Systematic Review

Both low and high knee flexion angles during tibial graft fixation yield comparable outcomes following ACL reconstruction with quadriceps tendon autograft: A systematic review

Hassaan Abdel Khalik, MD^a, Darius L. Lameire, MD^a, Jeffrey Kay, MD^b, Sachin R. Tapasvi, MD^c, Kristian Samuelsson, PhD^d, Darren de Sa, FRCSC^{b,*}

^a Michael G. DeGroote School of Medicine, McMaster University, Hamilton, Ontario, Canada

^b Division of Orthopaedic Surgery, McMaster University, Hamilton, Ontario, Canada

^c Department of Arthroplasty and Arthroscopy, The Orthopaedic Specialty Clinic, Pune, Maharashtra, India

^d Department of Orthopaedics, Institute of Clinical Sciences, The Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden

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ABSTRACT

Importance: A paucity of clinical evidence surrounds the effect of the knee flexion angle during tibial fixation of the graft during anterior cruciate ligament (ACL) reconstruction. While biomechanical studies have recently sought to revive this area of study in both single- and double-bundle graft populations, they have done so using variants of the hamstring graft. This does not shed light on the optimal fixation of other autograft options, namely, the quadriceps tendon (QT) autograft.

Objectives: To determine the effect of the knee flexion angle during tibial graft fixation on functional and clinical outcomes following ACL reconstruction using single-bundle QT autograft, inclusive of both soft-tissue and bone-plug graft types.

Evidence review: An electronic search of MEDLINE, EMBASE, Web of Science, and the Cochrane Library was carried out from database inception to June 2020. Following study screening, patient demographics and fixation technique as well as both subjective and objective clinical outcomes were abstracted. Studies were divided based on the knee flexion angle during tibial fixation of the graft. The low knee flexion angle (L-KFA) group included patients with a tibial fixation angle of < 30° of flexion, and the high knee flexion (H-KFA) group included those with a tibial fixation of exactly 30° of flexion. The data were qualitatively synthesized due to significant heterogeneity across the included studies.

Findings: Sixteen studies (1,169 patients) were included for analysis. There were 675 patients in the L-KFA group (mean age range, 18.7–34.5 years) and 494 patients in the H-KFA group (mean age range, of 23.2–32.1 years). Both groups yielded statistically significant improvements from preoperative to postoperative scores across several functional and clinical outcomes. Return to pre-injury activity levels ranged from 64% to 81% in L-KFA studies and from 73.3% to 86.7% in H-KFA studies. All-cause graft failure rates ranged from 1.4% to 4.3% in L-KFA studies and from 0%–10.7% in H-KFA studies.

Conclusion: Both low- and high-knee flexion angles during tibial graft fixation produce improved postoperative clinical and functional outcomes with comparable outcomes across groups. There is inconclusive evidence to recommend the ideal knee flexion angle for graft fixation in primary ACLR.

Level of evidence: Level IV.

*Corresponding author. Division of Orthopaedic Surgery, Department of Surgery, McMaster University, 1280 Main Street West, Hamilton, ON L8P 1H6, Canada. Tel.: +1 365 366 7638.

E-mail address: darren.desa@medportal.ca (D. de Sa).

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What is already known?

- Biomechanics studies have demonstrated that the knee flexion angle during tibial fixation of the graft during ACL reconstruction impacts various postoperative knee outcomes including, but not limited to, post-operative knee range of motion, in situ forces of the graft, and rotational knee stability

What are the new findings?

- Tibial fixation of a single-bundle quadriceps tendon autograft at both low and high knee flexion angles produces improved and comparable patient-reported and objective outcomes following ACL reconstruction
- Graft failure rates were comparable across both low and high knee flexion angles during tibial fixation of the graft during ACL reconstruction

Introduction

Anterior cruciate ligament (ACL) tears continue to be one of the most common orthopaedic injuries in the United States [1]. Orthopaedic surgeons can choose from several graft types [2] and surgical techniques [3, 4] when performing ACL reconstruction (ACLR). Though the patellar tendon and hamstring grafts have been historically more commonly used, the quadriceps tendon (QT) autograft has been recently gaining popularity due to its flexibility, ease of harvest, decreased donor-site morbidity, and favorable outcomes [5,6]. Several surgical techniques have been described for tibial fixation of the graft. Variables associated with these techniques include the use of interference screws, cortical fixation or cross pin fixation, the type of tunnel placement, and the knee flexion angle (KFA) during tibial graft fixation [7–10].

