al.,[42] 2014	II	8	26	25	30 ± 9	31 ± 8	21/5	21/4	Minimum, 24

NOTE. Data for age and follow-up are presented as mean, mean (range), or mean ± standard deviation unless otherwise indicated.
BPTB, bone–patellar tendon–bone; LOE, level of evidence; M/F, male-female ratio; MQOE, methodologic quality of evidence; NR, not reported; QT, quadriceps tendon.

Table 2. Study Characteristics and Patient Demographic Characteristics of QT Versus HT

			n		Age, yr		M/F		
Authors	LOE	MQOE	QT	HT	QT	HT	QT	HT	Follow-up
Buescu et al.,[30] 2017	I	5	24	24	29.2 ± 8.5	27.5 ± 5.6	NR		72 hrs
Cavaignac et al.,[31] 2017	III	8	45	41	32.1 ± 8	30.9 ± 9	25/20	24/17	43 mo (minimum, 36 mo)
Fischer et al.,[32] 2017	III	8	61	63	21.7 ± 7.4	21.5 ± 6.9	34/27	47/16	8 mo (NR)
Haner et al.,[36] 2016	II	8	25	26	35.9 ± 10.4	35.8 ± 13.1	17/8	18/8	Minimum, 24 mo (NR)
Hart et al.,[37] 2010	II	4	20	20	27 ± 7		26/14		Minimum, 12 mo (NR)
Joseph et al.,[38] 2006	II	6	18	21		NR			3 mo (NR)
Kim et al.,[40] 2013	II	6	142	65	NR		NR		Minimum, 24 mo (NR)
Lee et al.,[41] 2016	III	8	48	48	31.1 ± 10.0	29.9 ± 10.3	44/4	44/4	35 mo (24-61 mo)
Runer et al.,[43] 2017	III	9	40	40	34.6 ± 11.0	34.4 ± 11.0	23/17	23/17	Minimum, 24 mo (NR)
Sofu et al.,[44] 2013	III	7	23	21	26.8	28.6	21/2	21/0	38 mo (8-70 mo)

NOTE. Data for age and follow-up are presented as mean, mean (range), or mean ± standard deviation unless otherwise indicated.
hrs, hours; HT, hamstring tendon; LOE, level of evidence; M/F, male-female ratio; MQOE, methodologic quality of evidence; NR, not reported; QT, quadriceps tendon.

BPTB.[33-35,39,42] All 5 found a significantly lower rate of anterior knee pain with QT. However, Kim et al.[39] found that the Shelbourne and Trumper score for anterior knee pain was not significantly different between the 2 groups. The overall rate of anterior knee pain ranged from 4.8% to 19.0% with QT and from 26.7% to 48.2% with BPTB. Two studies compared the rate of numbness in patients with QT and BPTB.[33,42] Both found a significantly lower rate of numbness with QT. In addition, Lund et al.[42] found a greater area of sensitivity loss in patients with BPTB. The overall rate of numbness ranged from 1.5% to 4.8% with QT and from 38.9% to 53.3% with BPTB.

Graft Rupture. Four studies compared the rate of graft rupture in patients with QT and BPTB[33-35,42] (Table 4). None of those studies found a significant difference in the rate of graft rupture. The overall rate of graft rupture ranged from 0% to 2.8% with QT and from 1.4% to 5.6% with BPTB.

Knee Stability. Six studies compared knee stability between patients treated with QT and BPTB[33-35,39,40,42] (Table 5). Five studies compared the rate of a positive Lachman test in those with QT and BPTB.[33-35,39,40] None of those studies found a significant difference in the rate of a positive Lachman test. The overall rate of a positive Lachman test ranged from 4.9% to 5.1% with QT and from 3.5% to 3.7% with BPTB. Six studies compared the rate of a positive pivot-shift test in patients with QT and BPTB.[33-35,39,40,42] Of those studies, 5 found no significant difference in the rate of a positive pivot-shift test[33-35,39,40] and 1 found a significantly lower rate of a positive pivot-shift test with QT.[42] The overall rate of a positive pivot-shift test ranged from 4.2% to 14.3% with QT and from 3.1% to 38.9% with BPTB. Six studies compared anterior laxity using a KT arthrometer in patients with QT and BPTB.[33-35,39,40,42] Of those studies, 4 found no significant difference in the rate of anterior laxity of less than 3 mm[35,39,40,42] and 1 found a significantly lower rate of anterior laxity of less than 3 mm with QT.[33] None of the studies found a significant difference in the mean measurement of anterior laxity using a KT-1000 arthrometer.[33,34,39,42]

