Lateral Extra-articular Tenodesis Provides Similar Anterior Stability But Is Superior to Anterolateral Ligament Reconstruction for Internal Rotation Resistance When Combined With Anterior Cruciate Ligament Reconstruction: A Systematic Review and Meta-analysis

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Abstract

Background: While both lateral extra-articular tenodesis (LET) and anterolateral ligament reconstruction (ALLR) address rotational knee instability, their techniques and targeted anatomy differ, potentially leading to variations in effectiveness and stability.

Purpose: To conduct a systematic review and meta-analysis of basic science laboratory cadaver studies comparing anterior tibial translation and resistance to internal tibial rotation between ALLR and LET, both in combination with ACL reconstruction (ACLR).

Study Design: Systematic review and meta-analysis

Methods: Systematic review of Medline, Embase, Scopus, and Google Scholar, including all biomechanical studies comparing ALLR with LET in conjunction with ACLR. between 2000 and 2024. Study quality was evaluated using the CASP checklist for qualitative research and the BOBQAT scale. The I^2 statistic was used to assess heterogeneity within and between studies. The mean effect size was calculated, and a prediction interval was established to determine whether 95% of comparable populations would fall within the true effect size range. Publication bias was analysed through funnel plots and Egger's test.

Results: CASP assessment determined that all seven studies were valuable. Based on the BOBQAT scoring system, five studies were classified as moderate quality, while two were rated as fair quality. Egger's regression intercept was -0.681 (p-value of 0.81), and the funnel plot displayed symmetry, indicating no publication bias.

Comparisons of anterior tibial translation (ATT) between ALLR and LET across all flexion angles revealed no significant differences. Comparisons of internal rotation resistance (IRR) demonstrated significant differences at all flexion angles, favouring LET. When compared to the ACL-intact state, ALLR effectively restored knee stability for both ATT and IRR, closely to its native state. In contrast, LET also restored knee stability for ATT and IRR but resulted in significant over-constraint of IRR at 30° and 60° of knee flexion.

Conclusion: This meta-analysis demonstrated that lateral extra-articular tenodesis provided superior resistance to internal rotation but was also associated with a degree of over-constraint. No significant biomechanical differences in anterior tibial translation were observed between LET and anterolateral ligament reconstruction when combined with anterior cruciate ligament reconstruction. Anterolateral ligament reconstruction effectively restored both ATT and internal rotation resistance to near-native knee levels.

Clinical Relevance: When combined with ACLR, both ALLR and LET demonstrate comparable improvements in anterior tibial translation and internal rotation resistance. However, LET is generally recommended when the primary surgical goal is to maximize internal rotational stability.

Key Terms: ALL; anterolateral ligament; anterolateral ligament complex; ALL biomechanics; ALL reconstruction; Lateral Tenodesis; Lemaire tenodesis

What is known about the subject

LET and ALLR are both surgical techniques utilized to address anterolateral knee instability, particularly in conjunction with ACL reconstruction. LET is known to enhance stability, particularly in the rotational plane, by providing additional support

to the knee. However, potential drawbacks include the risk of irritation or over-tightening of the graft, which could restrict knee motion. Furthermore, LET does not directly address the structural deficiency of the anterolateral ligament (ALL) itself. In contrast, ALLR involves the reconstruction of the ALL using a graft—often taken from the hamstring or other autografts—and is placed in a way that closely mimics the original anatomy and function of the ligament. By directly restoring the ALL, ALLR potentially offers stability specific to the anterolateral aspect of the knee, with the goal of reinstating normal anatomic biomechanics and improving overall knee function. However, the procedure requires precise graft placement, and there is a risk of graft failure, particularly if the ligament is not positioned correctly.

What this study adds to existing knowledge

Only a limited number of biomechanical studies with small sample sizes have directly compared lateral extra-articular tenodesis (LET) and anterolateral ligament reconstruction (ALLR) at baseline, and these studies have reported conflicting results. Using meta-analysis tools, this study found no significant biomechanical differences in anterior tibial translation (ATT) between lateral extra-articular tenodesis (LET) and anterolateral ligament reconstruction (ALLR) when both were combined with anterior cruciate ligament reconstruction (ACLR). While ALLR effectively restored both ATT and internal rotation resistance (IRR) to near-native knee levels, LET demonstrated superior internal rotation resistance. However, LET was associated with some degree of over-constraint, potentially limiting knee motion. This finding supports the notion that LET introduces some over-constraint to internal rotation resistance, and the clinical relevance of this effect warrants further investigation.

Introduction

Despite advancements in surgical techniques, modern implant design, and fixation methods, anterior cruciate ligament (ACL) reconstruction continues to exhibit a failure rate of up to 20%. [24] While new trauma, technical failures, and biological factors are potential contributors to the high failure rate, persistent rotatory knee instability and unaddressed injuries to extra-articular structures have been identified as significant factors implicated in these outcomes. [26] As a result, ACL reconstruction (ACLR) alone may be insufficient to fully restore tibial rotational stability during high-demand activities. [35] The anterolateral ligament complex (ALLC) has been recently rediscovered [4,45] and demonstrated to play a significant role in maintaining rotational knee stability. In contrast, other studies have suggested that the anterolateral ligament (ALL) may not be the primary contributor to persistent rotational instability. Instead, the iliotibial band and Kaplan fibers have been identified as the principal restraints to internal tibial rotation. [1,11,22,44]

Clinical studies have demonstrated that combined ACL and ALLC reconstructions result in significantly improved long-term ACL graft survivorship, reduced reoperation rates, and enhanced rotational knee stability compared to ACLR alone. [32,40,42]
However, there are concerns that alterations in knee biomechanics, particularly due to over constraint and restricted internal rotation, may lead to increased contact pressures in the lateral compartment, potentially accelerating the development of early lateral compartment osteoarthritis. [8,16,19]

In general, anatomic reconstruction of the ALL can be performed using autograft or allograft tendons, or by utilizing a harvested strip of fascia lata. [3,41] Lateral extra-articular tenodesis (LET) has also gained popularity as an augmentation procedure to enhance stability of the anterior cruciate ligament (ACL) and address persistent rotatory knee instability. [27] In this technique, a strip of the iliotibial band, with its origin still attached to Gerdy's tubercle, is passed deep to the lateral collateral ligament and secured to the proximal lateral femoral epicondyle. [20] Both techniques

appear to yield similar clinical outcomes and contribute to a reduction in ACL reconstruction failure rates. [40] Biomechanical studies have shown little to no significant differences between the two procedures, with only subtle variations observed. [9,12,16,19,21,39,42,46]

Despite growing interest in the biomechanical differences between LET and ALLR the current body of evidence remains fragmented. While individual studies support the use of various surgical techniques, they are often limited by small sample sizes and considerable methodological heterogeneity—including variations in loading protocols, knee flexion angles, graft types, and fixation techniques—which increases the risk of bias and limits comparability. These methodological inconsistencies and reporting gaps highlight the need for a meta-analysis to synthesize existing biomechanical data. The purpose of this study was to conduct a systematic review and meta-analysis of basic science laboratory cadaver studies comparing anterior tibial translation and resistance to internal tibial rotation between anterolateral ligament reconstruction (ALLR) and lateral extra-articular tenodesis (LET), both in combination with ACL reconstruction. It was hypothesized that both surgical techniques would yield similar outcomes, but favours LET in enhancing internal rotation stability.

Methods

This study followed the guidelines outlined by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [31] and adhered to the updated procedures specified in the Cochrane Handbook. [6]

Eligibility criteria

The published literature from 2000 to 2024 was reviewed to identify biomechanical laboratory-based cadaver studies comparing ALLR to LET. Clinical studies, conference proceedings, abstracts, expert opinions (level V), systematic reviews, meta-analyses, editorials, case reports, animal studies, and review articles were excluded. However, relevant references from these sources

were reviewed and included if they met the inclusion criteria. While excluding grey literature may introduce publication bias, this approach reduces selection bias and ensures that only peer-reviewed studies meeting established publication standards were considered.

Information Sources and Literature Search

A systematic literature review was conducted to identify all relevant publications by screening the following databases: PubMed, Embase, Scopus, and Google Scholar. These databases were screened using the following terms and Boolean operators: “anterolateral ligament” AND/OR “anterolateral ligament complex” AND/OR “ALL” AND/OR “biomechanics”; AND/OR “biomechanical” AND/OR “cadaver study” AND/OR “ALL reconstruction”, AND/OR “biomechanical properties”, AND/OR “ALL tenodesis”, AND/OR “augmentation”, AND/OR “lateral tenodesis”, AND/OR “modified Lemaire”, AND/OR “lateral tenodesis”. For the Medline search, the MeSH term "ligament, knee" was used with the qualifiers "biomechanics," "biomechanics & kinematics." One reviewer independently screened the titles and abstracts, and after this, full-text articles were reviewed by two independent reviewers. Disagreements were resolved through consensus, and if consensus could not be reached, the senior author made the final decision regarding the inclusion or exclusion of the article.

Data extraction and quality assessment

Data were systematically extracted from each article using an electronic form, capturing details such as author, country, sample size, and biomechanical variables. When measurements were provided at different knee flexion angles, data from 0°, 30°, 60°, and 90° were selected for analysis. Kittl et al. has demonstrated that resistance to internal rotation and combined internal rotation/valgus is greatest at these flexion angles in both ACL-intact and ACL-deficient knees. [22]

The quality of the included studies was evaluated using the BOBQAT scoring system, a recently developed tool that assesses study quality across 15 variables. [14] This system employs a 100-point

scale, where scores of 90-100 indicate excellent quality, 80-89 represent good quality, 70-79 are considered moderate, 60-69 are fair, and scores below 60 reflect poor quality. [14]

Unfortunately, no established tool exists to assess the risk of bias in basic science studies, so an explicit risk of bias evaluation was not possible. However, the Critical Appraisal Skills Programme (CASP) checklist for qualitative research was used as an additional appraisal tool. [5,25] This checklist evaluates three main aspects: the validity of the study's results, the nature of the results, and their potential local impact. It includes 10 questions that can be answered with "yes," "no," or "can't tell." While the checklist is not intended for scoring, it helps guide researchers in systematically assessing potential issues in their own studies. For this systematic review, a study was considered of reasonable quality and low risk of bias if it received a "yes" answer to at least 6 of the 9 applicable questions, with the ethics item [7] answered "no." Item 6 of the CASP checklist, which addresses the researcher-participant relationship, was excluded from consideration as it was not relevant to this project. In summary, a study was deemed of reasonable quality and low risk of bias if it met a threshold of 78% in the CASP responses.

Statistical analysis

Heterogeneity within and between studies was evaluated using the I^2 statistic, funnel plot and the Q-test for heterogeneity. Publication bias was examined using funnel plots and Egger's test. Studies were pooled for analysis when three or more reported on the same biomechanical variables. If the heterogeneity among the included studies exceeded 25%, a random-effects model was employed; otherwise, a fixed-effects model was used. The standardized mean difference (SMD), standard error, variance, and 95% confidence intervals were used to analyse the pooled data. Anterolateral ligament reconstruction (ALLR) was compared to lateral extra-articular tenodesis (LET). Additionally, both ALLR and LET were compared to the ACL-intact state to assess whether native stability was restored or if either procedure resulted in ongoing instability or over-constraint. To evaluate whether the cumulative evidence in the meta-analysis was sufficient to draw reliable

conclusions, Trial Sequential Analysis (TSA) was conducted, including the calculation of the Required Information Size (RIS). This approach allows for the assessment of whether the available data provide adequate statistical power to detect a clinically meaningful effect, thereby minimizing the risk of type I and type II errors. Based on a presumed medium effect size (Cohen's d = 0.5), a control event rate of 20%, a type I error rate of 5%, and 80% statistical power, and accounting for moderate heterogeneity ($I^2 = 50\%$), the calculated Required Information Size (RIS) was approximately 63 specimens. Funnel and forest plots, and all statistical analyses, were performed using STATA SE (Version 13.0; StataCorp, College Station, Texas, USA) for Windows, and the comprehensive meta-analysis software package (CMA), version 4 (Biostat Inc, Englewood, NJ, USA).

