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No difference between full thickness and partial thickness quadriceps tendon autografts in anterior cruciate ligament reconstruction: a systematic review

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Abstract

Purpose The purpose of this review was to compare outcomes and complication profiles of anterior cruciate ligament reconstruction (ACL-R) between full thickness (FT-Q) and partial thickness (PT-Q) quadriceps tendon (QT) autografts.

Methods As per PRISMA guidelines, PubMed, EMBASE, and MEDLINE were searched in September 2017 for English language, human studies of all levels of evidence on patients undergoing primary ACL-R with FT-Q or PT-Q. This search was repeated in March 2018 to capture additional articles. Data regarding postoperative outcomes and complications were abstracted. Due to heterogeneous reporting, data were not combined in meta-analysis and were summarized descriptively.

Results Upon screening 3670 titles, 18 studies satisfied inclusion/exclusion criteria. The second search identified an additional two studies for a total of 20 studies (50% case–control, 50% case series). These studies examined 1212 patients (1219 knees) of mean age 29.8 years (range 15–59) followed a mean of 42.2 months (range 12–120). FT-Q and PT-Q autografts were used in eight studies (50.5% of knees), and thirteen studies (49.5% of knees), respectively. Only one study directly compared FT-Q to PT-Q. Instrumented laxity was less than 3 mm in 74.8 and 72.4% of the FT-Q and PT-Q groups, respectively. Postoperative IKDC Subjective Knee Form scores were similar between the FT-Q (82.5) and PT-Q (82.1) groups. Postoperative quadriceps strength, measured as a percentage of the contralateral side, were similar in the FT-Q (89.5%) and PT-Q (85.1%) groups. Graft failure rates for the FT-Q and PT-Q groups were 3.7 and 3.0%, respectively.

Conclusion Across the 20 studies included in this review, there appeared to be no difference in outcomes or complications between either FT-Q or PT-Q in primary ACL-R. Moreover, primary ACL-R using QT autografts appears to have successful outcomes with a low rate of graft failure, irrespective of tendon thickness. While further comparative studies are needed to better delineate the optimal thickness of quadriceps tendon for primary ACL-R, these data suggest that, in primary ACL-R, either FT-Q or PT-Q is efficacious and, in the clinical setting, surgeons may be justified in using either graft thickness.

Level of evidence IV, Systematic Review of Level III and IV studies.

Keywords Anterior cruciate ligament · ACL · Reconstruction · Quadriceps tendon · Quadriceps · Autograft · Graft · Thickness · Size · Systematic review · Clinical outcomes · Partial · Full · Failure

Abbreviations

ACL	Anterior cruciate ligament
ACL-R	Anterior cruciate ligament reconstruction
BPTB	Bone-patellar tendon-bone
FT-Q	Full thickness quadriceps tendon autograft
PT-Q	Partial thickness quadriceps tendon autograft
HS	Hamstring
QT	Quadriceps tendon

Introduction

Previous studies have found favorable results with the use of quadriceps tendon autografts (QT) during anterior cruciate ligament reconstruction (ACL-R) [13, 36]. Commonly cited benefits of QT over other commonly used autografts,

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including bone-patellar tendon-bone (BPTB) and hamstring (HS) autografts, include decreased graft-site morbidity, improved versatility, and predictability of size on pre-operative imaging [13, 16, 18, 28, 32, 36]. Compared to BPTB and HS, there are fewer studies investigating the optimal technique for performing ACL-R with QT, as exemplified by the finding in a 2010 study that only 2.7% of all reported autografts for ACL-R were QT [41]. Greater understanding of the benefits and drawbacks of various aspects of ACL-R with QT, including graft thickness, graft fixation, or the inclusion of a bone block, would assist clinicians in optimizing ACL-R with QT.

Techniques for ACL-R with QT have been described using both partial and full thickness quadriceps tendon grafts. Previous anatomic analyses of the quadriceps tendon have found the average thickness of the distal tendon to be approximately 8 mm with an average thickness of 16–18 mm at the patellar insertion [36, 44]. Techniques vary and have been described for harvesting either full thickness [1, 20] or partial thickness grafts, [15, 18, 28, 40] which range anywhere from 6 to 8 mm. Theoretical advantages of a full thickness graft include increased graft tensile strength, lower rates of graft failure, and improved stability, whilst theoretical drawbacks include increased graft site morbidity as well as the risk of entering the knee joint capsule or suprapatellar bursa during harvest. While one recent systematic review reported successful outcomes with ACL-R using QT, the authors did not specifically examine whether graft thickness influenced outcomes [36]. Previous studies of ACL-R with HS have found that increased graft size does correlate with reduced rates of graft failure requiring revision surgery and that a graft diameter less than 8 mm is specifically correlated with an increase revision rate [10, 30, 31, 39]. Given that reported techniques for partial thickness QT autografts report average graft thickness of 6–8 mm, [15, 18, 28, 40], a systematic investigation of graft thickness and outcomes is warranted. While there have been multiple published reviews of quadriceps tendon autografts in the last several years, [3, 19, 32, 36], none of these studies specifically examined the influence of graft thickness on outcomes. Consequently, there does not appear to be any consensus to guide surgeons in choosing whether to harvest a partial or full thickness QT during ACL-R. As evidence continues to come out in favor of the use of QT [3, 19, 33, 35] and as the use of QT grows in popularity [36], it will become increasingly important to optimize the technique for performing ACL-R with QT, specifically with regard to the clinical question of whether to harvest a partial or full thickness autograft.

