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ACL Revision Plus Lateral Extra-articular Procedure Results in Superior Stability and Lower Failure Rates Than Does Isolated ACL Revision But Shows No Difference in Patient-Reported Outcomes or Return to Sports

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Systematic Review

ACL Revision Plus Lateral Extra-articular Procedure Results in Superior Stability and Lower Failure Rates Than Does Isolated ACL Revision But Shows No Difference in Patient-Reported Outcomes or Return to Sports

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Running Title: Outcomes of Revision ACL Reconstruction

Systematic Review

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Abstract

Purpose: The aim of this systematic review was to determine whether comparative clinical studies demonstrate significant advantages of revision anterior cruciate ligament (ACL) reconstruction combined with a lateral extra-articular procedure (LEAP), with respect to graft rupture rates, knee stability, return to sport rates, and patient reported outcome measures (PROMS) when compared to isolated revision ACL reconstruction (RACLR).

Methods: Systematic review was conducted in accordance with Preferred Reporting Items for Systematic Reviews & Meta-Analyses Guidelines. A PubMed search was conducted using the keywords “revision anterior cruciate ligament reconstruction” combined with any of the following additional terms, “lateral extra-articular tenodesis” OR “anterolateral ligament reconstruction” OR “Lemaire”. All relevant comparative clinical studies were included. Key clinical data was extracted and evaluated.

Results: Eight comparative studies (seven level III studies and a one level IV study) were identified and included. Most studies reported more favorable outcomes with combined procedures with respect to failure rates (0% to 13% following RACLR+LEAP, and 4.4% to 21.4% following isolated RACLR), post-operative side-to-side AP laxity difference (1.3mm to 3.9mm following RACLR+LEAP and 1.8mm to 5.9mm following isolated RACLR), and high-grade pivot shift (0% to 11.1% following RACLR+LEAP and 10.2% to 23.8% in patients following isolated RACLR). There were no consistent differences between isolated and combined procedures with respect to return to sport or PROMS.

Conclusions: This systematic review demonstrates that the addition of a LEAP to RACLR was associated with an advantage with respect to ACL graft failure rates and avoidance of high grade post-operative knee laxity across almost all included studies.

Level of Evidence: IV, Systematic Review of level III to IV studies

Introduction

Revision anterior cruciate ligament reconstruction (RACLR) can be a technically challenging procedure[1] and functional outcomes are demonstrably inferior to primary anterior cruciate ligament reconstruction (ACLR).[2,3] Some of the key factors contributing to less favorable outcomes include the increasing incidence of meniscus and cartilage lesions at the time of RACLR, increasing patient age and decreasing activity levels.[4] In addition, it is also recognized that patients undergoing RACLR are at approximately four-fold greater risk of failure than those undergoing primary ACLR.[5] Although causes of failure of primary ACLR are well documented, studies investigating causes of failure of RACLR are sparse. Perhaps the most notable of these is from the MARS study group which reported that the use of allograft was a risk factor for failure of RACLR, but additional important risk factors were not identified.[6] Liechti et al in a systematic review, also failed to clearly identify important risk factors but suggested that increased tibial slope and undiagnosed concomitant ligament injuries should be investigated and addressed if present.[7] It can therefore be stated that causes of failure of RACLR are not clearly defined, but that the occurrence of failure represents an important clinical burden with reported rates between 0-25%.[5]

Until recently there has been little consensus on the optimum management of the failed primary ACL reconstruction. In 2022, the ESSKA European ACL consensus project published guidelines with the aim of achieving better and more reliable outcomes for this group of patients.[8] One of their recommendations was for the systematic use of an additional extraarticular anterolateral procedure in revision ACL-reconstruction, especially when patients present with gross laxity. Despite this recommendation, the authors cautioned that there is a lack of high levels of evidence in existing studies. The recommendation also appears to be somewhat inconsistent with current trends in practice. A survey of ACL Study Group members demonstrated that 89% of respondents believed in a role for extra-articular augmentation during RACLR, but only a small proportion adopted an "always" approach to its use (13% reported always, 26% often, 29% sometimes, 20% rarely and 12% never).[9] Furthermore, a recent study from Eggling et al did not find any advantage to performing a lateral extra-articular procedure (LEAP) at the time of RACLR.[10] This apparent conflict between consensus guidelines, current practice trends and recent studies serves to highlight a critical information gap in the literature. Ideally, this should be further investigated by a large, adequately powered, randomized controlled trial (RCT). In the meantime, the absence of an RCT provides justification for a systematic review including non-randomized studies[11].