Results

Study selection and characteristics

The initial literature search identified 735 studies for review. Of these, 214 were excluded due to duplication, and 198 were removed for other reasons (clinical studies, reviews, editorials, animal studies, computational studies or finite element analysis). After further screening, 268 records were excluded, leaving 55 studies for retrieval and examination. Nineteen studies were deemed eligible for inclusion. Twelve studies were excluded: 2 were case reports, 7 were clinical in-vivo studies, and 3 were technical notes. Ultimately, 7 studies were included in the final analysis. All included studies were published in English between 2016 and 2022, involving a total of 84 specimens (Figure 1). [9,12,19,21,39,42,64] The inclusion of 84 specimens in the meta-analysis exceeds the Required Information Size (RIS) threshold of 63 cases, as determined by Trial Sequential Analysis (TSA). This suggests that the cumulative evidence is sufficiently powered and supports the robustness and reliability of the meta-analytic findings. The characteristics of the studies are presented in Table 1.

PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only

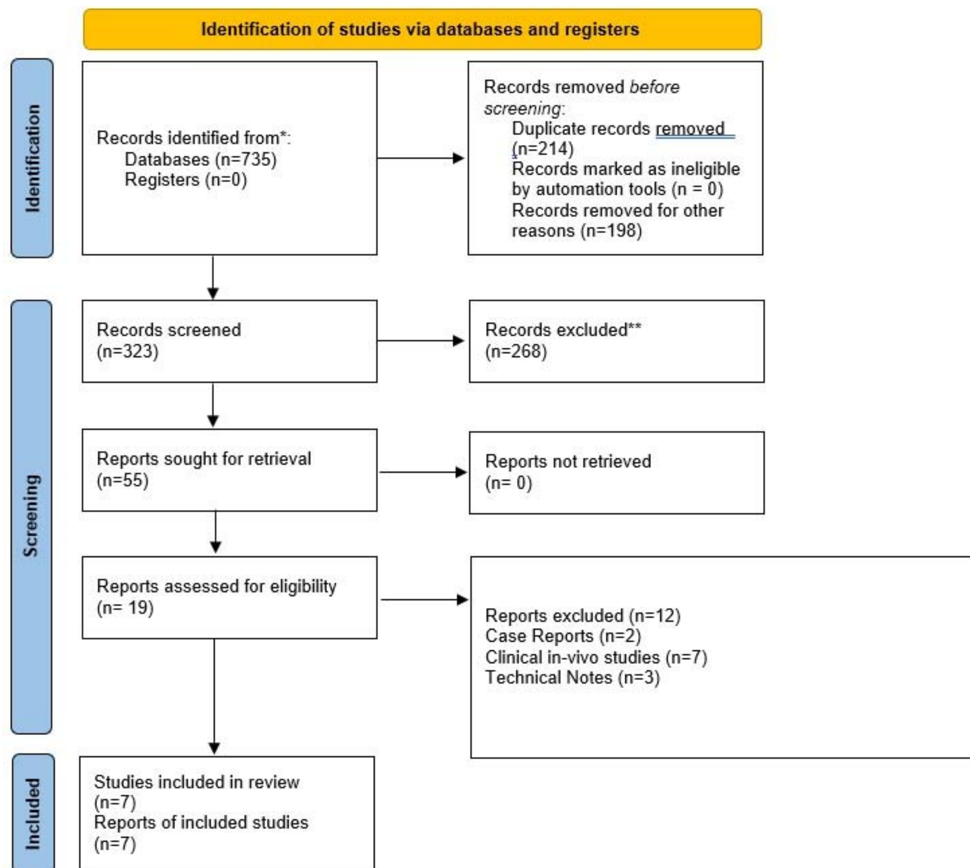


Figure 1.

Quality assessment and publication bias

The findings of the quality assessment are summarized in Table 2 and 3.

CASP

All seven studies were evaluated and deemed valuable. [9,12,19,21,39,42,46] Two studies achieved a perfect score of 100%. [8, 39] while the remaining five studies [12,19,21,42,46] scored 89%. The primary limitation preventing a 100% score was related to ethical considerations. Specifically, three studies did not provide an ethics approval number, [12,21,39] one study [42] failed to mention ethics approval entirely, and one study asserted that ethics approval was not required [Table 2]. [46]

BOBQAT

None of the included studies were classified as being of excellent or good quality. Five studies [9,12,19,39,46,] were assessed as having moderate quality, while two studies [21,42] were rated as having fair quality [Table 3]. The primary factors contributing to the limited quality of the studies were the absence of bone density assessments, the lack of cyclic loading evaluations, and the omission of sample size analyses.

Publication bias

Egger's regression intercept was -0.681 with a 2-tailed *p-value* of 0.81 and the funnel plot exhibits symmetry, suggesting that publication bias is unlikely. (Figure 2).

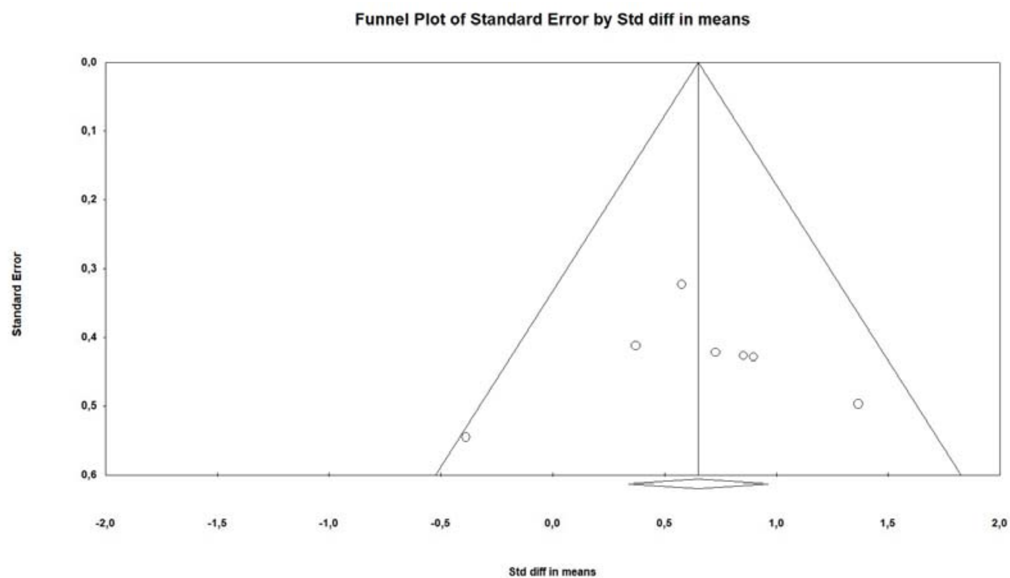


Figure 2. Publication bias

ALLR versus LET: Anterior Tibial Translation

Five studies compared ALLR versus LET at full extension. [9,19,21,39,46] The mean effect size was -0.100 with a 95% confidence interval of -0.975 to 0.774. The pooled analysis did not reveal significant between group differences (z=-0.225; p=0.882; I^2 79%; Q-statistic=18.611). (Figure 3). The prediction interval ranged from -3.235 to 3.035 suggesting that the true effect size in 95% of all populations falls in this interval.

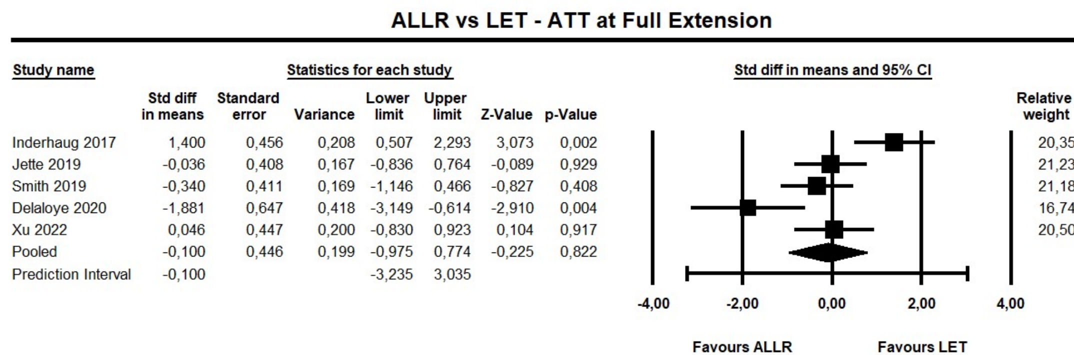
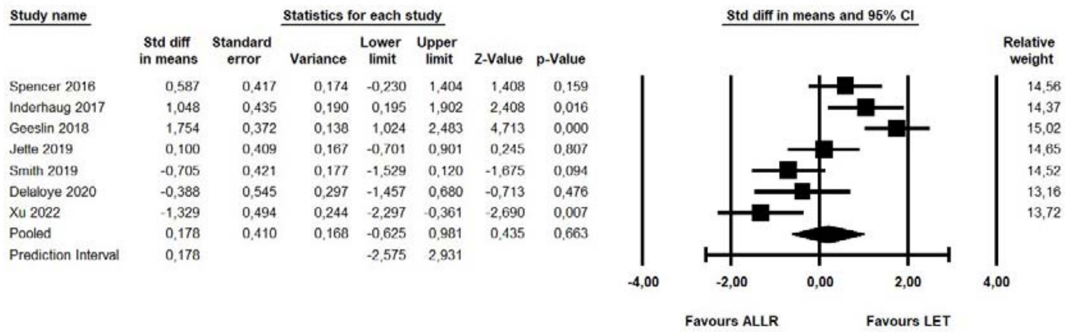


Figure 3. ALLR-LET Zero Degrees

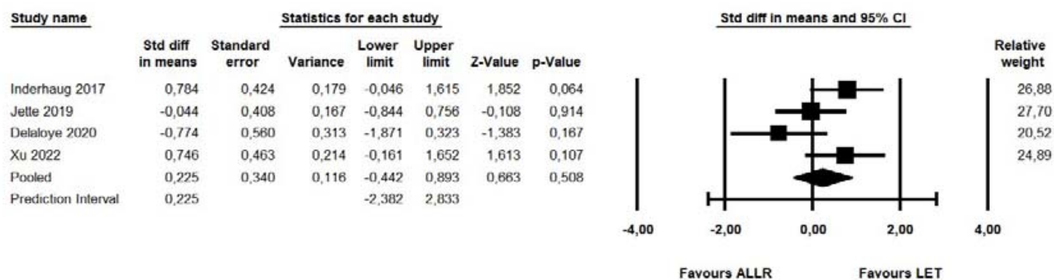
Seven studies [9,13,19,21,39,42,46] compared compared ALLR versus LET at 30 degrees of knee flexion. The mean effect size was 0.178 with a 95% confidence interval of -0.625 to 0.981. The pooled analysis did not reveal significant between group differences (z=0.435; p=0.663; I^2 84%; Q-statistic= 37.095). (Figure 4). The prediction interval ranged from -2.575 to 2.931 suggesting that the true effect size in 95% of all populations falls in this interval. Four studies [9,19,21,46] compared ALLR versus LET at 60 degrees of knee flexion. The mean effect size was 0.225 with a 95% confidence interval of -0.442 to 0.893. The pooled analysis did not reveal significant between group differences (z=0.663; p=0.508; I^2 55%; Q-statistic= 6.606). (Figure 5). The prediction interval ranged from -2.382 to 2.833 suggesting that the true effect size in 95% of all populations falls in this interval.