Thus, the purpose of this systematic review was to compare the outcomes and complication profiles after primary ACL-R with either full or partial thickness QT. It was hypothesized that, across all studies, full thickness grafts, when compared to partial thickness grafts, would be associated with improved clinical outcomes, including improved scores on patient-reported outcome (PRO) measures, decreased anterior laxity, and decreased incidence of graft failure, but increased rates of complications, including anterior kneeling pain.

Materials and methods

Search strategy

To search for clinical studies addressing the surgical procedures, outcomes and complications of primary ACL-R with QT, three databases (i.e., PubMed, Ovid (MEDLINE), and EMBASE) were searched as per PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines on September 1, 2017. The search was conducted using the terms "quadriceps tendon," "anterior cruciate ligament reconstruction," and "autograft." This search was repeated on March 31, 2018 to capture any additional or newly published articles. Appendix Fig. 1 in Supplementary material lists the detailed strategy used for the search. The PRISMA statement was used for the reporting of study selection.

Study screening

Two reviewers independently screened the titles, abstracts, and full-text articles in duplicate. The reviewers discussed all discrepancies to reach a consensus and a third senior reviewer was consulted as necessary when no consensus could be reached. The references of the included studies were subsequently searched by the reviewers to manually identify any articles that may have eluded the initial search (Fig. 1).

Assessment of study eligibility

The inclusion criteria were as follows: studies investigating primary anterior cruciate ligament reconstruction with quadriceps tendon autograft; English language studies; studies on humans of all ages; studies with reported clinical outcomes; and studies of all levels of evidence. Systematic reviews, conference abstracts, book chapters, and technical reports with no outcomes data were excluded.

Assessment of agreement

Inter-reviewer agreement for the title, abstract, and full-text articles was calculated with the kappa statistic (κ). The values were categorized a priori as follows: k of 0.81–0.99 was considered almost perfect agreement; k of 0.61–0.80, substantial agreement; k of 0.41–0.60,