The aim of this systematic review was to determine whether comparative clinical studies demonstrate significant advantages of RACLR combined with a LEAP, with respect to graft rupture rates, knee stability, return to sport rates, and PROMS when compared to isolated RACLR. The hypothesis, based on outcomes of LEAPs in primary ACLR[12], was that RACLR + LEAP would be associated with lower graft failure rates and better knee stability than isolated RACLR.

Methods

The systematic review was conducted in accordance with Preferred Reporting Items for Systematic Reviews & Meta-Analyses (PRISMA) guidelines.[13] The protocol was prospectively recorded (registration blinded for journal review). The search strategy was designed to identify clinical studies comparing the outcomes of isolated RACLR versus RACLR+LEAP.

Two investigators (initials blinded for journal review) independently applied the following search strategy to PubMed. The search was performed on 14th July 2022, and repeated on 16th July 2022 to ensure accuracy. The search was performed using the following keywords and automatic mapping to MeSH vocabulary: “revision anterior cruciate ligament reconstruction” combined with any of the following additional terms, “lateral extra-articular tenodesis” OR “anterolateral ligament reconstruction” OR “Lemaire”. The following limits were applied (English language, publication date after 1st January 2000). Abstracts were reviewed and used to determine study eligibility. All relevant comparative clinical studies were included. Any disagreements between the two evaluators regarding study eligibility were resolved by the first author. The reference lists for articles selected for inclusion were reviewed for further eligible studies and in addition Google Scholar was used to find any additional relevant citing articles (using the “Cited By” tool). The MINORS tool was used to assess the methodological quality of included studies.[14]

Data Extraction

The same two investigators independently extracted the following data from each of the included studies: study type and level of evidence, population demographics, surgical technique, and data regarding the following key outcome measures, when available: failure rates (defined for the purposes of this study as MRI confirmed graft failure or post-operative grade III pivot shift, at a minimum follow up of two years), return to sport rates, post-operative knee stability (Lachman, Pivot Shift, Side-to-side AP laxity difference), IKDC, KOOS, Tegner and complication rates. A meta-analysis of data was not attempted due to the lack of RCTs and considerable heterogeneity between published non-randomized studies

Results

The initial search strategy identified 107 articles. After application of the eligibility criteria, eight studies were selected for inclusion in the systematic review, as reported in the PRISMA flow chart (Fig. 1).[10,15–21] The methodological quality of studies, as evaluated with the MINORS tool, is reported in Table 1. Table 2 summarizes the characteristics of included studies. All were retrospective comparative studies (seven level III studies and a one level IV study). Overall, the included studies reported upon 716 patients (366 RACLR+LEAP, 350 RACLR). All studies, except Keizer et al[16], reported a minimum follow up of 24 months (range 12 to 192 months). The mean age of patients enrolled in each study, or treatment group, varied between 26.8 to 33.3 years. The type of LEAP was not standardized across studies and a variety of techniques were used (including ALL reconstruction, modified Lemaire and modified MacIntosh)

Six of the included studies reported failure rates. All included studies, except Eggling et al[10], demonstrated a trend in favor of RACLR+LEAP with respect to failure rates (Fig 2 and Table 3) but significant differences were only reported by Helito et al and Alm et al.[15,21] The rate of failure varied from 0% to 13% in patients undergoing RACLR+LEAP and 4.4% to 21.4% in those undergoing isolated RACLR

Data regarding the rates of post-operative high-grade pivot shift was available in five studies. The rate of high-grade pivot shift varied between 0% to 11.1% in patients undergoing RACLR+LEAP and 10.2% to 23.8% in patients undergoing isolated RACLR. There was a consistent trend across all studies in favor of lower absolute rates of high-grade pivot shift in patients undergoing RACLR+LEAP, but this finding was only reported to be statistically significant by Helito et al[21], (Fig 3).