ALLR vs LET - ATT at 30 Deg Flexion

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Spencer 2016	0,587	0,417	0,174	-0,230	1,404	1,408	0,159	14,56
Inderhaug 2017	1,048	0,435	0,190	0,195	1,902	2,408	0,016	14,37
Geeslin 2018	1,754	0,372	0,138	1,024	2,483	4,713	0,000	15,02
Jette 2019	0,100	0,409	0,167	-0,701	0,901	0,245	0,807	14,65
Smith 2019	-0,705	0,421	0,177	-1,529	0,120	-1,675	0,094	14,52
Delaloye 2020	-0,388	0,545	0,297	-1,457	0,680	-0,713	0,476	13,16
Xu 2022	-1,329	0,494	0,244	-2,297	-0,361	-2,690	0,007	13,72
Pooled	0,178	0,410	0,168	-0,625	0,981	0,435	0,663	
Prediction Interval	0,178			-2,575	2,931			

Figure 4. ALLR-LET ATT Flexion 30

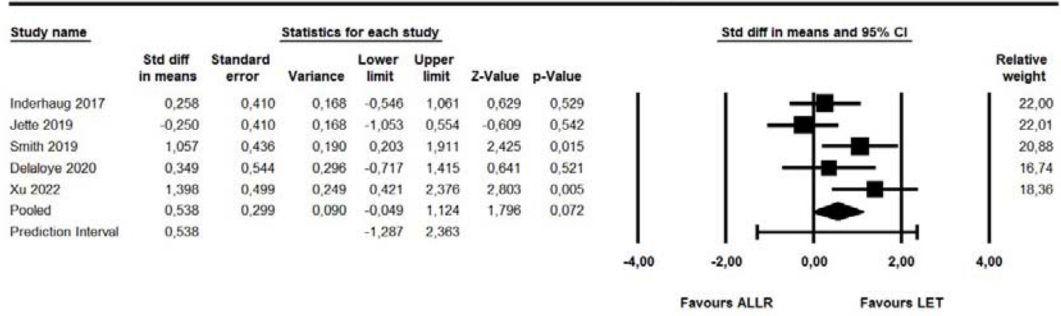


ALLR vs LET - ATT at 60 Deg Flexion

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Inderhaug 2017	0,784	0,424	0,179	-0,046	1,615	1,852	0,064	26,88
Jette 2019	-0,044	0,408	0,167	-0,844	0,756	-0,108	0,914	27,70
Delaloye 2020	-0,774	0,560	0,313	-1,871	0,323	-1,383	0,167	20,52
Xu 2022	0,746	0,463	0,214	-0,161	1,652	1,613	0,107	24,89
Pooled	0,225	0,340	0,116	-0,442	0,893	0,663	0,508	
Prediction Interval	0,225			-2,382	2,833			

Figure 5. ALLR-LET ATT Flexion 60

Five studies [9,19,21,39,46] compared ALLR versus LET at 90 degrees of knee flexion. The mean effect size was 0.538 with a 95% confidence interval of -0.049 to 1.124. The pooled analysis did not reveal significant between group differences (z=1.796; p=0.072; I^2 54%; Q-statistic=8.647). (Figure 6). The prediction interval ranged from -1.287 to 2.363 suggesting that the true effect size in 95% of all populations falls in this interval.



ALLR vs LET - ATT at 90 Deg Flexion

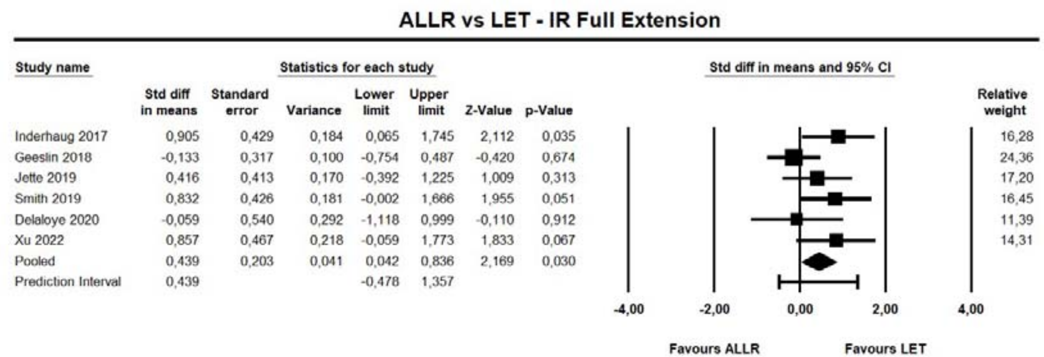
Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Inderhaug 2017	0,258	0,410	0,168	-0,546	1,061	0,629	0,529	22,00
Jette 2019	-0,250	0,410	0,168	-1,053	0,554	-0,609	0,542	22,01
Smith 2019	1,057	0,436	0,190	0,203	1,911	2,425	0,015	20,88
Delaloye 2020	0,349	0,544	0,296	-0,717	1,415	0,641	0,521	16,74
Xu 2022	1,398	0,499	0,249	0,421	2,376	2,803	0,005	18,36
Pooled	0,538	0,299	0,090	-0,049	1,124	1,796	0,072	
Prediction Interval	0,538			-1,287	2,363			

Figure 6. ALLR-LET ATT Flexion 90

It must be noted that all of the above results have been conducted with less than 10 studies in each comparison, and as a general rule, estimates of heterogeneity based on fewer than 10 studies are less likely to be reliable.

ALLR versus LET: Internal Tibial Rotation Resistance

Six studies [9,19,21,39,42,46] compared ALLR versus LET at full extension. The mean effect size was 0.439 with a 95% confidence interval of 0.042 to 0.836 The pooled analysis revealed significant between group differences in favour of LET (z=2.169; p=0.030; I^2 28%; Q-statistic=6.929). (Figure 7). The prediction interval ranged from -0.478 to 1.357 suggesting that the true effect size in 95% of all populations falls in this interval.

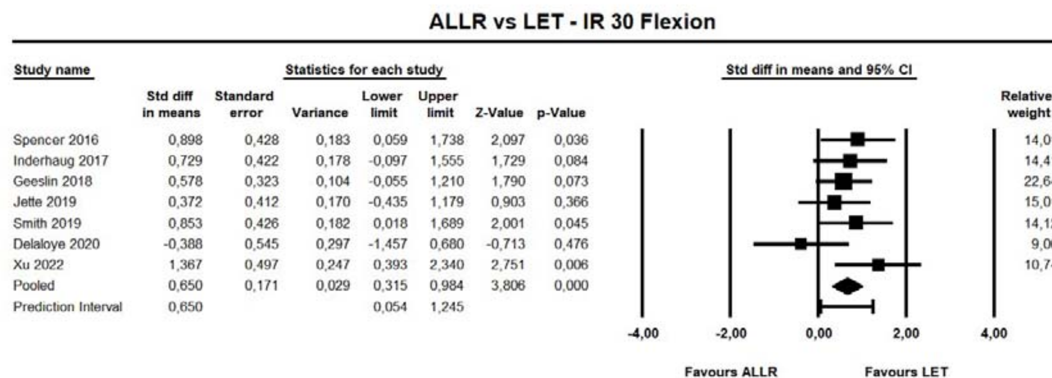


ALLR vs LET - IR Full Extension

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Inderhaug 2017	0,905	0,429	0,184	0,065	1,745	2,112	0,035	16,28
Geeslin 2018	-0,133	0,317	0,100	-0,754	0,487	-0,420	0,674	24,36
Jette 2019	0,416	0,413	0,170	-0,392	1,225	1,009	0,313	17,20
Smith 2019	0,832	0,426	0,181	-0,002	1,666	1,955	0,051	16,45
Delaloye 2020	-0,059	0,540	0,292	-1,118	0,999	-0,110	0,912	11,39
Xu 2022	0,857	0,467	0,218	-0,059	1,773	1,833	0,067	14,31
Pooled	0,439	0,203	0,041	0,042	0,836	2,169	0,030	
Prediction Interval	0,439			-0,478	1,357			

Figure 7. ALLR-LET IR Zero Degrees

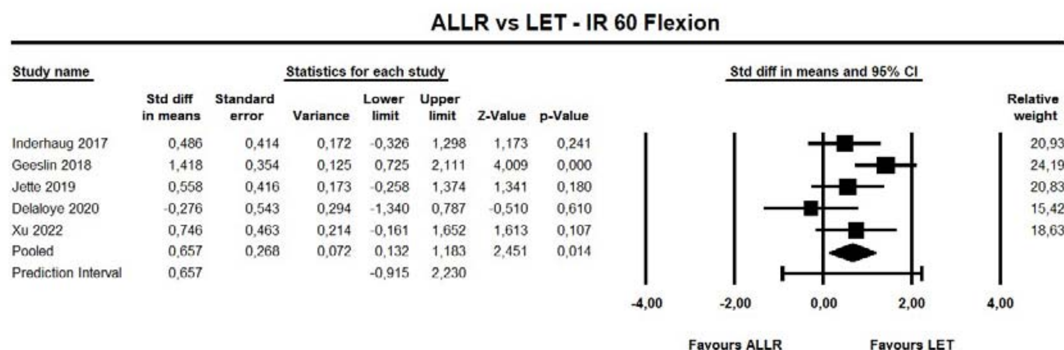
Seven studies [9,12,19,21,39,42,46] compared ALLR versus LET at 30 degrees of knee flexion. The mean effect size was 0.650 with a 95% confidence interval of 0.315 to 0.984. The pooled analysis revealed significant between group differences in favour of LET (z=3.806; p=0.000; I^2 12%; Q-statistic=6.816). (Figure 8). The prediction interval ranged from 0.054 to 1.245 suggesting that the true effect size in 95% of all populations falls in this interval.



Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Spencer 2016	0,898	0,428	0,183	0,059	1,738	2,097	0,036	14,01
Inderhaug 2017	0,729	0,422	0,178	-0,097	1,555	1,729	0,084	14,41
Geeslin 2018	0,578	0,323	0,104	-0,055	1,210	1,790	0,073	22,64
Jette 2019	0,372	0,412	0,170	-0,435	1,179	0,903	0,366	15,01
Smith 2019	0,853	0,426	0,182	0,018	1,689	2,001	0,045	14,12
Delaloye 2020	-0,388	0,545	0,297	-1,457	0,680	-0,713	0,476	9,06
Xu 2022	1,367	0,497	0,247	0,393	2,340	2,751	0,006	10,74
Pooled	0,650	0,171	0,029	0,315	0,984	3,806	0,000	
Prediction Interval	0,650			0,054	1,245			

Figure 8. ALLR-LET IR Flexion 30

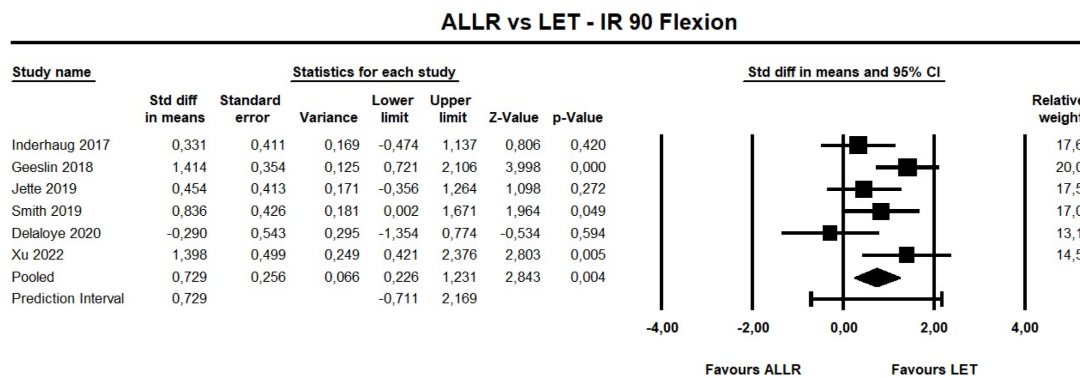
Five studies [9,12,19,21,46] compared ALLR versus LET at 60 degrees of knee flexion. The mean effect size was 0.657 with a 95% confidence interval of 0.132 to 1.183 The pooled analysis revealed significant between group differences in favour of LET (z=2.451; p=0.014; I^2 48%; Q-statistic=7.741). (Figure 9). The prediction interval ranged from -0.915 to 2.230 suggesting that the true effect size in 95% of all populations falls in this interval.



Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Inderhaug 2017	0,486	0,414	0,172	-0,326	1,298	1,173	0,241	20,93
Geeslin 2018	1,418	0,354	0,125	0,725	2,111	4,009	0,000	24,19
Jette 2019	0,558	0,416	0,173	-0,258	1,374	1,341	0,180	20,83
Delaloye 2020	-0,276	0,543	0,294	-1,340	0,787	-0,510	0,610	15,42
Xu 2022	0,746	0,463	0,214	-0,161	1,652	1,613	0,107	18,63
Pooled	0,657	0,268	0,072	0,132	1,183	2,451	0,014	
Prediction Interval	0,657			-0,915	2,230			

Figure 9. ALLR-LET IR Flexion 60

Six studies [9,12,19,21,39,46] compared ALLR versus LET at 90 degrees of knee flexion. The mean effect size was 0.729 with a 95% confidence interval of 0.226 to 1.231. The pooled analysis revealed significant between group differences in favour of LET (z=2.843; p=0.004; I^2 52%; Q-statistic=10.458). (Figure 10). The prediction interval ranged from -0.711 to 2.169 suggesting that the true effect size in 95% of all populations falls in this interval.



Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Inderhaug 2017	0,331	0,411	0,169	-0,474	1,137	0,806	0,420	17,64
Geeslin 2018	1,414	0,354	0,125	0,721	2,106	3,998	0,000	20,01
Jette 2019	0,454	0,413	0,171	-0,356	1,264	1,098	0,272	17,55
Smith 2019	0,836	0,426	0,181	0,002	1,671	1,964	0,049	17,08
Delaloye 2020	-0,290	0,543	0,295	-1,354	0,774	-0,534	0,594	13,19
Xu 2022	1,398	0,499	0,249	0,421	2,376	2,803	0,005	14,53
Pooled	0,729	0,256	0,066	0,226	1,231	2,843	0,004	
Prediction Interval	0,729			-0,711	2,169			

Figure10. ALLR-LET IR Flexion 90

It must be noted that all of the above results have been conducted with less than 10 studies in each comparison, and as a general rule, estimates of heterogeneity based on fewer than 10 studies are less likely to be reliable.

ACL Intact versus ALLR

Anterior tibial translation

Four studies [19,21,39,46] compared ACLI versus ALLR at full extension. The mean effect size was 0.731 with a 95% confidence interval of -0.594 to 2.056 The pooled analysis did not reveal significant between group differences (z=1.081; p=0.280; I^2 88%; Q-statistic=25.220). (Figure 11). The prediction interval ranged from -5.404 to 6.866 suggesting that the true effect size in 95% of all populations falls in this interval.

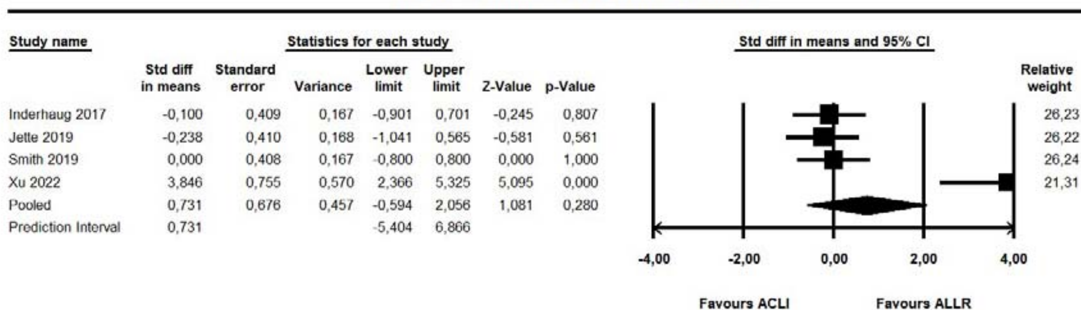


Figure 11. ACLI-ALLR ATT Zero

Four studies [19,21,39,,46] compared ACLI versus ALLR at 30 degrees of knee flexion. The mean effect size was 0.055 with a 95% confidence interval of -1.597 to 1.707 The pooled analysis did not reveal significant between group differences (z=0.065; p=0.948; I^2 92%; Q-statistic=36.547). (Figure 12). The prediction interval ranged from -7.750 to 7.860 suggesting that the true effect size in 95% of all populations falls in this interval.

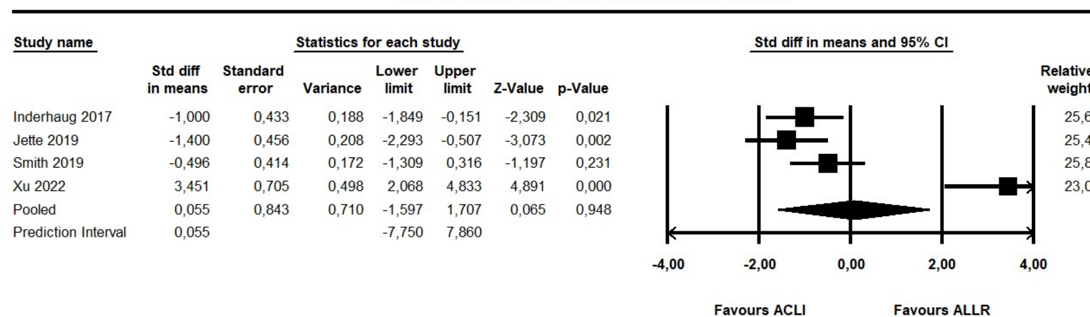
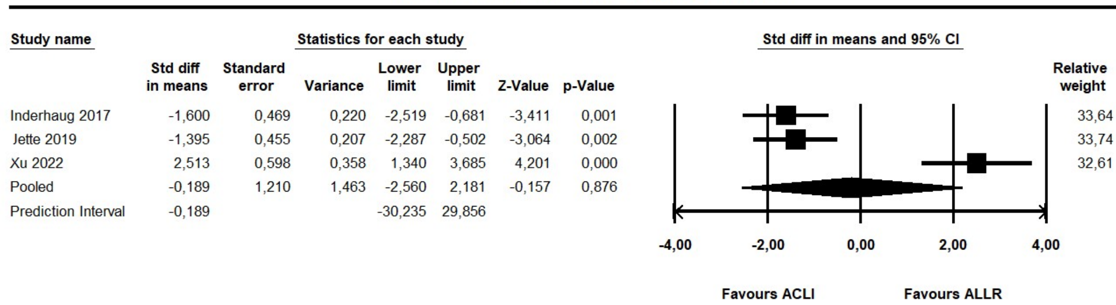


Figure 12. ACLI-ALLR ATT 30

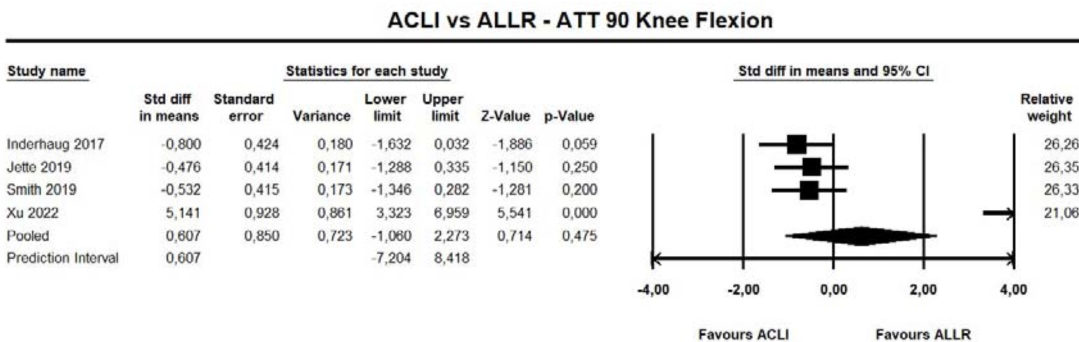
Three studies [19,21,39] compared ACLI versus ALLR at 60 degrees of knee flexion. The mean effect size was -0.189 with a 95% confidence interval of -2.560 to 2.181 The pooled analysis did not reveal significant between group differences (z=-0.157; p=0.876; I^2 94%; Q-statistic=34.662). (Figure 13). The prediction interval ranged from -30.235 to 29.856 suggesting that the true effect size in 95% of all populations falls in this interval.



Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Inderhaug 2017	-1,600	0,469	0,220	-2,519	-0,681	-3,411	0,001	33,64
Jette 2019	-1,395	0,455	0,207	-2,287	-0,502	-3,064	0,002	33,74
Xu 2022	2,513	0,598	0,358	1,340	3,685	4,201	0,000	32,61
Pooled	-0,189	1,210	1,463	-2,560	2,181	-0,157	0,876	
Prediction Interval	-0,189			-30,235	29,856			

Figure 13. ACLI-ALLR ATT 60

Four studies [19,21,39,46] compared ACLI versus ALLR at 90 degrees of knee flexion. The mean effect size was 0.607 with a 95% confidence interval of -1.060 to 2.273 The pooled analysis did not reveal significant between group differences (z=0.714; p=0.475; I^2 92%; Q-statistic=36.202). (Figure 14). The prediction interval ranged from -7.204 to 8.418 suggesting that the true effect size in 95% of all populations falls in this interval.