The effects of the knee flexion angle (KFA) during tibial graft fixation on knee biomechanics and clinical outcomes following ACLR have been evaluated for >30 years. The literature suggests two primary approaches to KFA during graft fixation: (1) fixation at full or near extension [8,9] and (2) fixation at 30° of flexion [10]. Proponents of low knee flexion angles may cite decreased rates of postoperative flexion contractures relative to high KFAs [8,11,12], a decreased likelihood of over-constraining over-constraining the graft [13], and decreased in situ graft forces [14,15]. Proponents of graft fixation and tensioning at higher KFAs, specifically 30° degrees, may cite closer to normal in situ graft forces [15], better restoration of rotational knee stability relative to low KFAs [16], and reduced anterior tibial translation (ATT) relative to low KFAs [15].

There remains a paucity of clinical studies or systematic reviews examining the effects of KFA on postoperative clinical and functional outcomes, especially pertaining to the QT autograft [16–20]. Therefore, this review aims to determine the effect of the knee flexion angle during tibial graft fixation on functional and clinical outcomes following ACLR using a single-bundle quadriceps tendon autograft, inclusive of both soft-tissue and bone-plug graft types. We assumed the null hypothesis, specifically, that there will be no difference in clinical or functional outcomes across either a KFA of <30° and a KFA of 30°, with similar rates of loss of extension across both groups.

Materials and methods

Comprehensive search strategy

This review followed the guidelines and algorithm of the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA)

[21]. A systematic search of MEDLINE, EMBASE, Web of Science, and the Cochrane Controlled Register of Trials (CENTRAL) was performed through June 30, 2020 by two reviewers (HAK and DLL) for literature related to anterior cruciate ligament reconstruction using quadriceps tendon. All studies published since 2000 were included. The search terms included ‘anterior cruciate ligament’, ‘reconstruction’, and ‘quadriceps tendon’. The complete search strategies used for each database can be found in [Appendix A](#). The inclusion criteria for this review were [1] primary anterior cruciate reconstruction, [2] single-bundle quadriceps tendon reconstruction with or without bone plug, [3] ipsilateral autograft, [4] outcomes data provided, [5] reported flexion angle during tibial graft fixation, [6] skeletally mature patients, [7] all levels of evidence, [8] human studies, and [9] studies published in English. Exclusion criteria consisted of [1] revision ACL reconstruction, [2] cadaveric studies, [3] biomechanical studies, [4] multi-ligamentous knee reconstruction, [5] no follow-up/outcomes data reported, [6] published before the year 2000, [7] double-bundle quadriceps tendon ACL reconstruction, and [8] review articles.

Study screening

The titles and abstracts of the identified studies were independently screened by two authors (HAK and DLL) using the inclusion and exclusion criteria. When necessary (i.e., insufficient data within the abstract), full-text review was performed. Disagreements were advanced to the full-text review stage to prevent premature exclusion. Any full-text disagreement was resolved by consulting a senior third author (DdS) and arriving at a consensus across all of the reviewers. After each screening state, a Kappa (κ) score was calculated to determine the level of agreement between reviewers along with a 95% confidence interval (CI). A κ score of ≥ 0.81 signifies almost perfect agreement, a κ score between 0.61 and 0.8 represents substantial agreement, and a κ score of <0.61 represents between moderate to poor agreement [22].

Assessment of study quality

The methodological quality of randomized control trials and prospective randomized trials were assessed using The Cochrane Collaboration's tool for assessing risk of bias in randomised trials by two authors (HAK and DLL) independently. The items on the questionnaire were determined as “low risk of bias,” “high risk of bias,” or “unclear risk of bias”. Any disagreements were resolved by the third author (DdS) [23]. The quality of the non-randomized studies was assessed using the Methodological Index for Non-randomized Studies (MINORS) [24]. The studies were assessed independently by two authors (HAK and DLL), and the scores were averaged ([Table 1](#)).

Data abstraction from included studies

Each reviewer abstracted data from half of the studies, with the second reviewer checking for accuracy, and vice versa. The data were abstracted and recorded into predetermined tables using Google Sheets. The following data were abstracted from the studies if available: study characteristics (journal, author, publication year, study design, level of evidence [LOE]), number of patients, follow-up length, participant characteristics (e.g., age, sex, etc.), details of the surgery performed (flexion angle during graft fixation, graft type), and both subjective and objective clinical outcomes. Subjective clinical outcomes included (1) International Knee Documentation Committee (IKDC) subjective score, (2) IKDC activity levels, (3) Lysholm score, and (4) Tegner Activity Score. Objective clinical outcomes included (1) anterior drawer test, (2) Lachman test, (3) pivot-shift test, (4) anteroposterior (AP) side-to-side difference, and (5) AP translation. Additional outcomes included range of motion deficits, return to sport/pre-injury activity levels, and graft failure or rupture rates. Further details regarding the reported subjective and objective clinical outcomes can be found in [Appendix B](#). The LOE of each

Table 1
Characteristics of included studies.