Data regarding the rates of post-operative high-grade Lachman were available in four studies. Three of the studies reported lower absolute rates of high-grade Lachman in patients undergoing RACLR+LEAP, but Eggling et al reported the opposite.[10,15,17,20] However, these findings did not reach statistical significance in any study (Fig 4). Overall, the rates of high-grade Lachman varied between 0% to 22.2% in patients undergoing RACLR+LEAP and 4.6% to 47.6% in patients undergoing isolated RACLR.

Data regarding post-operative side-to-side AP laxity difference were reported in six studies. Each of these studies reported a trend toward higher AP laxity in the isolated ACLR group. In three studies these findings were statistically significant (Alm et al, Helito et al and Yoon et al)[15,20,21] (Fig 5). Overall, the mean side-to-side AP laxity difference varied between 1.3 to 3.9 in patients undergoing RACLR+LEAP and between 1.8 to 5.9 in those undergoing isolated RACLR.

The rate of return to sport was reported in three studies.[10,16,17] The studies were conflicting in their findings, and none clearly demonstrated a significant difference between groups (Fig 6). The rates of return to sport varied between 47.8% to 88.1% in patients undergoing RACLR+LEAP and 30.6% to 88.4% in patients undergoing isolated RACLR. However, two studies reported rates of return to sport at the pre-injury level, with both in favor of RACLR+LEAP (rate of return to the pre-injury level of sport; Lee et al, 57.1% vs 25.6%, p = 0.008; Keizer et al, 30.1% vs 19.4%, p = not reported).[16,17]

The mean post-operative Tegner activity level was reported in six studies.[10,15–17,19,20] Results were conflicting between studies. The only study that reported a significant difference favored the RACLR+LEAP group (Fig 7).[17] Overall, the mean post-operative Tegner activity level varied between 4 to 7 in patients undergoing RACLR+LEAP and 4 and 6.3 in patients undergoing isolated RACLR.

The mean post-operative Lysholm score was reported in six studies.[10,15,17,19–21] Results were conflicting between studies, but four out of six studies reported absolute scores that were higher in the RACLR+LEAP group. Only two studies reported significant differences between groups, and both were in favor of RACLR+LEAP (Fig 8).[15,21] Overall, the mean post-operative Lysholm score varied between 58.7 to 95 in patients undergoing RACLR+LEAP and 62 to 87.8 in patients undergoing isolated RACLR

The mean post-operative IKDC score was reported in seven studies.[10,15–17,19–21] All except two studies reported absolute scores that were higher in the RACLR+LEAP group.[10,19] Three studies reported significant differences between groups, and all were in favor of RACLR+LEAP (Fig 9).[15,17,21] Overall, the mean post-operative IKDC score varied between 57.8 to 90 in patients undergoing RACLR+LEAP and 56.4 to 85.1 in patients undergoing isolated RACLR

Only three studies reported KOOS subdomains.[10,15,16] With respect to KOOS symptoms, all studies reported absolute values that were higher in the RACLR+LEAP group but only Alm et al[15] demonstrated a significant difference (Fig 10a). The range of KOOS symptoms scores varied between 60.7 to 100 in patients undergoing RACLR+LEAP and 60.7 to 87.6 in those undergoing isolated RACLR. With respect to KOOS pain, none of the studies demonstrated any significant differences between groups (Fig 10b). With respect to KOOS ADL, all studies except Keizer et al[16] (who reported no difference between groups) reported absolute values that were higher in the RACLR+LEAP group but only one study demonstrated a significant difference (Fig 10c). The range of KOOS ADL scores varied between 95.2 to 100 in patients undergoing RACLR+LEAP and 93 to 98.5 in those undergoing isolated RACLR. The studies were conflicting with respect to KOOS Sport, with Eggling et al[10] reporting a higher absolute mean score in patients undergoing isolated RACLR and the other two studies in favor of combined procedures. However, the only study that demonstrated a significant difference favored the RACLR+LEAP group (Fig 10d).[15] The range of KOOS Sport scores varied between 72.6 to 95 in patients undergoing RACLR+LEAP and 70 to 80 in those undergoing isolated RACLR. None of the studies demonstrated any significant difference between groups with respect to KOOS QOL. (Fig 10e). The range of KOOS QOL scores varied between 53.1 to 68.8 in the RACLR+LEAP group and 56 to 58.4 in the isolated RACLR group.