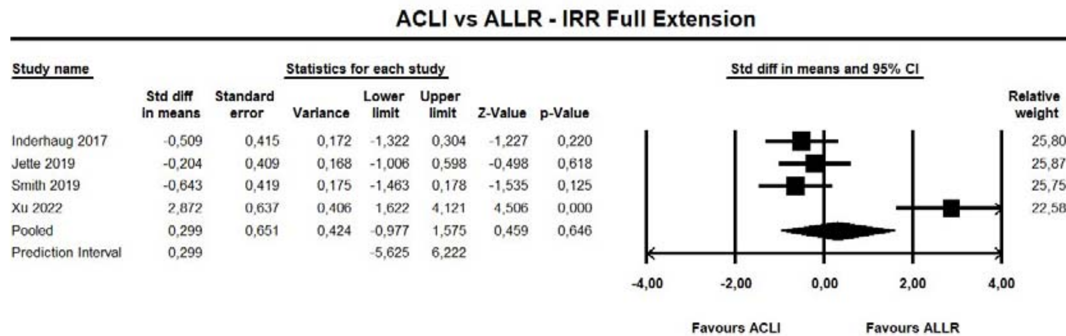
Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Inderhaug 2017	-0,800	0,424	0,180	-1,632	0,032	-1,886	0,059	26,26
Jette 2019	-0,476	0,414	0,171	-1,288	0,335	-1,150	0,250	26,35
Smith 2019	-0,532	0,415	0,173	-1,346	0,282	-1,281	0,200	26,33
Xu 2022	5,141	0,928	0,861	3,323	6,959	5,541	0,000	21,06
Pooled	0,607	0,850	0,723	-1,060	2,273	0,714	0,475	
Prediction Interval	0,607			-7,204	8,418			

Figure 14. ACLI-ALLR ATT 90

Internal Tibial Rotation Resistance

Four studies [19,21,39,46] compared ACLI versus ALLR at full extension. The mean effect size was 0.299 with a 95% confidence interval of -0.977 to 1.575 The pooled analysis did not reveal significant between group differences (z=0.459; p=0.646; I^2 88%; Q-statistic=24.384). (Figure 15).

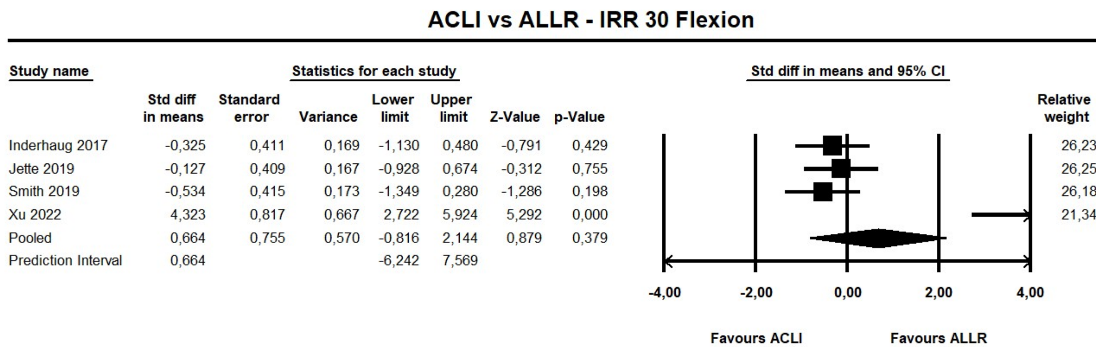
The prediction interval ranged from -5.625 to 6.222 suggesting that the true effect size in 95% of all populations falls in this interval.



Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Inderhaug 2017	-0,509	0,415	0,172	-1,322	0,304	-1,227	0,220	25,80
Jette 2019	-0,204	0,409	0,168	-1,006	0,598	-0,498	0,618	25,87
Smith 2019	-0,643	0,419	0,175	-1,463	0,178	-1,535	0,125	25,75
Xu 2022	2,872	0,637	0,406	1,622	4,121	4,506	0,000	22,58
Pooled	0,299	0,651	0,424	-0,977	1,575	0,459	0,646	
Prediction Interval	0,299			-5,625	6,222			

Figure 15. ACLI-ALLR IRR Zero

Four studies [19,21,39,46] compared ACLI versus ALLR at 30 degrees of knee flexion. The mean effect size was 0.664 with a 95% confidence interval of -0.816 to 2.144 The pooled analysis did not reveal significant between group differences (z=0.879; p=0.379; I^2 90%; Q-statistic=30.361). (Figure 16). The prediction interval ranged from -6.242 to 7.569 suggesting that the true effect size in 95% of all populations falls in this interval.

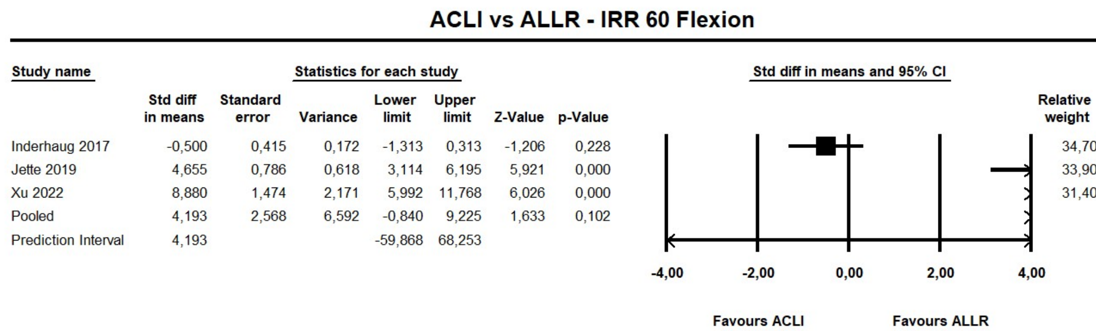


Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Inderhaug 2017	-0,325	0,411	0,169	-1,130	0,480	-0,791	0,429	26,23
Jette 2019	-0,127	0,409	0,167	-0,928	0,674	-0,312	0,755	26,25
Smith 2019	-0,534	0,415	0,173	-1,349	0,280	-1,286	0,198	26,18
Xu 2022	4,323	0,817	0,667	2,722	5,924	5,292	0,000	21,34
Pooled	0,664	0,755	0,570	-0,816	2,144	0,879	0,379	
Prediction Interval	0,664			-6,242	7,569			

Figure 16. ACLI-ALLR IRR 30

Three studies [19,21,46] compared ACLI versus ALLR at 60 degrees of knee flexion. The mean effect size was 4.193 with a 95% confidence interval of -0.840 to 9.225 The pooled analysis did not reveal significant between group differences (z=1.633; p=0.102; I^2 97%; Q-statistic=63.215).

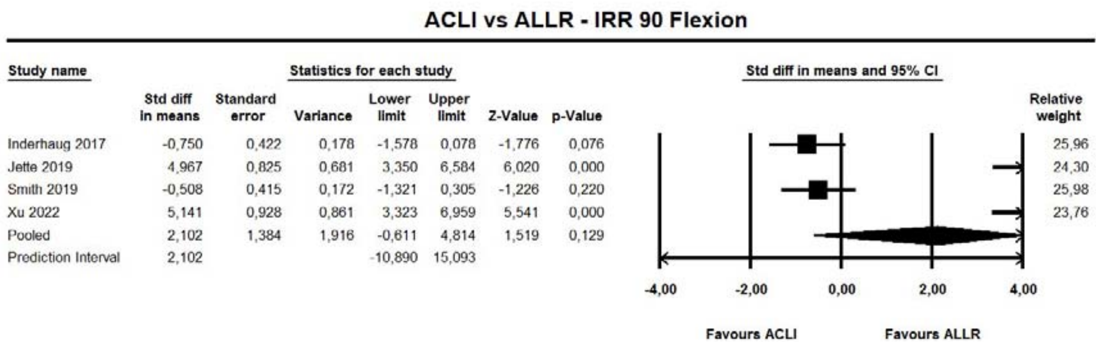
(Figure 17). The prediction interval ranged from -59.868 to 68.253 suggesting that the true effect size in 95% of all populations falls in this interval.


ACLI vs ALLR - IRR 60 Flexion

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Inderhaug 2017	-0,500	0,415	0,172	-1,313	0,313	-1,206	0,228	34,70
Jette 2019	4,655	0,786	0,618	3,114	6,195	5,921	0,000	33,90
Xu 2022	8,880	1,474	2,171	5,992	11,768	6,026	0,000	31,40
Pooled	4,193	2,568	6,592	-0,840	9,225	1,633	0,102	
Prediction Interval	4,193			-59,868	68,253			

Figure 17. ACLI-ALLR IRR 60

Four studies [19,21,39,46] compared ACLI versus ALLR at 90 degrees of knee flexion. The mean effect size was 2.102 with a 95% confidence interval of -0.611 to 4.814 The pooled analysis did not reveal significant between group differences (z=1.519; p=0.129; I^2 96%; Q-statistic=68.949). (Figure 18). The prediction interval ranged from -10.890 to 15.093 suggesting that the true effect size in 95% of all populations falls in this interval.


ACLI vs ALLR - IRR 90 Flexion

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Inderhaug 2017	-0,750	0,422	0,178	-1,578	0,078	-1,776	0,076	25,96
Jette 2019	4,967	0,825	0,681	3,350	6,584	6,020	0,000	24,30
Smith 2019	-0,508	0,415	0,172	-1,321	0,305	-1,226	0,220	25,98
Xu 2022	5,141	0,928	0,861	3,323	6,959	5,541	0,000	23,76
Pooled	2,102	1,384	1,916	-0,611	4,814	1,519	0,129	
Prediction Interval	2,102			-10,890	15,093			

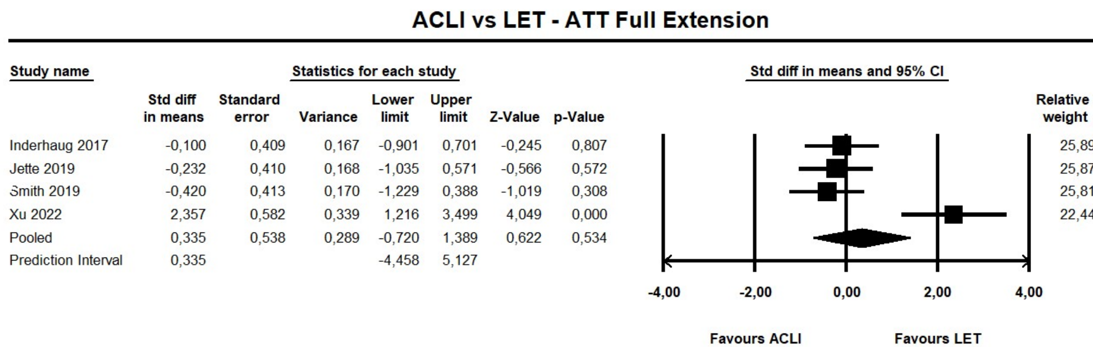
Figure 18. ACLI-ALLR IRR 90

It must be noted that all of the above results have been conducted with less than 10 studies in each comparison, and as a general rule, estimates of heterogeneity based on fewer than 10 studies are less likely to be reliable.

ACL Intact versus LET

Anterior tibial translation

Four studies [19,21,39,46] compared compared ACLI versus LET at full extension. The mean effect size was 0.335 with a 95% confidence interval of -0.720 to 1.389 The pooled analysis did not reveal significant between group differences (z=0.622; p=0.534; I^2 83%; Q-statistic=17.512). (Figure 19). The prediction interval ranged from -4.458 to 5.127 suggesting that the true effect size in 95% of all populations falls in this interval.



ACLI vs LET - ATT Full Extension

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Inderhaug 2017	-0,100	0,409	0,167	-0,901	0,701	-0,245	0,807	25,89
Jette 2019	-0,232	0,410	0,168	-1,035	0,571	-0,566	0,572	25,87
Smith 2019	-0,420	0,413	0,170	-1,229	0,388	-1,019	0,308	25,81
Xu 2022	2,357	0,582	0,339	1,216	3,499	4,049	0,000	22,44
Pooled	0,335	0,538	0,289	-0,720	1,389	0,622	0,534	
Prediction Interval	0,335			-4,458	5,127			

Figure 19. ACLI-LET ATT Zero

Four studies [19,21,39,46] compared ACLI versus LET at 30 degrees of knee flexion. The mean effect size was 0.418 with a 95% confidence interval of -1.342 to 2.179 The pooled analysis did not reveal significant between group differences (z=0.466; p=0.641; I^2 93%; Q-statistic=40.551). (Figure 20). The prediction interval ranged from -7.914 to 8.750 suggesting that the true effect size in 95% of all populations falls in this interval.