Author (Year)	Country	Study design	LOE	Patients	Knees	Average follow-up, Mo (minimum follow-up, Mo)	Mean age, Yr	Male, %	Tibial fixation knee flexion angle, °	Mean MINORS score
Akoto (2012) [29]	Germany	Case series	IV	30	30	NR (12)	31.0	57%	30	10.5
Barie (2020) [30]	Germany	RCT	II	30	30	12.2 (NR)	30.5	57%	0	N/A
Cavaignac (2017) [37]	Switzerland	Cohort	III	50	50	40.8 (NR)	32.1	60%	30	19.5
Chen (2006) [38]	Taiwan	Case series	IV	38	38	62.0 (NR)	26.0	68%	0	11.0
Galan (2020) [39]	Argentina	Cohort	III	291	291	NR (72)	23.2	92%	30	11.5
Geib (2009) [40]	United States	Case series	IV	191	198	55.6 (24)	31.7	53%	20–30	17.0
Gorschewsky (2007) [35]	Switzerland	Cohort	III	124	124	34.0 (NR)	NR	NR	0	19.0
Han (2008) [41]	South Korea	Cohort	III	72	72	39.7 (NR)	27.8	94%	0	20.5
Kim (2018) [42]	South Korea	Cohort	III	42	42	17.9 (NR)	30.3	83%	30	18.5
+ Remnant	South Korea	Cohort	III	33	33	18.2 (NR)	26.0	85%	30	18.5
- Remnant	South Korea	Cohort	III	28	28	NR (24)	26.1	79%	10–15	20.0
Kim (2009) [36]	South Korea	Cohort	III	28	28	NR (24)	26.1	79%	10–15	20.0
Kwak (2018) [43]	South Korea	Cohort	IV	45	45	29.8 (24.9)	34.5	84%	0	18.0
Lee (2016) [44]	South Korea	Cohort	III	48	48	35.6 (NR)	31.1	92%	30	18.5
Lee (2004) [31]	South Korea	Case series	IV	67	67	41.0 (NR)	28.0	87%	0	12.0
Lund (2014) [32]	Denmark	RCT	II	26	26	NR (24)	30.0	81%	20	N/A
Martin-Alguacil (2018) [33]	Spain	RCT	II	26	26	NR (24)	18.7	88%	20	N/A
Perez (2019) [34]	United States	Cohort	III	28	28	31.6 (24)	23.1	61%	10	19.5

LOE, level of evidence; NR, not reported; RCT, randomized control trial.

article was classified based on the authors statement, and in cases in which they did not state the LOE, we classified the LOE based on the American Academy of Orthopaedic Surgeons (AAOS) Evidence-Based Practice Committee guidelines [25].

Studies that reported ACL reconstruction failures were categorized into three categories. Graft failure is defined as an atraumatic graft failure based on subjective or clinical outcomes (i.e., increased laxity), graft rupture is defined as a traumatic tear of the ACL due to injury, and

Fig. 1. Outline of systematic search strategy.

unclear graft failure/rupture was used to categorize all graft complications without clear causation [26].

Statistical analysis

The included studies were divided into two groups based on the knee flexion angle when fixating the graft to the tibia. The low flexion angle group (L-KFA) included patients with a knee flexion angle of < 30° during fixation, and the high flexion angle group (H-KFA) included those with a knee flexion angle of exactly 30°. A threshold angle of 30° was based on previous biomechanical studies evaluating the effect of KFA on knee stability and in situ forces following ACLR using various single-bundle grafts [11,13–16]. At minimum, these studies evaluated the aforementioned outcomes following KFAs of 0° and 30° of flexion. As such, this systematic review similarly proceeded with two comparative groups separated by a 30° of flexion threshold. Further, none of the included studies performed tibial fixation of the graft at a knee flexion angle of >30°.

Due to the significant heterogeneity between the included studies with variations in patient population, length of follow-up, surgical technique, surgeons, and graft type, we did not pool the data in a meta-analysis. Instead, all outcomes consistently reported have been presented in forest plots. Additionally, a subgroup analysis of objective knee outcomes was performed comparing L-KFA and H-KFA studies across transtibial and anatomic ACLR techniques to account for reported variations in the aforementioned techniques’ anteroposterior and rotational stability outcomes [27,28].