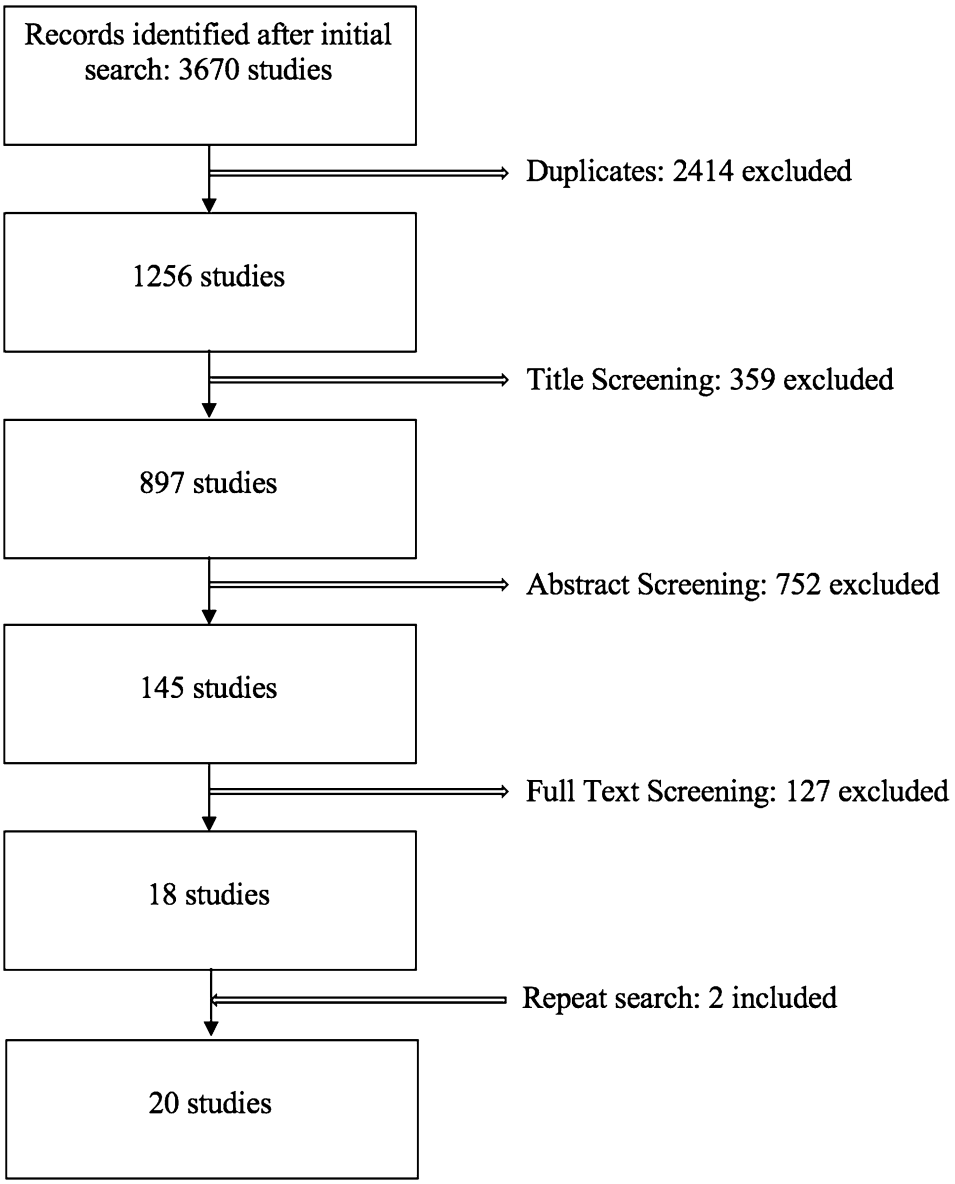

Fig. 1 Flow diagram of screening process—PRISMA flow diagram demonstrating the systematic review of the literature for the outcomes performed with either full thickness or partial thickness quadriceps tendon autografts

moderate agreement; *k* of 0.21–0.40, fair agreement; and *k* of 0.20 or less, slight agreement [29].

Quality assessment

The level of evidence of the included studies was assessed using the American Academy of Orthopaedic Surgeons classification system for the orthopaedic literature [43]. The MINORS (methodological index for non-randomized studies) checklist was used as well to assess the methodologic quality of the included studies.

Data extraction and analysis

Data were extracted from the included studies and recorded in a Microsoft Excel spreadsheet (version 2016; Microsoft, Redmond, WA). The recorded data included study characteristics as well as individual patient demographics, surgical techniques, and subjective/objective outcomes. If a paper stated in their methods section either that their graft thickness or diameter was 7 mm or greater or that the entire quadriceps tendon was harvested, it was classified as full thickness based on previous anatomic studies of the quadriceps tendon [38]. Alternatively, if the paper stated that their

graft thickness or diameter was less than 7 mm or that part of the quadriceps tendon, such as the vastus intermedius, was left behind, then it was classified as partial thickness. If a study did not specifically report its graft thickness but stated, it used the technique of a previously published paper, that paper was reviewed, and the study of interest was classified based on the technique used in previously published paper. Because of limited and heterogeneous reporting, these data were not combined in a meta-analysis and were summarized descriptively. Descriptive statistics, including means, frequencies, standard deviations, and ranges, were calculated as appropriate for recorded data. All statistics were calculated by use of Minitab statistical software (version 17; Minitab, State College, PA).

Results

Search strategy

The initial search yielded a total of 3670 studies. After 2414 duplicates were removed, 1256 unique studies remained for assessment. Systematic screening of the titles, abstracts, and full-text articles was performed, resulting in 18 studies that met the inclusion criteria for evaluation in this review. An additional two studies were identified in the repeat search for a total of 20 studies (Fig. 1). There was substantial agreement between reviewers at the title ($\kappa = 0.71$) and almost perfect agreement between reviewers at the abstract ($\kappa = 0.90$) and full-text ($\kappa = 0.97$) screening stages.

Study quality

Twenty studies (50% case-control, 50% case series) satisfied all inclusion and exclusion criteria and were included in the final analysis [1, 2, 7–9, 15, 17, 18, 20, 21, 23–29, 33, 34, 40]. Only one of the included studies directly compared FT-Q to PT-Q [25]. The mean follow-up time was 42.2 months. The MINORS score for all studies are listed in Table 1.

Study characteristics

A total of 1212 patients (1219 knees) across 20 studies underwent primary ACL-R with a QT autograft. The mean age of patients was 29.8 years (range, 15–59). The average follow-up time was 42.2 months (range, 12–120). Table 2 shows a comparison of the patient characteristics of the pooled FT-Q and PT-Q cohorts. A detailed summary of the study characteristics is shown in Table 1. Concomitant injuries (significant articular cartilage erosion of more than grade II per the Outerbridge classification, concomitant posterior cruciate ligament reconstruction, posterolateral instability, medial collateral ligament injury, meniscal lesion that led to total meniscectomy) were reported in 11 studies. In three studies, such injuries were considered exclusion criteria [24, 25, 28].