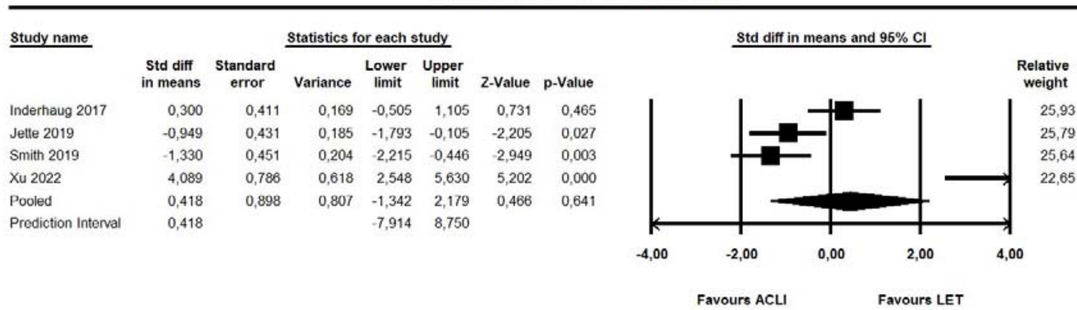


Figure 20. ACLI-LET ATT 30

Three studies [19,21,46] compared ACLI versus LET at 60 degrees of knee flexion. The mean effect size was 0.571 with a 95% confidence interval of -1.564 to 2.706. The pooled analysis did not reveal significant between group differences (z=0.524; p=0.600; I^2 93%; Q-statistic=29.395). (Figure 21). The prediction interval ranged from -26.329 to 27.471 suggesting that the true effect size in 95% of all populations falls in this interval.

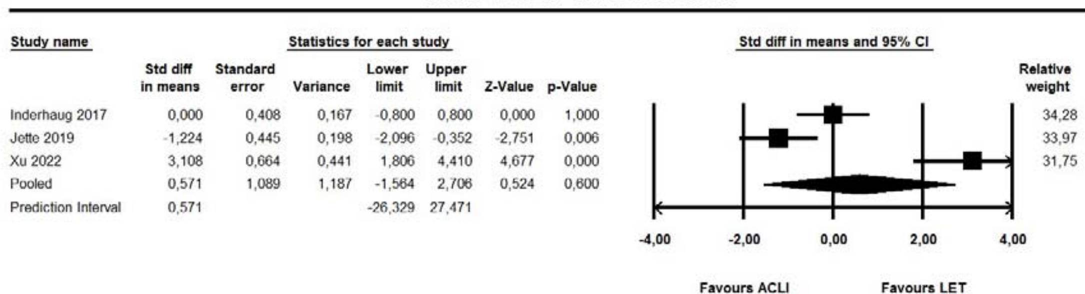


Figure 21. ACLI-LET ATT 60

Four studies [19,21,39,46] compared ACLI versus LET at 90 degrees of knee flexion. The mean effect size was 0.580 with a 95% confidence interval of -1.372 to 2.531 The pooled analysis did not reveal significant between group differences (z=0.582; p=0.561; I^2 93%; Q-statistic=44.735). (Figure 22). The prediction interval ranged from -8.609 to 9.768 suggesting that the true effect size in 95% of all populations falls in this interval.

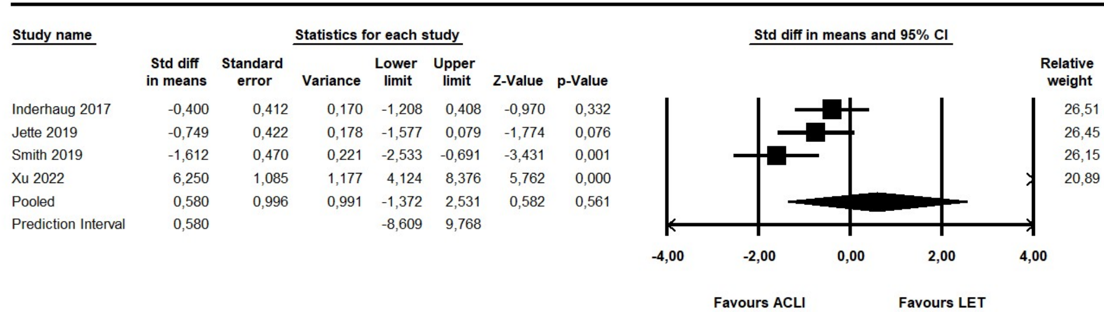


Figure 22. ACLI-LET ATT 90

Internal Tibial Rotation Resistance

Four studies [19,21,39,46] compared ACLI versus LET at full extension. The mean effect size was 1.177 with a 95% confidence interval of -0.139 to 2.493 The pooled analysis did not reveal significant between group differences (z=1.752; p=0.080; I^2 87%; Q-statistic=23.609). (Figure 23). The prediction interval ranged from -4.870 to 7.224 suggesting that the true effect size in 95% of all populations falls in this interval.

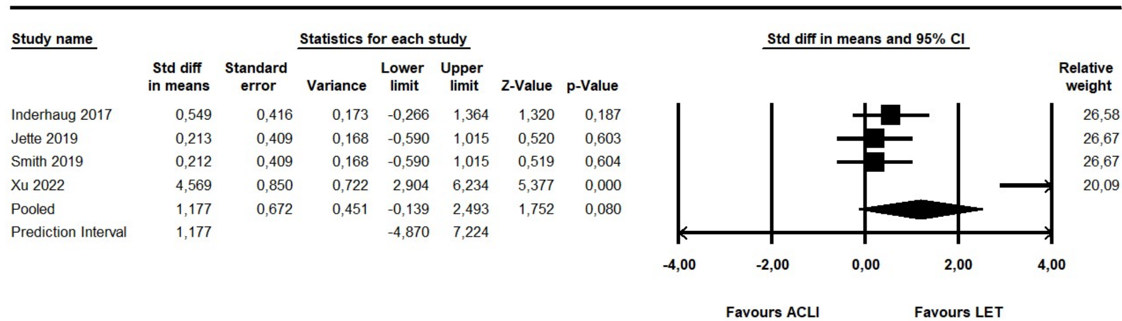
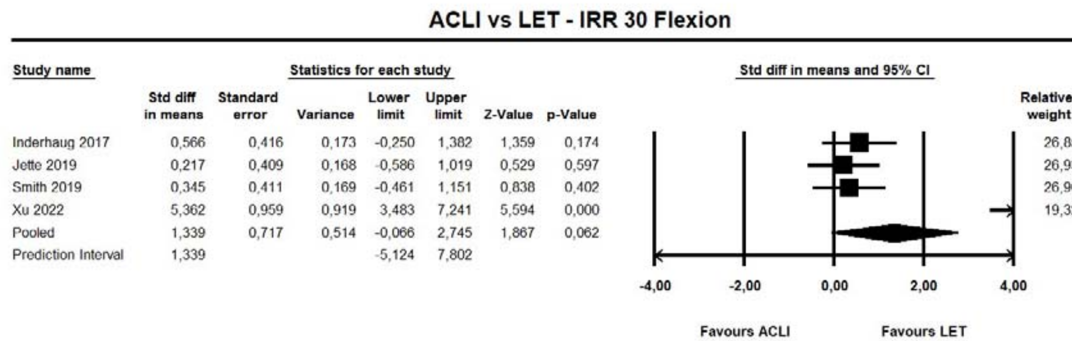


Figure 23. ACLI-LET IRR Zero

Four studies [19,21,39,46] compared ACLI versus LET at 30 degrees of knee flexion. The mean effect size was 1.339 with a 95% confidence interval of -0.066 to 2.745 The pooled analysis did not reveal significant between group differences (z=.867; p=0.062; I^2 88%; Q-statistic=25.876). (Figure

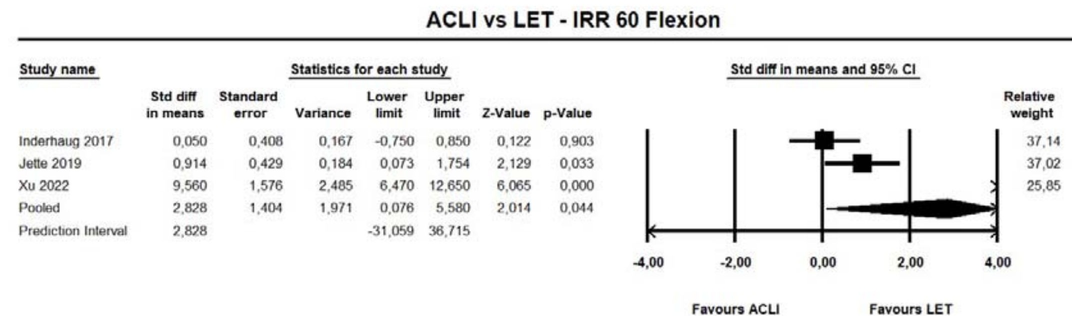
24). The prediction interval ranged from -5.124 to 7.802 suggesting that the true effect size in 95% of all populations falls in this interval.



Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Inderhaug 2017	0,566	0,416	0,173	-0,250	1,382	1,359	0,174	26,85
Jette 2019	0,217	0,409	0,168	-0,586	1,019	0,529	0,597	26,93
Smith 2019	0,345	0,411	0,169	-0,461	1,151	0,838	0,402	26,90
Xu 2022	5,362	0,959	0,919	3,483	7,241	5,594	0,000	19,32
Pooled	1,339	0,717	0,514	-0,066	2,745	1,867	0,062	
Prediction Interval	1,339			-5,124	7,802			

Figure 24. ACLI-LET IRR 30

Three studies [19,21,46] compared ACLI versus LET at 60 degrees of knee flexion. The mean effect size was 2.828 with a 95% confidence interval of 0.076 to 5.580 The pooled analysis did not reveal significant between group differences (z=2.014; p=0.044; I^2 94%; Q-statistic=34.316). (Figure 25). The prediction interval ranged from -31.059 to 36.715 suggesting that the true effect size in 95% of all populations falls in this interval.

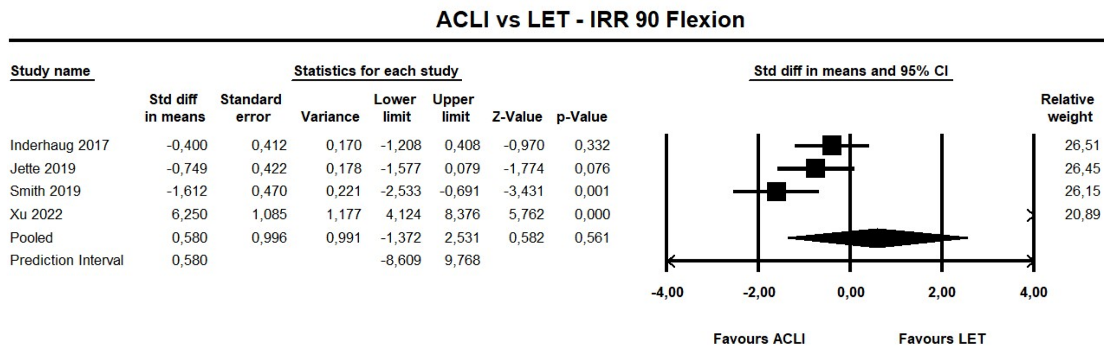


Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Inderhaug 2017	0,050	0,408	0,167	-0,750	0,850	0,122	0,903	37,14
Jette 2019	0,914	0,429	0,184	0,073	1,754	2,129	0,033	37,02
Xu 2022	9,560	1,576	2,485	6,470	12,650	6,065	0,000	25,85
Pooled	2,828	1,404	1,971	0,076	5,580	2,014	0,044	
Prediction Interval	2,828			-31,059	36,715			

Figure 25. ACLI-LET IRR 60

Four studies [19,21,39,46] compared compared ACLI versus LET at 90 degrees of knee flexion. The mean effect size was 0.580 with a 95% confidence interval of -1.372 to 2.531 The pooled analysis did not reveal significant between group differences (z=0.582; p=0.561; I^2 93%; Q-

statistic=44.735). (Figure 26). The prediction interval ranged from -8.609 to 9.768 suggesting that the true effect size in 95% of all populations falls in this interval.