Results

There were an initial 6,636 studies that resulted from the search of MEDLINE, EMBASE, Web of Science, and CENTRAL, with 3,277 remaining after exclusion of duplicates. After screening using the inclusion and exclusion criteria, there were 16 studies that were used for this review (Fig. 1) [29–44]. The title and abstract screening had substantial inter-reviewer agreement as the κ score was 0.73 (95% CI, 0.66–0.80), and there was almost perfect agreement after the full text screening, with a k score of 0.84 (95% CI, 0.72–0.95). Any studies that cited surgical techniques had the subsequent techniques reviewed for KFA. The risk of bias assessment for the randomized studies is presented in Fig. 2. The average MINORS score for comparative studies is 18.9 (± 1.1), or moderate quality, and 11.3 (± 0.6), or moderate quality, for non-comparative studies (Table 1).

The included studies comprised 1,169 patients (1,176 knees) with an average age ranging from 18.7 to 34.5 years at the time of ACLR with a quadriceps tendon graft. There were 675 patients in the L-KFA tibial fixation group with a fixation angle of <30°, with no study reporting fixation in hyperextension. The mean age range was 18.7–34.5 years, the percentage of male patients ranged from 53% to 94%, and the average follow-up ranged from 12.2 to 62 months postoperatively. There were 494 patients in the H-KFA tibial fixation group with a reported fixation angle of 30°. The mean age range was 23.2–32.1 years, the percentage of male patients ranged from 57% to 92%, and the average follow-up ranged from 17.9 to 40.8 months postoperatively (Table 1).

Characterization of surgical technique

The majority of patients in the L-KFA group underwent a form of transtibial drilling of the femoral tunnel (647 patients) [30–33,35,36,38, 40,41,43], with one study using the anteromedial portal technique (28 patients) [34]. In the H-KFA group, there were two studies using a form of the transtibial technique (123 patients) [42,44], two studies using a form of the anteromedial technique (321 patients) [29,39], and one study using the outside-in method (50 patients) [37]. Further details regarding the use of a bone block as well as the anchoring devices used for femoral and/or tibial fixation of the graft can be found in Table 2.

Subjective clinical outcomes

Included subjective clinical outcomes were IKDC scores, IKDC activity levels, Lysholm scores, and Tegner activity scores. The details of preoperative and postoperative subjective scores reported across the included studies are available in Table 3. Postoperative mean IKDC scores ranged from 67.3 to 94.8 [30,32,34,37,43] and from 70.1 to 86.1 [29,42,44] in L-KFA and H-KFA groups, respectively (Fig. 3). Postoperative Lysholm scores ranged from 87.0 to 95.6 [30,33–36,38,41,43] and from 89.0 to 92.1 [37,39,42,44] in L-KFA and H-KFA groups, respectively (Fig. 4). One study in the L-KFA group reported a mean postoperative Tegner score of 6.0 [34], while three studies in the H-KFA group reported scores ranging from 4.1 to 5.9 [37,42,44].

Objective clinical outcomes

Included objective clinical outcomes were the anterior drawer test, Lachman test, pivot-shift test, and anteroposterior translation. The details of preoperative and postoperative objective scores reported across the included studies are available in Table 4. Two L-KFA studies reporting postoperative anterior drawer test outcomes found 96%–100% of knees to be either grade I or grade II [31,43]. Two H-KFA studies reporting postoperative anterior drawer test outcomes found 98%–100% of knees to be either grade I or II [42,44]. Four L-KFA studies reported post-operative Lachman grading, and the percentage of grade-I or II laxity ranged from 96% to 98% [31,36,38,43]. Two H-KFA studies reported postoperative Lachman grading, and the percentage of grade-I or II laxity ranged from 98% to 100% [42,44]. Three L-KFA studies reported post-operative pivot-shift grading, and the percentage of grade-I or II knees ranged from 96% to that 100% [31,36,43]. Three H-KFA reported post-operative pivot-shift grading, and all reported that 100% of knees were either grade I or II [37,42,44]. Anteroposterior side-to-side differences ranged from 0.94 mm to 2.64 mm [30,32,36,40,43] and from 1.0 mm to 2.21 mm [29,37,39,42,44] in the L-KFA and H-KFA groups, respectively (Fig. 5). Subgroup analysis of transtibial technique studies across the L-KFA and H-KFA groups found comparable results across the

Fig. 2. Risk of bias assessment.

Table 2

Characteristics of surgical and fixation techniques used in included studies.