Functional Outcomes. Five studies compared functional outcomes between patients treated with QT and BPTB[34,35,39,40,42] (Table 6). Two studies compared the subjective IKDC score in those with QT and BPTB.[40,42]

Table 3. Donor-Site Morbidity

Authors	Anterior Knee Pain	Numbness
Quadriceps tendon autograft vs bone–patellar tendon–bone autograft		
Geib et al.,[33] 2009	4.6% vs 26.7%*	1.5% vs 53.3%*
Gorschewsky et al.,[34] 2007	15% vs 51%*	
Han et al.,[35] 2008	5.5% vs 35%*	
Kim et al.,[39] 2009	19% vs 46.4%*	
Lund et al.,[42] 2014	5% vs 34%*	48% vs 73%*
Quadriceps tendon autograft vs hamstring tendon autograft		
Haner et al.,[36] 2016	35% vs 55%	
Hart et al.,[37] 2010	0% vs 0%	
Runer et al.,[43] 2017	17.5% vs 15%	
Sofu et al.,[44] 2013	21.7% vs 14.3%	

*Statistically significant.

Table 4. Graft Rupture

Authors	Graft Rupture
Quadriceps tendon autograft vs bone–patellar tendon–bone autograft	
Geib et al.,[33] 2009	2% vs 3.3%
Gorschewsky et al.,[34] 2007	1.6% vs 2.2%
Han et al.,[35] 2008	2.8% vs 1.4%
Lund et al.,[42] 2014	0% vs 5.5%
Quadriceps tendon autograft vs hamstring tendon autograft	
Cavaignac et al.,[31] 2017	2.2% vs 4.9%
Haner et al.,[36] 2016	0% vs 0%
Hart et al.,[37] 2010	0% vs 0%
Runer et al.,[43] 2017	0% vs 2.5%

Table 5. Knee Stability

Authors	Negative Lachman Test	Negative Pivot-Shift Test	KT Arthrometer <3 mm	KT-1000, mm	KT-2000, mm
Quadriceps tendon autograft vs bone–patellar tendon–bone autograft					
Geib et al.,[33] 2009	94.9% vs 96.7%	94.9% vs 72.3%	88.6% vs 66.7%*		
Gorschewsky et al.,[34] 2007	SNR ($P = .32$)	SNR ($P = .13$)		SNR ($P = .326$)	
Han et al.,[35] 2008	>95% in both	>95% in both	66.7% vs 72.2%		
Kim et al.,[39] 2009	81.5% vs 81.0%	88.9% vs 89.7%	57.1% vs 66.7%		2.8 ± 1.3 vs 2.7 ± 1.5
Kim et al.,[40] 2013	78.9% vs 82.4%	82.4% vs 82.4%	78.9% vs 82.4%	2.3 vs 2.3	
Lund et al.,[42] 2014		86% vs 62%	77% vs 76%	0.8 ± 1.7 vs 1.1 ± 1.4	
Quadriceps tendon autograft vs hamstring tendon autograft					
Cavaignac et al.,[31] 2017	90% vs 46%*	90% vs 64%		1.1 ± 0.9 vs 3.1 ± 1.3*	
Haner et al.,[36] 2016		SNR ($P = .661$)		2.0 ± 1.2 vs 3.0 ± 2.9	
Hart et al.,[37] 2010				1.5 ± 0.4 vs 2.0 ± 0.6	
Kim et al.,[40] 2013	78.9% vs 75.4%	82.4% vs 81.5%	78.9% vs 75.4%	2.3 vs 2.7	
Lee et al.,[41] 2016			47.9% vs 90.4%		2.1 ± 1.9 vs 1.9 ± 2.1
Sofu et al.,[44] 2013					5.6 (3.5-8) vs 3.7 (3-5.5)*

NOTE. Data for KT-1000 and KT-2000 are presented as mean, mean (range), or mean ± standard deviation.
SNR, score not reported.
*Statistically significant.