ACLI vs LET - IRR 90 Flexion

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Inderhaug 2017	-0,400	0,412	0,170	-1,208	0,408	-0,970	0,332	26,51
Jette 2019	-0,749	0,422	0,178	-1,577	0,079	-1,774	0,076	26,45
Smith 2019	-1,612	0,470	0,221	-2,533	-0,691	-3,431	0,001	26,15
Xu 2022	6,250	1,085	1,177	4,124	8,376	5,762	0,000	20,89
Pooled	0,580	0,996	0,991	-1,372	2,531	0,582	0,561	
Prediction Interval	0,580			-8,609	9,768			

Figure 26. ACLI-LET IRR 90

It must be noted that all of the above results have been conducted with less than 10 studies in each comparison, and as a general rule, estimates of heterogeneity based on fewer than 10 studies are less likely to be reliable.

Discussion

The results of this meta-analysis demonstrated significant between-group differences in internal rotation resistance favoring lateral extra-articular tenodesis across all flexion angles but did not show any significant differences between anterolateral ligament reconstruction and lateral extra-articular tenodesis in anterior tibial translation at any flexion angle.

When using the ACL-intact knee as a benchmark, ALLR demonstrated no significant differences compared to the intact knee. This suggests that a combined ACLR and ALLR may restore knee stability to a level close to its native state for both ATT and IRR. However, the meta-analysis indicated that, with regard to IRR, the ACL-intact knee appears to be more stable across all flexion angles. Although the p-values did not reach statistical significance, 75% of the included studies reported greater stability in the ACL-intact knee. These findings imply that the addition of ALLR

may not provide a significant clinical benefit. It is important to note that the small sample sizes of the included studies likely contributed to a type II error. Therefore, increasing the sample size, either through the inclusion of additional studies or by expanding the sample sizes within individual studies, could potentially yield significant findings favouring the stability of the ACL-intact knee. The Trial Sequential Analysis (TSA), based on the estimated Required Information Size (RIS), indicates that this meta-analysis is adequately powered. This supports the robustness and reliability of the observed findings and reduces the likelihood that the results are due to random error. However, despite meeting the RIS threshold, the overall sample size remains relatively modest, which may limit the generalizability of the findings. As such, while the results are statistically robust, they should be interpreted with some caution.

Similar to ALLR, LET did not show any significant between-group differences in ATT when using the ACL-intact knee as a benchmark. However, in contrast to ALLR, LET demonstrated significant between-group differences favouring LET at 30° and 60° of knee flexion. Additionally, LET nearly reached significance at full extension and 90° of knee flexion. These findings suggest that LET may overly constrain the knee in terms of IRR. Previously, Slette et al. reported that LET procedures over-constrain the knee and restrict internal tibial rotation. [38] However, their findings were based on comparisons between ACL-deficient and ACL-intact knees, which limits the direct comparability to the results of this meta-analysis. Schon et al. demonstrated that ALLR results in over-constraint of the knee across all flexion angles. [37] In contrast, the systematic review by Van der Wal et al. concluded that both LET and ALLR effectively restore native knee kinematics during pivot shift. [44] This finding underscores the current controversies and lack of consensus in the field.

The potential over-constraint observed may be attributed to factors related to the surgical technique, including the position of the femoral tunnel, the location of fixation, and the fixation angle, all of which may play a critical role. Saithna et al. demonstrated that selecting a femoral attachment site at the level of the lateral epicondyle restricts internal rotation during knee flexion. [36] Given that the

ALL is an anisometric structure, the anatomical femoral attachment or tunnel position should be located proximal and posterior to the lateral epicondyle to optimize function and avoid over-constraint. [2,18] Since the ligament is tight in extension and lax in flexion, allowing for physiological internal rotation, fixation performed in flexion may contribute to over-constraint. [13]

Interestingly, these considerations are not supported by clinical findings from a recent meta-analysis. [23] Kolin et al. reviewed the effects of high and low knee flexion fixation angles and reported good to excellent patient-reported outcomes, along with low graft failure rates, regardless of whether ALLR/LET fixation was performed at low or high knee flexion angles. [23]

One contributing factor to the ongoing confusion is the unclear role of the ALL, iliotibial band (ITB), and Kaplan fibers in providing anterolateral knee stability. While several studies emphasize the significant role of the ALL in rotational knee stability, [7,11,12] other research suggests that the ITB and Kaplan fibers serve as the primary stabilizers against internal rotation. [22,34] Furthermore, other studies have shown that even complete sectioning of both the ALL and ITB resulted in only minor, clinically insignificant changes in rotational knee stability. [17,29,30] Finally, the ALL is not always present, with a recent systematic review reporting its prevalence as 82% in North Americans, 65% in Europeans, and 46% in Asians, highlighting notable regional differences. [15]

Even when the ALL is present, its contribution to rotational knee stability may not be significant. [16] Parsons et al. reported that the ALL contributed 30%, 37%, and 44% to internal rotation (IR) at 30°, 45°, and 60° of knee flexion, respectively. [33] In contrast, Kittl et al. found that its contribution ranged from only 2% to 5% between 15° and 45° of knee flexion in ACL-deficient knees. [22] Additionally, Huser et al. demonstrated that transecting the ALL in ACL-deficient knees resulted in only marginal increases in ATT and internal rotation resistance. [17]

The authors employed the Critical Appraisal Skills Programme (CASP) [5] to perform a subjective and qualitative assessment of the seven studies included in this analysis. This evaluation classified all studies as valuable, with good study quality and low risk of bias. However, these assessments were not supported when using a more comprehensive and validated tool for biomechanical studies, the Biomechanical Outcome Bias and Quality Assessment Tool (BOBQAT). [14] None of the included studies were rated as excellent or good quality, with the majority classified as moderate or fair, suggesting that the results of this meta-analysis should be interpreted with some caution.

Despite these limitations, it can be tentatively concluded that LET may be superior to ALLR but potentially over-constrains internal rotation across all knee flexion angles. The medium- and long-term consequences of over-constraint remain unclear at this stage. Neri et al. conducted a small pilot study that demonstrated an increase in lateral compartment pressure when LET was performed in conjunction with ACL reconstruction. [28] Theoretically, the increase in compartment pressure may predispose the cartilage and lateral meniscus to damage, potentially leading to meniscus tears and degenerative changes over time. [28] However, the current available evidence indicates that the rate of knee osteoarthritis (OA) remains low for up to 11 years, with the presence of a meniscus injury at the time of the initial surgery being the most significant predictor of OA development. [10]

Limitations

This systematic review has several limitations. Many of the cadavers used in the included studies were sourced from older donors, and several studies involved small sample sizes. Furthermore, variations in testing conditions and the quality of the cadavers may have influenced the results. It is important to note, however, that although statistical differences were not detected in some comparisons, small between-group differences may still be clinically meaningful. Additionally, the inclusion of more studies could lead to different outcomes. The search engines used are primarily optimized for English-language queries, which may result in the exclusion of studies published in other languages. Biomechanical cadaveric studies represent immediate, time-zero findings under

artificial conditions, which may not accurately replicate the complex biological and functional environment seen in vivo.

Conclusions

This meta-analysis demonstrated that lateral extra-articular tenodesis provided superior resistance to internal rotation but was also associated with a degree of over-constraint. No significant biomechanical differences in anterior tibial translation were observed between LET and anterolateral ligament reconstruction when combined with anterior cruciate ligament reconstruction. Anterolateral ligament reconstruction effectively restored both ATT and internal rotation resistance to near-native knee levels.

References

[1] Amis AA. Anterolateral knee biomechanics. *Knee Surg Sports Traumatol* 2017; 25 (4): 1015-1023. [PMID 28299387]

[2] Blache Y, Kouevidjin B, de Guise J, Dumas R, Saithna A, Sonnery-Cottet B, Thaunat M. Lateral extra-articular reconstruction length changes during weightbearing knee flexion and pivot shift: A simulation study. *Orthop Traumatol Surg Res* 2019; 105 (4): 661-667. [PMID 31005698]

[3] Chahla J, Menge TJ, Mitchell JJ, Dean CS, LaPrade RF. Anterolateral Ligament Reconstruction Technique: An Anatomic-Based Approach. *Arthrosc Techn* 2016; 5 (3): e453-457. [PMID 27656361]

[4] Claes S, Vereecke E, Maes M, Victor J, Verdonk P, Bellemans J. Anatomy of the anterolateral ligament of the knee. *J Anat* 2013; 223 (4); 321-328. [PMID 23906341]

[5] Critical appraisal skills programme. 2018 Available at: https://casp-uk.net/casp-tools-checklists/qualitative-studies-checklist/. Accessed 15 July 2024

[6] Cumpston M, Li T, Page MJ, Chandler J, Welch VA, Higgins JPT, et al. Updated guidance for trusted symptomatic reviews of the Cochrane handbook for systematic reviews of interventions. *Cochrane Database Syst Rev* 2019; 10:ED000142. [PMID 31643080]

[7] Daggett M, Stephenson C, Dobson J, Whitaker A, Redler A, Monaco E, et al. Anatomic and histological study of the anterolateral aspect of the knee: A SANTI group investigation. *Orthop J Sports Med* 2018; 6 (10): 2325967118799970. [PMID 30345320]

[8] Declercq J, Schuurmans M, Tack L, Verhelst C, Truijen J. Combined lateral extra-articular tenodesis and anterior cruciate ligament reconstruction: risk of osteoarthritis. Europ J Orthop Surg Traumatol 2023; 33 (4): 1075-1082. [PMID 35362778]

[9] Delaloye JR, Hartog C, Blatter S, Schläppi M, Müller D, Denzler D. Anterolateral Ligament Reconstruction and Modified Lemaire Lateral Extra-Articular Tenodesis Similarly Improve Knee Stability After Anterior Cruciate Ligament Reconstruction: A Biomechanical Study. *Arthroscopy* 2020; 36 (7): 1942-1950. [PMID 32251683]

[10] Devitt BM, Bouguennec N, Barford KW, Porter T, Webster KE, Feller JA. Combined anterior cruciate ligament reconstruction and lateral extra-articular tenodesis does not result in an increased rate of osteoarthritis: a systematic review and best evidence synthesis. *Knee Surg Sports Traumatol Arthrosc* 2017; 25 (4): 1149-1160. [PMID 28289822]