Tibial fixation knee flexion angle	Study	ACLR technique	Bone block	Anchoring device, femoral side	Anchoring device, tibial side
<30°	Barie (2020)	Transtibial	Yes	Press-fit	Hybrid (bone wedge + sutures tied over bone bridge)
	Chen (2006)	Transtibial	Yes	Interference screw (NR)	Bicortical screw and washer
	Gorschewsky (2007)	Transtibial	Yes	Interference screw (absorbable)	Interference screw (absorbable)
	Geib (2009)	Transtibial	Combined	Interference screw (absorbable)	Interference screw (absorbable)
	Han (2008)	Transtibial	Yes	Interference screw (metal)	Interference screw (absorbable)
	Kim (2009)	Transtibial	Yes	Interference screw (absorbable)	Interference screw (absorbable)
	Kwak (2018)	Modified transtibial technique	Yes	Interference screw (metal)	Interference screw (metal)
	Lee (2004)	Transtibial	Yes	Interference screw (metal)	Interference screw (absorbable)
	Lund (2014)	Transtibial	Yes	Interference screw (metal)	Interference screw (metal)
	Martin-Alguacil (2018)	Transtibial	No	Interference screw (absorbable)	Interference screw (absorbable)
	Perez (2019)	Anteromedial portal technique	No	Loop suspensory cortical fixation	Interference screw (non-absorbable polymer)
30°	Akoto (2012)	Anteromedial portal	Yes	Press-fit	Split bone wedge + sutures tied over bone bridge + distal bone plug press-fit anterior tibial tunnel
	Cavaignac (2017)	Outside-in method	Yes	Interference screw (absorbable)	Interference screw (absorbable)
	Galan (2020)	All-inside technique (anteromedial portal)	Yes	Interference screw (NR)	Retroscrew
	Kim (2018) (+/- Remnant)	Modified transtibial technique	Yes	Interference screw (metal)	Interference screw (absorbable)
	Lee (2016)	Transtibial	Yes	Interference screw (metal)	Interference screw (absorbable)

NR, not reported.

Lachman test, pivot-shift test, and side-to-side anteroposterior translation (Appendix C). No subgroup analysis was performed across anatomic technique studies due to a lack of objective outcomes reported in the L-KFA group.

Range of motion deficits

Five studies in the L-KFA group reported on postoperative limitations in knee extension. One study reported limitations of knee extension in 3.3% of patients due to the development of cyclops lesions, which were re-operated on, ultimately leading to full extension [30]. One study reported that 4.2% of patients had a deficit of <5° and that one patient (1.4%) had a 10° extension deficit [41]. One study reported that 3.6% of patients had a deficit of >5° [36]. Another study reported that 3% of patients had an extension deficit of >3° [31]. One study in the H-KFA group reported that 1 patient (3.3%) had an extension deficit of >3° [29].

Six studies in the L-KFA group reported on postoperative flexion deficits. In studies defining flexion as a loss of ≥5°, flexion deficit rates ranged from 3% to 4.2% [36,38,41]. Among those studies, one knee was specified to experience a flexion deficit of 6° to 15° [38], another knee experienced a flexion deficit of 10° [41], and the third knee experienced a flexion deficit of 40° [41]. One additional reported a mean postoperative flexion deficit of 0.3° [40]. Lastly, one study reported a 99% flexion loss rate defined as <5° [31]. One study in the H-KFA group reported a mild flexion loss rate of 3.3%, although the degrees of flexion were not specified [29].

Return to sport/pre-injury activity levels

Two studies in the L-KFA group reported return to sport or pre-injury activity rates. One study reported return to pre-injury levels based on the Tegner score, with 64% of patients achieving their pre-injury Tegner score [30]. Another study reported an 81% return to sport rate [35]. Two studies in the H-KFA group reported return to pre-injury activity rates ranging from 73.3% to 86.7% based on the Tegner score [29,39].

Table 3

Preoperative and postoperative patient reported outcomes.