Both found no significant difference in the subjective IKDC score. The overall IKDC score ranged from 84 to 87 with QT and from 70 to 88 with BPTB. Four studies compared the objective IKDC score in patients with QT and BPTB.[34,35,39,40] Of those studies, 3 found no significant difference in the objective IKDC score[34,35,39] and 1 found a significantly better objective IKDC score with BPTB.[34] One study evaluated the Lysholm score, with no significant difference between the grafts.[34] One study evaluated the Knee Injury and Osteoarthritis Outcome Score (KOOS), with a significant difference in favor of QT.[42]

Range of Motion. Three studies compared the postoperative range of motion in patients with QT and BPTB[33,35,39] (Table 7). Of those studies, 2 found no significant difference in extension loss[35,39] and 1 found a significantly lower loss of extension with QT.[33] No study found a difference in flexion loss.[33,35,39] One study found similar levels of postoperative isokinetic extension and flexion strength.[35]

Clinical Outcomes of QT Versus HT

Donor-Site Morbidity. Five studies compared donor-site morbidity between patients treated with QT and HT[36,37,41,43,44] (Table 3). Five studies compared the rate of anterior knee pain in those with QT and HT.[36,37,41,43,44] None of those studies found a significant difference in the rate of donor-site

Table 6. Functional Outcomes

Authors	Subjective IKDC Score	Objective IKDC Score (A or B)	Lysholm Score	KOOS
Quadriceps tendon autograft vs bone–patellar tendon–bone autograft				
Gorschewsky et al.,[34] 2007		83% vs 97%*	94 ± 9 vs 95 ± 7	
Han et al.,[35] 2008		92% vs 94%		
Kim et al.,[39] 2009		85.7% vs 85.2%	90.1 (75-100) vs 92.4 (66-100)	
Kim et al.,[40] 2013	87 vs 88	81.7% vs 83.7%	88.1 vs 89.1	
Lund et al.,[42] 2014	84 ± 13 vs 70 ± 16*			82 ± 16 vs 72 ± 21*
Quadriceps tendon autograft vs hamstring tendon autograft				
Cavaignac et al.,[31] 2017	84 ± 13 vs 80 ± 17		89 ± 6.9 vs 83.1 ± 5.3*	90 ± 11.2 vs 81 ± 10.3*
Fischer et al.,[32] 2017				
Haner et al.,[36] 2016		90% vs 80%	82.5 ± 18 vs 73.8 ± 19	
Hart et al.,[37] 2010	80 ± 10 overall ($P > .05$)		89 ± 12 vs 87.9 ± 11	
Kim et al.,[40] 2013	87 vs 87.3	81.7% vs 78.4%	88.1 vs 88.2	
Lee et al.,[41] 2016	80.2 ± 10 vs 77.9 ± 12.2		92.1 ± 8.7 vs 88.4 ± 11.9	
Runer et al.,[43] 2017			93.4 ± 7.5 vs 93.4 ± 8.7	
Sofu et al.,[44] 2013			SNR	

NOTE. Data for Lysholm score and KOOS are presented as mean, mean (range), or mean ± standard deviation.
IKDC, International Knee Documentation Committee; KOOS, Knee Injury and Osteoarthritis Outcome Score; SNR, score not reported.
*Statistically significant.

Table 7. Range of Motion

Authors	Loss of Extension	Loss of Flexion
Quadriceps tendon autograft vs bone−patellar tendon−bone autograft		
Geib et al.,[33] 2009	0.6° vs 2.5°*	0.3° vs 0.5°
Han et al.,[35] 2008	5.6% vs 2.8%	2.8% vs 2.8%
Kim et al.,[39] 2009	9.5% vs 7.4%	4.8% vs 11.1%

*Statistically significant.

morbidity. The overall rate of anterior knee pain ranged from 0% to 26.9% with QT and from 0% to 44% with HT. In addition, Buescu et al.[30] found that QT resulted in lower pain levels and analgesic consumption in the immediate postoperative period. None of the studies evaluated postoperative numbness.

Graft Rupture. Four studies compared the rate of graft rupture in patients with QT and HT[31,36,37,43] (Table 4). None of those studies found a significant difference in the rate of graft rupture. The overall rate of graft rupture ranged from 0% to 2.2% with QT and from 0% to 4.9% with HT.