Surgical management

Table 3 shows a detailed overview of the techniques used for each, including graft preparation, how graft thickness was determined, fixation technique, and drilling technique, i.e., transtibial versus anteromedial portal. The suprapatellar approach for graft harvesting was similar in all studies assessed. FT-Q autografts were used in eight studies (50.5% of knees), and PT-Q autografts were used in thirteen studies (49.5% of knees). In the one study that directly compared FT-Q and PT-Q autografts, double-bundle technique was used with FT-Q and single-bundle technique was used with PT-Q. Four studies used an isolated all-soft tissue tendon graft, and 16 used a tendon graft with an adjacent bone block. There were a variety of graft fixation methods used across studies, with most studies using interference screw fixation for both the tibial and femoral sides.

Outcomes

A detailed summary of the outcomes and complication profiles across all studies is shown in Table 4, and a comparison of a few selected outcomes between the FT-Q and PT-Q groups across all reported data is shown in Table 5. Instrumented laxity was noted to be less than 3 mm in 74.8% of the FT-Q group (four studies, 505 knees) and 72.8% of the PT-Q group (eight studies, 324 knees). Range of motion was restored within 5° of full extension for 95.1% of the FT-Q group (three studies, 308 knees) and 95.2% of the PT-Q group (four studies, 155 knees). Postoperative quadriceps strength, measured as a percentage of the contralateral side, was similar between both groups with reported means of 87.4 and 86.1% for FT-Q (two studies, 295 knees) and PT-Q (five studies, 333 knees), respectively.

Postoperative Lysholm scores were similar between both groups with means of 90.4 for FT-Q (four studies, 355 knees) and 91.0 for PT-Q (10 studies, 506 knees). Postoperative International Knee Documentation Committee Subjective Knee Form (IKDC-SKF) scores were also similar between groups with means of 82.5 for FT-Q (two studies, 78 knees) and 82.1 for PT-Q (four studies, 174 knees). Mean postoperative anterior knee pain was similar for FT-Q patients at rates of 5.2% (two studies, 227 knees) compared to PT-Q patients at 4.0% (five studies, 225 knees).

Table 1 Study characteristics and methodology

Authors	Year	Study design (level of evidence)	MINORS score	Graft type	Number of patients	Number of knees	% Female	Age, years	Follow-up time, months
Akoto et al.	2012	Case series (IV)	10 of 16	FT-Q	87	87	14.9	31 (16–47)	12
Han et al.	2008	Therapeutic (III)	19 of 24	PT-Q	72	72	6.0	27.8 (15–51)	39.7 (24–90)
Geib et al.	2009	Case series (IV)	15 of 24	FT-Q	191	198	47.3	31.65	55.6
Theut et al.	2003	Case series (IV)	7 of 16	PT-Q	68	68	42.6	31 (15–46)	20 (12–29)
Lee et al.	2007	Therapeutic (III)	8 of 16	PT-Q	137	137	10.2	27 (16–51)	59 (37–73)
Kim et al.	2009	Therapeutic (III)	17 of 24	FT-Q	29	29	62.0	25.3 (20–39)	24
S. Lee et al.	2007	Case series (IV)	10 of 16	FT-Q	247	247	11.3	29 (16–58)	44 (25–87)
Akoto et al.	2015	Therapeutic (III)	19 of 24	FT-Q	12	12	NR	27.4 (18–44)	12.7 (6–18)
Kim et al. (2)	2009	Therapeutic (III)	17 of 24	PT-Q	21	21	14.2	27.1 (18–48)	25.8 (24–37)
Chen et al.	2006	Case series (IV)	12 of 16	PT-Q	34	34	35.2	26 (20–59)	62 (48–84)
Chen et al.	1999	Case series (IV)	12 of 16	PT-Q	12	12	33.3	26 (20–39)	18 (15–24)
Kim et al. (3)	2009	Therapeutic (III)	16 of 24	FT-Q and PT-Q	59	31 FT-Q, 28 PT-Q	22.0	25.8 (18–48)	24
Cavaignac et al.	2017	Therapeutic (III)	16 of 24	PT-Q	45	45	45.0	32.1	43.2
Lee et al.	2004	Case series (IV)	8 of 16	PT-Q	67	67	13.4	28 (18–51)	41 (27–49)
Lee et al.	2016	Therapeutic (III)	17 of 24	FT-Q	48	48	8.3	31.1 (17–57)	35.6 (24–61)
Guimaraes et al.	2009	Case series (IV)	11 of 16	PT-Q	17	17	11.8	28.53	120
Joseph et al.	2006	Therapeutic (III)	16 of 24	PT-Q	18	18	NR	NR	NR
Iriuchishima et al.	2017	Case series (IV)	8 of 16	FT-Q	20	20	90.0	49 + 8	12
Runer et al.	2018	Therapeutic (III)	20 of 24	PT-Q	40	40	42.5	34.6	24
Kwak et al.	2018	Therapeutic (III)	18 of 24	PT-Q	45	45	15.6	34.5	29.8