[11] Geeslin AG, Chahla J, Moatshe G, Muckenhirn KJ, Kruckeberg BM, Brady AW. Anterolateral Knee Extra-articular Stabilizers: A Robotic Sectioning Study of the Anterolateral Ligament and Distal Iliotibial Band Kaplan Fibers. *Am J Sports Med* 2018; 46 (6): 1352-1361. [PMID 29558208]

[12] Geeslin AG, Moatshe G, Chahla J, Kruckeberg BM, Muckenhirn KJ, Dornan GJ, et al. Anterolateral Knee Extra-articular Stabilizers: A Robotic Study Comparing Anterolateral Ligament Reconstruction and Modified Lemaire Lateral Extra-articular Tenodesis. *Am J Sports Med* 2018; 46 (3): 607-616. [PMID 29268024]

[13] Getgood A, Brown C, Lording T, Amis A, Claes S, Geeslin A, Musahl V, ALC Consensus Group. The anterolateral complex of the knee: results from the International ALC Consensus Group Meeting. *Knee Surg Sports Traumatol Arthrosc* 2019; 27 (1): 166-176. [PMID 30046994]

[14] Hohmann E, Paschos N, Keough N, Erbulut D, Oberholster A, Glatt V, Molepo M, Tetsworth K. Cadaveric biomechanical laboratory research can be quantitively scored for quality with the Biomechanics Objective Basic Science Quality Assessment Tool: The BOBQAT score. *Arthroscopy* 2024 40 (8): 2263-2272. [PMID 38185184]

[15] Hohmann E, Keough N, Molepo M, Arciero R, Imhoff A. The anterolateral ligament is present in 82% of North Americans and 65% of Europeans but only in 46% of Asian studies: a systematic review of frequency and anatomy. *Arthroscopy* 2024 [online ahead of print]. [PMID 39505156]

[16] Hohmann E, Keough N, Molepo M, Arciero R, Imhoff A. The anterolateral ligament complex has limited impact on anterior tibial translation or internal rotational stability in ACL-deficient and ACL-reconstructed knees. A systematic review of biomechanical cadaver studies. Arthroscopy 2025. [online ahead of print]. [PMID 40306468]

[17] Huser LE, Noyes FR, Jurgensmeier D, Levy MS. Anterolateral ligament and iliotibial band control of rotational stability in the anterior cruciate ligament- intact knee: defined by tibiofemoral compartment translations and rotations. *Arthroscopy* 2017; 33 (3): 595-604. [PMID 27964969]

[18] Imbert P, Lutz C, Daggett M, Niglis L, Freychet B, Dalmay F, Sonnery-Cottett B. Isometric Characteristics of the Anterolateral Ligament of the Knee: A Cadaveric Navigation Study. *Arthroscopy* 2016; 32 (10): 2017-2024. [PMID 27157662]

[19] Inderhaug E, Stephen JM, Williams A, Amis AA. Anterolateral Tenodesis or Anterolateral Ligament Complex Reconstruction: Effect of Flexion Angle at Graft Fixation When Combined With ACL Reconstruction. *Am J Sports Med* 2017; 45 (13): 3089-3097. [PMID 28898106]

[20] Jesani S, Getgood A. Modified Lemaire Lateral Extra-Articular Tenodesis Augmentation of Anterior Cruciate Ligament Reconstruction. *JBJS Essent Surg Tech* 2019; 9 (4): e41.1-7. [PMID 32051777]

[21] Jette C, Gutierrez D, Sastre S, Llusa M, Combalia A. Biomechanical comparison of anterolateral ligament anatomical reconstruction with a semi-anatomical lateral extra-articular tenodesis. A cadaveric study. *Knee* 2019; 26 (5): 1003-1009. [PMID 31427244]

[22] Kittl C, Inderhaug E, Williams A, Amis AA. Biomechanics of the anterolateral structures of the knee. *Clin Sports Med* 2018; 37 (1): 21-31. [PMID 29173554]

[23] Kolin DA, Jones RH, Heyworth BE.Jivanelli B, SATURN study group, et al. No difference in stability among various knee flexion angles during fixation of anterolateral ligament reconstruction or lateral extra-articular tenodesis: A systematic review and meta-analysis of biomechanical studies. *J Exp Orthop* 2024; 11 (3): e12079

[24] Laboudie P, Douiri A, Bouguennec N, Biset A, Graveleau N. Combined ACL and ALL reconstruction reduces the rate of reoperation for graft failure or secondary meniscal lesions in young athletes. *Knee Surg Sports Traumatol Arthrosc* 2022; 30 (10): 3488-3498. [PMID 35364738]

[25] Long HA, French DP, Brooks JM. Optimizing the value of the critical appraisal skills programme (CASP) tool for quality appraisal in qualitative evidence synthesis. *Res Meth Med Health Sci* 2020; 1 (1): 31-42.

[26] MARS Group, Wright RW, Huston LJ, Haas AK, Pennings JS, Allen CR, et al. Surgical predictors of clinical outcome 6 years after revision ACL reconstruction. *Am J Sports Med* 2024; 52 (13): 3286-3294. [PMID 39503722]

[27] Nazzal EM, Keeling LE, Ryan PM. Herman ZJ, Hughes JD. The Role of Lateral Extra-articular Tenodesis in Anterior Cruciate Ligament Reconstruction and Treatment of Rotatory Knee Instability: a Scoping Review. Curr Rev Musculoskelet Med 2023; 16 (6): 235-245. [PMID 36995532]

[28] Neri T, Cadman J, Beach A, Grasso S, Dabirrahmani D, Putnis S, et al. Lateral tenodesis procedures increase lateral compartment pressures more than anterolateral ligament reconstruction, when performed in combination with ACL reconstruction: a pilot biomechanical study. J ISAKOS 2021; 6 (2): 66-73. [PMID 33832979]

[29] Noyes FR, Huser LE, Jurgensmeier D, Walsh J, Levy MS. Is an anterolateral ligament reconstruction required in ACL-reconstructed knees with associated injury to the anterolateral structures? A robotic analysis of rotational knee stability. *Am J Sports Med* 2017; 45 (5): 1018-1027. [PMID 28056513]

[30] Noyes FR, Huser LE, West J, Jurgensmeier D, Walsh J, Levy MS. Two different knee rotational instabilities occur with anterior cruciate ligament and anterolateral ligament injuries: a robotic study on anterior cruciate ligament and extra-articular reconstructions in restoring rotational stability. *Arthroscopy* 2018; 34 (9): 2683-2695. [PMID 30173809]

[31] Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Syst Rev 2021*; 10 (1): 89. [PMID 33781348]

[32] Park YB, Lee HJ, Cho HC, Pujol N, Kim SH. Combined lateral extra-articular tenodesis or combined anterolateral ligament reconstruction and anterior cruciate ligament reconstruction improves outcomes compared to isolated reconstruction for anterior ligament tear: a network meta-analysis of randomized controlled trials. *Arthroscopy* 2023; 39 (3): 758-776. [PMID 36567183]

[33] Parsons EM, Gee AO, Spiekerman C, Cavanagh PR. The biomechanical function of the anterolateral ligament of the knee. *Am J Sports Med* 2015; 43 (3): 669-674. [PMID 25556221]

[34] Rahnemai-Azar AA, Miller RM, Guenther D, Fu FH, Lesniak BP, Musahl V, Debski RE. Structural properties of the anterolateral capsule and iliotibial band of the knee. *Am J Sports Med* 2016; 44 (4): 892-897. [PMID 26811306]

[35] Ristanis S, Stergiou N, Patras HS, Vasiliadis HS, Giakas G, Georgoulis AD. Excessive tibial rotation during high-demand activities is not restored by anterior cruciate ligament reconstruction. *Arthroscopy* 2005; 21 (11): 1323-1329. [PMID 16325082]

[36] Saithna A, Thaunat M, Deloloye JR, Ouanezar H, Fayard JM, Sonnery-Cottet B. Combined ACL and Anterolateral Ligament Reconstruction. *JBJS Essent Surg Tech* 2018; 8 (1): e2. [PMID 30233974]

[37] Schon JM, Moatshe G, Brady AW, Cruz RS, Chahla J, Dornan GJ, et al. Anatomic Anterolateral Ligament Reconstruction of the Knee Leads to Overconstraint at Any Fixation Angle. *Am J Sports Med* 2016; 44 (10): 2546-2556. [PMID 27407088]

[38] Slette EL, Mikula JD, Schon JM, Marchetti DC, Kheir MM, Turnbull TL, LaPrade RF. Biomechanical Results of Lateral Extra-articular Tenodesis Procedures of the Knee: A Systematic Review. *Arthroscopy* 2016; 32 (12): 2592-2611. [PMID 27324970]

[39] Smith PA, Thomas DM, Pomajzl RJ, Bley JA, Pfeiffer FM, Cook JL. A Biomechanical Study of the Role of the Anterolateral Ligament and the Deep Iliotibial Band for Control of a Simulated Pivot Shift With Comparison of Minimally Invasive Extra-articular Anterolateral Tendon Graft Reconstruction Versus Modified Lemaire Reconstruction After Anterior Cruciate Ligament Reconstruction. *Arthroscopy* 2019; 35 (5): 1473-1483. [PMID 30926192]

[40] Sonnery-Cottet B, Barbosa NC, Vieira TD, Saithna A. Clinical outcomes of extra-articular tenodesis/anterolateral reconstruction in the ACL injured knee. *Knee Surg Sports Traumatol Arthrosc* 2018; 26 (2); 596-604. [PMID 28608009]

[41] Sonnery-Cottet B, Haidar I, Rayes J, Fradin T, Ngbilo C, Vieira TD, et al. Long-term Graft Rupture Rates After Combined ACL and Anterolateral Ligament Reconstruction Versus Isolated ACL Reconstruction: A Matched-Pair Analysis From the SANTI Study Group. *Am J Sports Med* 2021; 49 (11): 2889-2897. [PMID 34351825]

[42] Spencer L, Burkhart TA, Tran MN, Rezansoff AJ, Deo S, Caterine S. Biomechanical analysis of simulated clinical testing and reconstruction of the anterolateral ligament of the knee. *Am J Sports Med* 2015; 43 (9): 2189-2197. [PMID 26093007]

[43] Tollefson LV, Kennedy ML, Kennedy NL, LaPrade RF. Anatomic Anterolateral Ligament Reconstruction with Iliotibial Band Graft and Concomitant Anterior Cruciate Ligament Reconstruction. *Arthrosc Techn* 2024; 13 (4): 102906. [PMID 38690330]

[44] Van der Wal WA, Meijer DT, Hoogeslag RAG, LaPrade RF. The iliotibial band is the main secondary stabilizer for anterolateral rotatory instability and both a Lemaire tenodesis and anterolateral ligament reconstruction can restore native knee kinematics in the anterior cruciate ligament reconstructed knee: a systematic review of biomechanical cadaveric studies. *Arthroscopy* 2024; 40 (2): 632-647. [PMID 37207919]

[45] Vincent JP, Magnussen RA, Gezmez F, Uguen A, Jacobi M, Weppe F, et al. The anterolateral ligament of the human knee: an anatomic and histological study. *Knee Surg Sports Traumatol Arthrosc* 2012; 20 (1): 147-152. [PMID 21717216]

[46] Xu J, Han K, Lee TQ, Xu C, Su C, Su W, et al. Anterolateral structure reconstruction similarly improves the stability and causes less overconstraint in anterior cruciate ligament-reconstructed knees compared with a modified Lemaire lateral extra-articular tenodesis: a biomechanical study. *Arthroscopy* 2022; 38 (3): 911-924. [PMID 34358641]