Knee Stability. Six studies compared knee stability between patients treated with QT and HT[31,32,37,40,41,44] (Table 5). Four studies compared the rate of a positive Lachman test in those with QT and HT.[31,32,40,41] Of those studies, 3 found no significant difference in the rate of a positive Lachman test[32,40,41] and 1 found a significantly lower rate of a positive Lachman test with QT.[31] The overall rate of a positive Lachman test ranged from 0% to 4.6% with QT and from 2.1% to 10.3% with HT. Five studies compared the rate of a positive pivot-shift test in patients with QT and HT.[31,32,37,40,41] None of those studies found a significant difference in the rate of a positive pivot-shift test. The overall rate of a positive pivot-shift test ranged from 0% to 4.6% with QT and from 0% to 9.1% with HT. Six studies compared anterior laxity using a KT arthrometer in patients with QT and HT.[31,32,37,40,41,44] Of those studies, 2 found no significant difference in the rate of anterior laxity of less than 3 mm[40,44] and 1 found a significantly lower rate of anterior laxity of less than 3 mm with QT.[31] A significant difference in the mean measurement of anterior laxity using a KT-1000 or KT-2000 arthrometer was found in favor of QT in 1 study and in favor of HT in another study,[31,44] and 4 studies found no significant difference.[32,37,40,44]

Functional Outcomes. Seven studies compared functional outcomes between patients treated with QT and HT[31,36,37,40,41,43,44] (Table 6). Four studies compared the subjective IKDC score in those with QT and HT.[31,37,40,41] Of those studies, 3 found no significant difference in the subjective IKDC score[37,40,41] and 1 found a significantly better subjective IKDC score with QT.[31] The overall IKDC score ranged from 80 to 87 with QT and from 78 to 87 with HT. Two studies compared the objective IKDC score in patients with QT and HT.[36,40] None of those studies found a significant difference in the objective IKDC score. Seven studies compared the Lysholm score in patients with QT and HT.[31,36,37,40,41,43,44] Of those studies, 6 found no significant difference in the Lysholm score[36,37,40,41,43,44] and 1 found a significantly better Lysholm score with QT.[31] The overall Lysholm score ranged from 88 to 92 with QT and from 83 to 88 with HT. Two studies compared the KOOS in patients with QT and HT.[31,36] Of those studies, 1 found no significant difference in the KOOS[36] and 1 found a significantly better KOOS with QT.[31]

Range of Motion. Two studies compared the postoperative range of motion in patients with QT and HT[31,32] (Table 7). Of those studies, 1 found no significant difference in extension strength[31] and 1 found significantly higher extension strength with HT.[32] Moreover, 1 found no significant difference in flexion strength[31] and 1 found significantly higher extension strength with QT.[32] No study evaluated loss of range of motion.

Discussion

QT is of growing interest for ACL reconstruction. Given the increasing numbers of patients requiring ACL reconstruction, availability of proven graft options is of ongoing interest to our community. Our analysis indicates that QT is a viable option for this purpose, showing that in the reports provided, it had statistically similar outcomes to BPTB and HT, confirming our hypothesis.

QT was first introduced in 1979 by Marshall et al.[22] and has been less frequently used, but it recently has gained popularity as an option in ACL reconstruction.[27] Two surveys conducted in 2010 showed that fewer than 3% of surgeons used QT in ACL reconstruction[6,7]; however, a survey of surgeons across 20 countries conducted in 2014 by Middleton et al.[5] found that 11% of ACL reconstructions used QT. A recent systematic review by Slone et al.[27] found that QT is a safe, reproducible, and versatile graft that should be considered in ACL reconstruction. In another review, Mulford et al.[26] found that there was minimal donor-site morbidity with QT. The QT can be harvested with or without a bone block, and Geib et al.[33] found no significant benefit in harvesting with a bone block.

Erickson et al.[8] found that surgeons treating National Football League and National Collegiate Athletic Association football players were more likely to choose BPTB in younger competitive athletes than older recreational athletes. Although there were large numbers of patients included in our review, there is a need for further high-quality randomized studies on QT because most studies were retrospective. Although BPTB has been considered the gold standard in ACL reconstruction by many surgeons, in the studies included in our review, QT resulted in similar functional outcomes and stability but lower donor-site morbidity.[8] Donor-site morbidity is a concern for some surgeons with BPTB in ACL reconstruction, and QT results in reduced anterior knee pain and numbness. The reduced donor-site morbidity suggests QT should be considered alongside HT in cases in which patients work on their knees or are from certain ethnic groups for whom kneeling is more common culturally.[19] It is worth noting that the mean age of the patients in the studies was close to 30 years and that this patient population differs significantly from younger competitive athletes involved in cutting field sports, in whom higher failure rates may be seen.