Data for age and follow-up time are presented as mean or mean (range) unless otherwise indicated

FT-Q full thickness quadriceps tendon autograft, *PT-Q* partial thickness quadriceps tendon autograft, *NR* not reported

Complications

Only one study using FT-Q examined post-operative graft site numbness with a reported incidence of 1.0% (one study, 198 patients) [15]. Two cases of post-operative patellar fractures were reported for a total incidence of 0.7%; both occurred in cases using PT-Q (2 studies, 154 knees). Both were the result of mechanical falls: one case ultimately required osteosynthesis [17] and the other was treated non-operatively [18, 28]. Both cases utilized a QT autograft with an adjacent bone block.

Standards for graft failure were different across studies, with some studies defining graft failure as an increase of 5 mm in the side-to-side difference in anterior laxity on instrumented testing [25] versus other studies which defined it as either arthroscopically confirmed graft rupture, positive

Table 2 Demographics

	FT-Q	PT-Q	Total
# of knees (*n*)	615	604	1219
Age (year)	31.2	28.3	29.8
% Female (%)	29.0	21.4	25.3
Follow-up time (months)	45.4	39.0	42.2

All values reported as a weighted mean based on the available pooled data

FT-Q full thickness quadriceps tendon autograft, *PT-Q* partial thickness quadriceps tendon autograft

pivot shift postoperatively, or an increased side-to-side difference in anterior laxity of greater than 5 mm on instrumented testing [15]. Using a broad definition of graft failure including graft rupture as well as symptomatic instability or increased anterior laxity, the overall rate of graft failure was 3.7% in FT-Q (three studies, 476 knees) and 3.0% in PT-Q (four studies, 230 knees), and 3.5% across all studies (seven studies, 706 knees).

Discussion

The most important finding of the present study was that there appears to be no difference in clinical outcomes or complication rates between either FT-Q or PT-Q autografts in primary ACL-R, thus disproving the hypothesis under study. There were no major differences in postoperative Lysholm or IKDC-SKF scores, range of motion, quadriceps strength, instrumented laxity, anterior knee pain, or incidence of graft failure between both graft types, although only one study directly compared FT-Q versus PT-Q. Moreover, based on the studies presented here, ACL-R with either FT-Q or PT-Q appears to have successful short-term outcomes. While statistical significance could not be assessed, it is worth noting that many of the differences, such as the differences in the Lysholm score and IKDC-SKF which were both less than 1 point, are well below the minimum detectable change (MDC) (IKDC-SKF, 8.8–16.4; Lysholm, 10.1) [4, 22] and, thus, highly unlikely to be of statistical or clinical significance. This finding is important for clinical practice as it suggests that either FT-Q or PT-Q are viable graft choices during ACL-R. Moreover, if FT-Q and PT-Q are equally efficacious in ACL-R, surgeons may choose to utilize the PT-Q given the inherent, albeit low, risks of FT-Q harvesting, such as violation of the joint capsule. Such complications were not reported in any studies and may be under-estimated or under-reported. While heterogenous reporting precluded combining data in a meta-analysis, this review nonetheless includes data from over 1200 patients. Moreover, demographics between the FT-Q and PT-Q cohorts were similar with respect to age, sex, and follow-up time, thus allowing for a valid comparison between the two cohorts.

Previous studies have yielded mixed findings regarding the relationship between graft size and outcomes. Multiple previous studies have found no statistically significant differences in re-rupture rate, clinical outcomes or biomechanical characteristics between 4- and 5-strand hamstring grafts for ACL-R [5, 6]. Another recent study analyzing the association between graft rupture rate and dichotomized graft size in HS and BPTB autografts reported that increasing autograft diameter did not lead to a reduction in revision ACL-R surgery [42]. However, another recent study found that an increase in the graft diameter between 7.0 and 10.0 mm resulted in a 0.86 times lower likelihood of revision surgery with every 0.5-mm increase [37]. Previous studies of ACL-R with HS autografts have found that increased graft size does correlate with reduced rates of graft failure requiring revision surgery, and that graft diameter less than 8 mm is specifically correlated with an increase revision rate [10, 30, 31, 39]. This disparity between studies may be explained by the notion that that the collagen content of a graft, rather than its diameter, may be the more important parameter [12]. As well, graft orientation, tension for fixation, and extremity position for fixation are but few of the multiple technical factors apart from graft thickness that can affect surgical outcomes. Given that certain graft preparation techniques have been shown to reduce graft diameter [12] without necessarily changing their collagen content, many of the above-mentioned studies may be confounded by differences in graft preparation techniques. Ultimately, larger, multi-center comparative studies or randomized controlled trials will be valuable in further investigating the role of graft thickness in ACL-R with QT autografts.