	Preoperative	Postoperative	P value
<30°			
IKDC subjective score (mean ± SD)			
Kwak (2018)	42.7 ± 22.6	67.3 ± 16.8	<0.001
IKDC activity levels (strenuous: moderate: light: sedentary)			
Chen (2006)	5:4:6:19	17:9:5:3	NR
Kim (2009)	3:5:15:5	11:13:4:0	<0.05
Lee (2004)	11:54:2:0	9:50:8:0	NR
Lysholm (mean ± SD)			
Barie (2020)	59.7 ± 18.6	95.6 ± 7.8	NR
Chen (2006)	61.4 ± 8.9	93.0 ± 7.9	<0.05
Han (2008)	70.7 ± NR	91.5 ± 9.7	NR
Kim (2009)	75.8 ± 8.2	91.8 ± 9.7	<0.05
Kwak (2018)	62.4 ± 8.4	87.0 ± 5.3	<0.001
Lee (2004)	71	90	<0.05
Martin-Alguacil (2018)	76.3 ± NR	93.8 ± NR	NR
Tegner (median, IQR)			
Barie (2020)	4, 0-8	6, 4-9	0.645
Kwak (2018)	2.8, 1.8-4.0	7.2, 6.3-8.2	<0.001
30°			
IKDC subjective score (mean ± SD)			
Kim (2018) + Remnant Group	44.3 ± 17.7	70.1 ± 9.1	<0.001
Kim (2018) - Remnant Group	51.9 ± 16.9	72.3 ± 10.1	<0.001
Lee (2016)	60.3 ± 17.8	80.2 ± 10.0	<0.001
Lysholm (mean ± SD)			
Galan (2020)	64.0 ± 6.1	91.0 ± 6.1	NR
Kim (2018) + Remnant Group	68.4 ± 20.5	90.1 ± 7.0	<0.001
Kim (2018) - Remnant Group	73.6 ± 13.7	89.3 ± 10.7	<0.001
Lee (2016)	70.2 ± 9.6	92.1 ± 8.7	<0.001
Tegner (mean ± SD)			
Kim (2018) + Remnant Group	3.9 ± 2.0	4.2 ± 1.1	n.s.
Kim (2018) - Remnant Group	3.6 ± 1.9	4.1 ± 1.4	n.s.
Lee (2016)	4.6 ± 1.8	4.7 ± 1.2	0.819

NR, not reported; n.s., not significant.

Fig. 3. Postoperative mean IKDC subjective scores across both low- and high-knee flexion groups.

Graft failure or rupture

Graft failure rates defined as atraumatic persistent laxity and ranged from 1.4% to 4.5% in the L-KFA group [31,36,40,41], with no H-KFA studies reporting this outcome. Graft rupture rates ranged from 1.4% to 3.8% [31,33,35,41] and from 0% to 2% [29,37,42] in the L-KFA and H-KFA groups, respectively. Rates of unclear mechanisms of graft failure/rupture ranged from 3.3% to 4.3% in the L-KFA group [30,34], with one H-KFA study reporting a rate of 10.7% [39].

Discussion

The key finding of this systematic review is that both low and high knee flexion angles during tibial graft fixation produce comparable clinical and functional outcomes following single-bundle QT autograft ACLR, with statistically significant improvements from preoperative to postoperative evaluations. Furthermore, both L-KFA and H-KFA groups experienced similarly low rates of extension and flexion deficits, with several cases of extension deficit in the L-KFA group being attributable to cyclops deformities independent of the knee flexion angle. Both L-KFA and H-KFA knees experienced comparable rates of return to pre-injury activity levels as well as low rates of all-cause graft failure rates.

To date, several biomechanical studies have sought to examine the impact of the knee flexion angle during tibial graft fixation on single-

bundle graft function. A notable study that assessed knee kinematics (specifically, anterior tibial translation) and in situ graft forces across four knee positions during tibial graft fixation found that 30° of flexion with a 134-N posterior force best replicated knee kinematics and in situ graft forces observed in the native knee [15]. Additional positions examined were (1) full extension, (2) 30° of flexion with no posterior load applied, and (3) 30° of flexion with 67N of posterior load applied. Only four studies included in this review reported the use of posterior loading and lacked the specific force used, thus preventing any meaningful analysis [31,34,37,42]. Furthermore, a recent study that sought to examine the effects of the knee flexion angle during graft fixation on rotational knee stability found that 30° of flexion during anatomic ACLR best restored rotational stability relative to (1) anatomic reconstruction in full extension, (2) non-anatomic reconstruction in 30° flexion, and (3) non-anatomic reconstruction in full extension [16]. With regard to the relationship of graft fixation angle and the position of the tibia relative to the femur, it has been demonstrated that graft fixation at 20° best replicated normal knee positioning compared to graft fixation at 0° and 90° [19]. Despite the strong evidence trending towards high KFAs during tibial graft fixation, a study that sought to examine the effects of knee flexion, initial graft tension, and femoral graft attachment site on graft forces and anteroposterior stability concluded that graft fixation at full extension 44 N of tension produce similar outcomes relative to the intact knee [13]. Furthermore, grafts fixed at 30° flexion were over-constrained

Fig. 4. Postoperative mean Lysholm scores across both low- and high-knee flexion groups.

Table 4

Preoperative and postoperative objective clinical outcomes.