Several studies also found that QT resulted in statistically similar levels of flexion and extension deficits compared with BPTB, with a small percentage of patients not regaining recurvatum, which can have a significant impact on patients' postoperative function.[32-34,37] However, although the functional outcomes were similar between both groups, the IKDC score, Lysholm score, and KOOS were limited by under-reporting in studies. Whereas postoperative strength is a concern with QT, Han et al.[35] also found that QT and BPTB resulted in statistically similar levels of isokinetic strength at a mean of 3.5 years postoperatively. When compared with BPTB, QT is longer and thicker, with a larger cross-sectional area, and both have similar mean ultimate tensile failure loads.[45] The size of the QT reduces tibial tunnel widening because its larger cross-sectional area reduces tunnel-graft mismatch.[46] The QT also results in statistically similar levels of postoperative stability, with similar outcomes in terms of the Lachman test, pivot-shift test, KT arthrometer laxity, and graft rerupture.

HT is often chosen over BPTB for its lower risk of anterior knee pain and pain when kneeling, and our findings show that QT has equivalent outcomes when compared with HT. A randomized controlled trial by Buescu et al.[30] found that QT and HT result in similar levels of immediate postoperative pain. QT also has the added advantage over the preservation of the hamstrings, given that decreased hamstring strength has been linked to ACL injuries and Farber et al.[47] found hamstring weakness to be the greatest concern among surgeons treating elite soccer players.[48,49] Knee stability was similar between QT and HT, with QT having greater KT-1000 arthrometer results. However, the evidence was mixed on the number of patients having KT arthrometer laxity greater than 3 cm, with 1 study heavily favoring QT and another heavily favoring HT.[30,44] Although both the pivot-shift test and Lachman test trended toward favoring QT, further research is needed to clarify whether there is any difference between QT and HT in terms of stability.

There was a low number of graft reruptures across the studies, with no study reporting any difference in rerupture rates.[4,33] This is an important factor in selecting an ACL graft, and because QT resulted in similar rates of rerupture to BPTB as well, a significant difference between QT and HT could help surgeons and their patients decide between the 2 grafts. Thus, further research is needed in this area. Functionally, both outcomes appear similar in terms of IKDC and Lysholm scores, and only 1 study found a significant difference in the Lysholm score favoring QT.[30] Three studies found that QT and HT resulted in similar levels of isokinetic strength, with some favoring QT for flexor strength and HT for extensor strength, although these findings were not statistically significant.[30,31,40]

Surgeon experience as well as training is an important aspect of selecting a graft, with HT being more commonly used by European surgeons and BPTB often being preferred among American surgeons.[8,16,17] Decisions should be made on a case-by-case basis, with surgeon experience being an important factor. Although recent surveys have shown that QT is being increasingly used, the predominance of BPTB and HT in fellowship training may lead to them remaining the grafts of choice.[5-8]

Although the evidence in the current literature does support the use of QT, this literature consists mostly of retrospective studies and includes heterogeneous patient groups, suggesting that further randomized controlled trials are needed to confirm our findings. Further studies should focus on the rerupture rates and knee stability indices because these are 2 of the most important aspects in graft selection for young high-level athletes. In addition, as the prevalence of this graft choice rises, the long-term outcomes become an important question.

Limitations

There are several limitations including potential bias inherent in our study. First, because this is a systematic review, the limitations inherent in the included studies are inherent in our study. Our search strategy was limited to English-language articles; as such, there is a potential selection bias, because it may prevent the inclusion of studies from journals published in other languages. Most of the studies were retrospective, which limits the strength of our conclusions. In addition, the statistical power in some of the reported outcome measures may be underpowered to detect a significant difference.

Conclusions

Current literature suggests QT is a viable option in ACL reconstruction, with published literature showing comparable knee stability, functional outcomes, donor-site morbidity, and rerupture rates compared with BPTB and HT.

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