The graft failure across all patients in this study was 3.5%. However, the reporting of complications was limited across studies, exemplified by the fact that only 9 of 20 studies reported on the incidence of graft failure. Across available clinical data though, the overall failure rate is low in comparison to other common autograft sources. While mechanisms of graft failure were not uniformly reported, at least seven out of the 25 cases of graft failure (28%) were attributable to traumatic mechanisms. This rate compares favorably to a previous systematic review of 14 studies and 1532 patients with a minimum 10-year follow-up which found an ACL graft failure rate, including both graft rupture or increased anterior laxity, of 10.3% [11]. Given that the mean follow-up time in the present study was only 3.5 years, however, future long-term studies will be needed to better characterize the incidence of graft failure with QT autograft, in order to delineate any meaningful clinical differences FT-Q and PT-Q.

Table 3 Surgical techniques of studies

Authors	Year	Graft type/thickness	Femoral tunnel drilling	Fixation technique
Akoto et al.	2012	QT + BB: Entire thickness of quadriceps tendon was harvested	AMP	Femoral: BB press fit tibial: bone plug + sutures over bone bridge
Han et al.	2008	QT + BB: 6–8-mm-thick, part of the vastus intermedius was left behind	TT	Femoral: BB + MIS tibial: BIS + sutures with bicortical screw
Geib et al.	2009	SQT: 7–8 mm thick	TT	Femoral: BIS tibial: BIS + sutures through periosteum
Theut et al.	2003	SQT: 6–7 mm thick	TT	Femoral: suspensory button ($n = 19$), interference screw ($n = 5$), and suspensory button/interference screw ($n = 1$). Tibial: sutures tied over a post ($n = 12$) or suspensory button ($n = 7$), interference screw ($n = 2$), and interference screw/suspensory button ($n = 4$)
Lee et al.	2007	QT + BB: 6–8 mm thick, refers to prior paper which states that part of the vastus intermedius was left behind	TT	Femoral: MIS tibial: BIS + sutures with bicortical screw
Kim et al.	2009	QT + BB: entire thickness of quadriceps tendon was harvested. All quadriceps tendon grafts were > 7 mm thickness	TT (2 sockets)	Femoral: BIS tibial: BB + BIS
S. Lee et al.	2007	QT + BB: 6–8 mm thick, part of the vastus intermedius was left behind (stated in discussion)	TT	Femoral: MIS tibial: BIS + sutures with bicortical screw
Akoto et al.	2015	QT + BB: 8–9 mm thick	NR	Femoral: BB press fit tibial: bone plug + sutures over bone bridge
Kim et al. (2)	2009	QT + BB: 6–7 mm thick	NR	Femoral: BIS tibial: BB + BIS
Chen et al.	2006	QT + BB: 6 mm thick, part of the vastus intermedius was left behind	TT	Femoral: BB + MIS tibial: sutures with bicortical screw/washer
Chen et al.	1999	QT + BB: 6–7 mm thick, part of the vastus intermedius was left behind	NR	Femoral: BB + MIS tibial: sutures with bicortical screw/washer
Kim et al. (3)	2009	QT + BB: for single bundle cohort, 6–7 mm thick, for double bundle cohort, 8 mm thick which included entire thickness of quadriceps tendon	AMP (2 sockets)	Femoral: BIS tibial: BB + BIS
Cavaignac et al.	2017	QT + BB: entire thickness of quadriceps tendon was harvested (stated in discussion)	NR	Femoral: BIS tibial: BB + BIS
Lee et al.	2004	QT + BB: 6–8 mm thick, part of the vastus intermedius was left behind	NR	Femoral: BB + MIS tibial: BIS + sutures with bicortical screw/washer
Lee et al.	2016	QT + BB: 6–8 mm thick	TT	Femoral: BB + MIS tibial: BIS + sutures with bicortical screw/washer
Guimaraes et al.	2009	QT + BB: refers to prior paper which refers to a prior paper which states graft was 6–7 mm thick	TT	Femoral: BB + MIS tibial: sutures with bicortical screw/washer
Joseph et al.	2006	QT + BB: refers to prior paper, 6–7 mm thick	TT	NR
Iriuchishima et al.	2017	SQT: average graft diameter was 8.1 ± 1.4 mm	AMP	Femoral: suspensory button + double spike plate tibial: sutures with bicortical screw/washer
Runer et al.	2018	QT + BB: 5 mm, measured using specialized tendon cutting device	AMP	Femoral: Suspensory button Tibial: BIS, sutures tied over a cortical bone bridge or equivalent
Kwak et al.	2018	QT + BB: 8 mm, part of the vastus intermedius was left behind	TT	Femoral: MIS tibial: MIS with sutures tied over a cortical screw

SQT all-soft tissue quadriceps tendon, *QT + BB* quadriceps tendon with bone block, *AMP* drilled through anteromedial portal, *TT* drilled through tibia, *NR* not reported, *MIS* metal interference screw, *BIS* bio-absorbable interference screw