	Preoperative	Postoperative	p-value
<30°			
Anterior drawer test (grade I:II:III:IV)			
Kwak (2018)	4:15:21:5	32:13:0:0	<0.001
Lee (2004)	0:11:50:6	50:14:3:0	NR
Lachman test (grade I:II:III:IV)			
Chen (2006)	0:0:24:10	30:3:1:0	NR
Kim (2009)	0:2:21:5	23:4:1:0	NR
Kwak (2018)	3:14:19:9	29:15:1:0	<0.001
Lee (2004)	0:10:52:4	47:17:3:0	NR
Pivot-shift test (grade I:II:III:IV)			
Kim (2009)	0:1:24:3	24:3:1:0	NR
Kwak (2018)	4:22:14:5	29:16:0:0	<0.001
Lee (2004)	0:11:42:14	41:23:3:0	NR
AP side-to-side difference, mm (mean ± SD)			
Barie (2020)	5.0 ± 1.4	1.0 ± 1.1	NR
Kwak (2018)	4.5 ± 1.8	1.8 ± 1.6	<0.001
AP translation, mm (mean ± SD)			
Chen (2006)	11.9 ± 1.1	1.7 ± 1.8	<0.01
Lee (2004)	7.2 ± NR	2.1 ± NR	<0.05
Martin-Alguacil (2018)	5.4 ± NR	3.3 ± NR	NR
30			
Anterior drawer test (grade I:II:III:IV)			
Kim (2018) + Remnant Group	3:21:16:2	31:11:0:0	<0.001
Kim (2018) - Remnant Group	2:22:8:1	27:6:0:0	<0.001
Lee (2016)	5:25:15:3	34:13:1:0	<0.001
Lachman test (grade I:II:III:IV)			
Kim (2018) + Remnant Group	0:25:1:0	36:6:0:0	<0.001
Kim (2018) - Remnant Group	2:14:14:3	24:9:0:0	<0.001
Lee (2016)	6:23:17:2	32:15:1:0	<0.001
Pivot-shift test (grade I:II:III:IV)			
Kim (2018) + Remnant Group	1:16:24:1	32:10:0:0	<0.001
Kim (2018) - Remnant Group	0:7:19:7	23:10:0:0	<0.001
Lee (2016)	12:15:19:2	32:16:0:0	<0.001
AP side-to-side difference, mm (mean ± SD)			
Kim (2018) + Remnant Group	3.5 ± 2.1	2.3 ± 1.7	<0.001
Kim (2018) - Remnant Group	3.2 ± 1.6	2.1 ± 1.6	<0.001
Lee (2016)	3.9 ± 1.5	2.1 ± 1.9	<0.001

NR, not reported; n.s., not significant

regardless of the tension applied, which results in the tibia being more posterior relative to the intact knee. While there is a robust foundation of biomechanical literature examining the effects of the knee flexion angle during graft fixation on graft function, there remains to be a clear consensus regarding the optimal KFA during tibial graft fixation. Additionally, further high-quality in vivo studies are necessary to draw similar conclusions in the clinical setting given the limitations of cadaveric robotic studies, including the inability to replicate functional loading of the knee as well as not adequately accounting for in vivo variables that could affect long-term graft function (e.g., graft healing, patient demographics, activity levels).

When assessing the impact of graft tensioning during tibial graft fixation on ACLR outcomes, one cannot overlook the possible impact of the femoral positioning of the graft resulting from the ACLR technique

utilized by the surgeon. The transtibial technique is a commonly used ACLR technique that has been recently called into question due to not replicating the ACL's native oblique orientation, with subsequently hindered rotatory stability of the knee [45,46] and high rates of revision surgery [47]. The present review found that the knee flexion angle produced comparable objective clinical outcomes across both L-KFA and H-KFA groups. Recently, the anatomic reconstruction of the ACL has gained traction in the orthopaedic surgery community due to more favorable clinical outcomes, ranging from improved rotatory stability and decreased tibial translation in the short term [28] to reduced rates of post-traumatic osteoarthritis in the long term [48]. The present review lacked an adequate sample size to run a subgroup analysis evaluating the effect of the knee flexion angle during tibial graft fixation in anatomic ACLR techniques. Looking ahead, investigators evaluating the effect of the knee flexion angle during tibial graft fixation are encouraged to make the clear distinction between transtibial and anatomic ACLR techniques in order to minimize any possible confounding factors.