Discussion

The main findings of this systematic review were that the addition of a LEAP to RACLR was associated with improved outcomes with respect to failure rates, side-to-side AP laxity difference, and avoidance of high grade post-operative pivot shift in most studies that reported these outcomes. However, significant differences were frequently not observed. Regardless the broadly consistent trends across most studies suggests that the lack of significance is probably related to small study populations and underpowering. The observed trends mirror the literature for primary ACLR, for which the strength of available evidence is considerably higher due to the number of available studies and considerably larger study populations[12,22]. The evidence relating to primary ACLR demonstrates that the addition of a LEAP confers significantly reduced ACL graft rupture rates and better knee stability.[12,23] Specifically, several comparative clinical studies, including a randomized controlled trial[24], have demonstrated lower primary ACL graft rupture rates when combined reconstructions are performed, including in high-risk populations (young active patients participating in contact/pivoting sports[25], those with chronic ACL injuries[26], hyperlaxity[27], professional athletes[28]). Furthermore, it has recently been demonstrated that the significant reductions in graft rupture rates observed in numerous studies at short- to mid-term follow-up are also maintained at long term follow-up[29]. Overall, these findings suggest that despite potentially important differences in the characteristics of patients undergoing RACLR, when compared to those undergoing primary ACLR (including the proportion of meniscus and cartilage injuries, increased tibial slope, coronal plane malalignment, Beighton score, family history, activity level, bony defects, and tunnel widening)[30], adding a LEAP likely remains of value in reducing graft rupture rates and improving rotational knee stability.

The clinical findings reported in this systematic review are also consistent with previous biomechanical studies demonstrating that combined reconstructions more reliably restore normal knee kinematics, particularly in the setting of combined ACL and anterolateral injuries.[31] It is important to note that these combined injuries patterns are common[32–35], and occur significantly more frequently in patients undergoing RACLR than primary ACLR.[36] Furthermore in the primary ACLR setting these injuries have been shown to be associated with inferior outcomes if managed with isolated ACLR only.[37] Furthermore, biomechanical studies have demonstrated that LEAPs load share with ACL grafts by conferring a protective effect upon them[38–41]. This protective effect also appears to extend to meniscal repairs performed concomitant to ACLR, with significantly reduced secondary meniscectomy rates observed following combined ACLR+ALLR when compared to isolated ACLR[42,43]. Unfortunately, none of the studies included in this systematic review reported secondary meniscectomy rates, so whether this finding also holds true in the RACLR setting could not be evaluated. However, it seems logical to postulate that the protective effect conferred by LEAPs due to load sharing and improved knee kinematics should also hold true in the RACLR setting.

Limitations

Overall, confidence in the benefit of adding a LEAP to RACLR is moderate because of the consistent findings across studies as described above, and the fact that all except one of the included studies demonstrated at least some significant advantages of combined procedures. In the outlying study, Eggling et al[10] only included patients with low grade anterior knee laxity (defined as <5mm side to side AP laxity difference), which is not a widely recognized indication for combined procedures. Additionally, this study was almost certainly underpowered to identify a difference between groups (only 23 patients in the combined reconstruction group, of which seven had between 2-4 previous ACL procedures, limiting the external validity of this study). Although underpowering is likely to have affected several of the included studies, the study from Eggling et al[10] was also limited by notable baseline differences between groups with respect to RACLR graft choice and the proportion of patients with pre-operative high grade pivot shift (both likely favoring the isolated ACLR group). Due to these limitations, it is unclear whether patients with low grade anterior laxity are less likely to benefit from a combined reconstruction or not, and further study is required.