Table 4 Summary of clinical outcomes and complications of all studies

Authors	Year	Graft used	Outcome	Complications
Akoto et al.	2012	FT-Q	Positive pivot shift: 5 (16.6%) IKDC subjective knee form: 86.1/100 Side-to-side difference in anterior laxity with Rolimeter and manual maximum force: 1.6 mm	Graft rupture: 0 (0%) DVT: 0 (0%) Infection: 0 (0%)
Han et al.	2008	PT-Q	Lysholm: 91.5 Instrumented anterior laxity < 3mm: 66.6%	Moderate to severe kneeling pain: 4/72 (5.5%) Graft Rupture: 2 (2.8%)
Geib et al.	2009	FT-Q	Positive pivot shift: 10 (5.1%) Post-operative flexion loss: 0.3° Post-operative extension loss: 0.55° Instrumented anterior laxity < 3mm: 82.3%	Graft rupture: 11 (5.6%) Anterior knee PAIN: 9 (4.6%) Graft site numbness: 3 (1.5%)
Theut et al.	2003	PT-Q	IKDC subjective knee form: 86/100 Side-to-side difference in anterior laxity with KT-1000 and manual maximum force: 2.1 mm	Graft rupture: 4 (5.9%)
Lee et al.	2007	PT-Q	Positive pivot shift: 37 (27%) Lysholm: 93 Side-to-side difference in anterior laxity with KT-1000 and manual maximum force: 2.4 mm	Graft rupture: 0 (0%)
Kim et al	2009	FT-Q	Positive pivot shift: 0 (0%) Lysholm: 91.1 Side-to-side difference in anterior laxity with KT-2000 and manual maximum force: 2.03 mm	
S. Lee et al.	2007	FT-Q	Lysholm: 90 Moderate or severe kneecap pain: 22/247 (9%) Side-to-side difference in anterior laxity with KT-1000 and manual maximum force: 2.4 mm	Graft rupture: 7 (2.83%)
Akoto et al.	2015	FT-Q	Positive PIVOT Shift: 2 (20%) IKDC subjective knee form: 89.5/100	
Kim et al. (2)	2009	PT-Q	Positive pivot shift: 4 (19.0%) Moderate kneeling pain: 4/21 (19%) IKDC activity level I/strenuous: 8/21 (38%) IKDC activity level II/moderate: 10/21 (48%) Instrumented anterior laxity < 3mm: 57.1%	
Chen et al.	2006	PT-Q	Knee pain during moderate or strenuous activity: 3/34 (9%) IKDC activity level I (competitive): 17/34 (50%) IKDC activity Level II (strenuous): 9/34 (26%) Side-to-side difference in anterior laxity with KT-1000 and manual maximum force: 1.74 mm	Lateral paresthesias: 2 (5.88%) Stitch abscess: 2 (5.88%) Tibial screw irritation: 1 (2.94%) Quadriceps dysfunction (loss of 10 mm in thigh girth compared to contralateral leg): 9 (26.4%)
Chen et al.	1999	PT-Q	IKDC subjective knee form: 86.5/100 Anterior knee pain: 1/12 (8.3%) Return to sports (same or higher level of pre-injury sports activity level): 10/12 (83.3%)	
Kim et al. (3)	2009	FT-Q and PT-Q	PT-Q: Positive pivot shift: 4 (14.3%) Instrumented anterior laxity < 3mm: 82.1% IKDC knee examination form: $A = 11$ (39.3%), $B = 13$ (46.4%), $C = 4$ (14.3%), $D = 0$ (0%) FT-Q: Positive pivot shift: 0 (0%) Instrumented anterior laxity < 3mm: 90.3% IKDC knee examination form: $A = 18$ (48.4%), $B = 13$ (41.9%), $C = 3$ (9.7%), $D = 0$ (0%)	

Table 4 (continued)