A challenging aspect of establishing the ideal knee flexion angle during tibial graft fixation is the trade-off between knee stability and range of motion. While the present review lacked sufficient data to draw any conclusions regarding this relationship, a clinical study found that grafts fixed at 30° of flexion presented with superior stability measures, but with significantly inferior range of motion outcomes, relative to grafts fixed at full extension [11]. Similar findings were reported in an in vivo study that found increasingly normal anterior stability and anterior tibial position were correlated with increases in extension deficits relative to the contralateral knee [49].

This review is not without its limitations. First, this systematic review only evaluated the effect of the knee flexion angle during tibial graft fixation when using the QT autograft. Therefore, the findings of this study may not be generalizable to other ACLR graft choices. Second, the included studies comprised several surgical techniques, including various ACLR techniques (anatomic ACLR, transtibial ACLR, etc.) as well as graft fixation methods (with or without bone plugs, bioabsorbable vs. metal interference screws, etc.), all of which could have impacted the selected outcomes. While studies have demonstrated conflicting findings regarding the impact of ACLR technique on outcomes [50,51], there do not appear to be any notable differences in clinical and functional outcomes pertaining to the use of metal versus interference screws [52–54], the use of aperture versus suspensory fixation [55], or the use of press-fit fixation [56]. Additionally, this review's subgroup analysis across transtibial L-KFA and H-KFA studies demonstrated comparable objective clinical outcomes across both groups. Furthermore, no difference in outcomes has been demonstrated across ACLR with full- or partial-thickness QT autografts [57]. Third, the method of measuring the knee flexion angle during tibial graft fixation was not always explicitly reported; therefore, variation within studies may exist. Last, included studies were primarily non-comparative Level-III or IV evidence, preventing any pooling or meta-analysis of outcomes. As such, conclusions should only be drawn while appropriately considering the quality of evidence in the studies cited.

Fig. 5. Postoperative mean anteroposterior side-to-side difference across both low- and high-knee flexion groups.

Conclusion

Both low and high knee flexion angles during tibial graft fixation produce improved postoperative clinical and functional outcomes, with comparable outcomes across groups. There is inconclusive evidence to recommend the ideal knee flexion angle for graft fixation in primary ACLR.

Author's contribution

All authors contributed equally in the design, execution, and finalization of this manuscript.

Declaration of competing interest

None.

Appendix A. Search strategy

MEDLINE	Embase	Web of science	CENTRAL
1. Anterior cruciate ligament.mp. or Anterior Cruciate Ligament/		TS = (ACL OR anterior cruciate ligament) AND	("ACL" or "anterior cruciate ligament") and ("quadriceps")
2. Reconstruction.mp. or Anterior Cruciate Ligament Reconstruction/		TS = (recon* OR arthroscop*) AND TS = (quad*)	
3. Recon*.mp.			
4. Arthroscopic*.mp.			
5. Quad*.mp.			
6. Repair*.mp.			
7. 2 or 3 or 4 or 6			
8. acl.mp.			
9. 1 or 8			
10. 5 and 7 and 9			
11. 10 not (animals/not (humans/and animals/))			

Appendix B. Definitions of subjective and objective clinical outcomes

Subjective clinical outcomes

The IKDC subjective score is a validated patient-outcomes questionnaire developed to detect the improvement or deterioration of knee function and symptoms after knee impairment [58,59]. The Lysholm score evaluates outcomes of knee ligament surgery and knee instability on a 0 to 100 scale, with the maximum score of 100 representing no symptoms or disability [60,61]. The Tegner Activity Score focuses on work and sporting activities on a 0 to 10 scale, representing the ability to participate in sports on an elite level [60].

Objective clinical outcomes

Studies that reported anterior drawer and Lachman test results graded laxity based on a scale of I, II, III, of IV, with I representing mild laxity of up to 5 mm, II representing moderate laxity with 5–10 mm of translation, III representing severe laxity with 10–15 mm of translation, and IV representing gross laxity of >15 mm [62]. The pivot-shift test was graded on a I–IV scale, with I representing no slip or jerk; II representing a slip but no jerk; III representing an obvious jump, thud, or jerk; and IV representing gross subluxation that requires the examiner to stop their assessment [62]. Studies that reported anteroposterior translation used either the KT-1000 (MEDmetric® Corp., San Diego, CA, USA) or the KT-2000 (MEDmetric® Corp., San Diego, CA, USA), using either 134 lb or maximal manual force.

Appendix C. Objective outcomes sub-group analysis

	L-KFA			H-KFA		
	N.S.	Min	Max	N.S.	Min	Max
Trans-tibial technique						
Lachman test, grade I + II	4	96%	98%	2	98%	100%
Pivot shift, grade I + II	3	96%	100%	2	100%	100%
Side-to-side AP translation, mm	5	0.94	2.64	2	2.1	2.21

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