Authors	Year	Graft used	Outcome	Complications
Cavaignac et al.	2017	PT-Q	Positive pivot shift: 4/45 (6.9%) IKDC subjective knee form: 84.0/100 Lysholm: 89.0 Instrumented anterior laxity < 3mm: 88.9%	Graft rupture: 1 (2.2%)
Lee et al.	2004	PT-Q	Positive pivot shift: 26 (38.8%) Moderate kneeling pain: 4/64 (6%) Severe kneeling pain: 0/64 (0%) Pain during moderate or strenuous activity: 8/67 (12%) Return to sports (resumed at preinjury level): 59/67 (88%) IKDC activity level I/competitive athletic activity: 9/67 (13%) IKDC activity level II/moderate: 50/67 (75%) Instrumented anterior laxity < 3mm: 74.6%	Graft rupture: 4 (6%) Post-operative patellar fracture: 1 (1.49%)
Lee et al	2016	FT-Q	Positive pivot shift: 16 (33%) IKDC subjective knee form: 80.2/100 Lysholm: 92.1 Side-to-side difference in anterior laxity with KT-2000 and manual maximum force: 2.1 mm	
Guimaraes et al.	2009	PT-Q	Positive pivot shift: 4/17 (23.53%) Lysholm: 97.35 Complete return to sports: 15/17 (88%) Return to sports with modification: 1/17 (11%) Return to sports with sport change: 1/17 (11%)	Post-operative patellar fracture: 1 (5.88%)
Joseph et al.	2006	PT-Q	Duration of pain medication usage: 5.4 days Time to attainment of full extension: 3.9 weeks Time to attainment of straight leg raise without lag: 3.7 weeks Time to attainment of 120° of flexion while prone: 4.7 weeks	
Iriuchishima et al.	2017	FT-Q	IKDC knee examination form: A = 18 (90%), B = 2 (10%), C = 0 (0%), D = 0 (0%) Positive pivot shift: 0 (0%) Mean anterior tibial translation on stress radiograph: 1.0 ± 0.8 mm	Graft site pain: 0 (0%)
Runer et al.	2018	PT-Q	Lysholm score: 93.4 ± 7.5 VAS pain score: 0.6 Tegner activity level: 6 (2–9) Return to pre-injury tegner activity level: 67% Constant anterior knee pain: 0 (0%)	Graft rupture: 0 (0%) Intra-operative patellar fracture: 0 (0%) Numbness: 0 (0%) Graft site irritation: 0 (0%)
Kwak et al.	2018	PT-Q	IKDC subjective knee form: 67.3 Lysholm: 87 Tegner: 7.2 Instrumented anterior laxity < 3mm: 75.6% Positive pivot shift: 16/45 (35.6%)	Lateral paresthesia: 2/45 (4.4%, no longer present after 2 months) Graft rupture: 0 Post-operative infection: 0

FT-Q full thickness quadriceps tendon autograft, *PT-Q* partial thickness quadriceps tendon autograft

This study, which has a number of strengths including reporting several objective and PRO measures from a pooled cohort of 1212 patients and 20 studies, has numerous implications for clinical practice. Given that there appears to be no difference in the clinical outcome and complication profiles of FT-Q and PT-Q, surgeons may be justified in using either graft type based on their preference or experience with harvesting a particular graft type. Given the growing body of evidence supporting QT autografts over other autograft options [3, 14, 19, 33] as well as the growing popularity of QT autografts [36], these findings are particularly important as they may help reaffirm to clinicians that there is evidence to support primary ACL-R using QT, both full and partial thickness.

This review was limited by the quantity and quality of studies available on primary ACL-R with FT-Q or PT-Q autograft. Many of the included studies had significant methodologic flaws such as a low sample size,

Table 5 Comparison of full and partial thickness quadriceps tendon autografts

Outcome measure	FT-Q	PT-Q
Lysholm score (mean)	90.4	91.0
IKDC-SKF score (mean)	82.5	82.1
Extension deficit < 5° (% of patients)	94.9	94.8
Quadriceps strength (% of contralateral leg)	89.5	85.1
Instrumented laxity < 3 mm (% of patients)	74.8	72.8
Anterior knee pain (% of patients)	5.2	4.0
Graft failure (% of patients)	3.7	3.0

FT-Q full thickness quadriceps tendon autograft, *PT-Q* partial thickness quadriceps tendon autograft, *IKDC-SKF* International Knee Documentation Committee Subjective Knee Form, *ROM* range of motion

retrospective evaluation of data, limited reporting of technique such as the tools used to measure graft thickness, and lack of a control group for comparison. Only one of the included studies directly compared FT-Q to PT-Q. There was fairly significant heterogeneity in the included studies regarding graft preparation, graft fixation technique, and the reporting of outcomes and complications. Apart from functional scores, more data are needed to evaluate time to return to sport at preinjury level.

Conclusions

Across the 20 studies included in this review, there appeared to be no difference in outcomes or complications between either FT-Q or PT-Q in primary ACL-R. Moreover, primary ACL-R using QT autografts appear to have successful outcomes with a low rate of graft failure, irrespective of tendon thickness. While larger, multi-center comparative studies are needed to better delineate the optimal thickness of quadriceps tendon for primary ACL-R, these data suggest that, in primary ACL-R, either FT-Q or PT-Q is efficacious, and surgeons may be justified in using either graft thickness.

Author contributions ACK, OAO performed the screening of all titles, abstracts, and full-texts. MEA and ACK performed the abstraction of all data. PBS and ACK drafted the original manuscript. DdS, ACK, BPL, and VM participated in the editing of the original manuscript. DdS, ACK, BPL, and VM participated in the conception and design of the original study. All authors read and approved the final manuscript.

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Compliance with ethical standards

Conflict of interest The authors of this study confirm that they have no conflicts of interest related to this study.

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