An additional important finding of this systematic review was that consistent significant differences between groups were not demonstrated for any of the PROMs evaluated. Results of studies were often conflicting, and where significant differences did exist, they were often in isolation and did not meet the known minimally clinically important difference (MCID) thresholds.[44–46] Furthermore, this particular aspect of the systematic review may have been particularly susceptible to confounding due to baseline differences between groups, particularly given that higher activity level patients may have been more likely to undergo combined procedures than those with low athletic demand, and therefore be more likely to also achieve better post-operative scores. Similarly, no significant advantages were demonstrated with respect to overall return to sport rates, but this was not well studied, with only three studies reporting this metric. Interestingly, there was also little consensus with respect to rates of return to sport within each group, with very broad ranges reported for patients undergoing RACLR+LEAP (47.8% to 88.1%) or isolated RACLR (30.6% to 88.4%). However, two studies reported rates of return to sport at the pre-injury level, with both in favor of RACLR+LEAP (rate of return to the pre-injury level of sport; Lee et al, 57.1% vs 25.6%, p = 0.008; Keizer et al, 30.1% vs 19.4%, p = not reported).[16,17]

It is important to interpret the findings of this systematic review within the context of the methodological quality and limitations of the included studies. Assessment with the MINORS tool demonstrated that the quality score varied between 10-17 (max 24), indicating poor to moderate quality with significant risk of bias. Concerns that affected many/all of the included studies were their retrospective design and inherent risk of treatment selection bias, small sample sizes and underpowering, and the use of non-contemporary groups and lack of baseline equivalence. These issues indicate that there is a clear need for a large (preferably multi-center study to ensure adequate sample size) RCT to confirm the current findings, but to the knowledge of the authors, no such study is currently underway. In the meantime, clinical outcomes of RACLR require improvement and LEAP appears to be a safe and effective option, particularly given the broadly consistent findings across the majority of studies.

Additional limitations of this systematic review include the lack of comprehensive reporting amongst included studies with respect to key outcomes, most notably, return to sport. Given that return to sport is one of the most frequent reasons patients choose to undergo RACLR this is an important deficiency and should be a key focus for future study. A further limitation was that it was not possible to determine whether any of the LEAP procedures performed in included studies were more effective than any other. To the knowledge of the authors clinical differences between different types of LEAP have not been extensively studied, though Rayes et al demonstrated equivalent outcomes of ACLR+ALLR and ACLR+Lemaire in the RACLR setting.[47] A further limitation of this study was that one of the concerns of LEAP at the time of ACLR is tunnel collision[48,49] (and this is more likely in the RACLR setting), but due to lack of explicit reporting of this outcome in the included studies it could not be assessed.

Conclusions

This systematic review demonstrates that the addition of a LEAP to RACLR was associated with an advantage with respect to ACL graft failure rates and avoidance of high grade post-operative knee laxity across almost all included studies.

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Author, Year of Publication	Alm 2020	Eggeling 2022	Helito 2022	Keizer 2022	Lee 2019	Trojani 2012	Ventura 2021	Yoon 2021
Level of Evidence	III	III	III	III	III	IV	III	III
Study Design	RC	RC	RC	RC	RC	RCC	RC	RC
Clearly stated aim	2	1	2	2	2	2	2	2
Inclusion of consecutive patients	2	1	2	0	2	0	2	2
Prospective collection of data	0	0	0	0	0	0	0	0
Endpoint appropriate to the study aim	2	2	2	2	2	2	2	2
Unbiased evaluation of endpoints	0	0	0	0	0	0	0	2
Follow-up period appropriate to the major endpoint	2	2	2	1	2	2	2	1
Loss to follow up not exceeding 5%	0	2	1	0	1	0	1	1
An adequate control group	2	2	2	2	2	2	2	2
Contemporary groups	2	1	2	1	1	0	1	1
Baseline equivalence of groups	2	1	2	0	2	0	1	2
Prospective calculation of the sample size?	0	0	0	0	0	0	0	0
Statistical analyses adapted to the study design	2	2	2	2	2	2	2	2
Total (max 24)	**16**	**14**	**17**	**10**	**16**	**10**	**15**	**17**

Table 1. Methodological quality of included studies evaluated using the MINORS tool. RC – Retrospective comparative; RCC – Retrospective Case Control

Journal Pre-proof

Included Studies (Publication Year)	n	Age, y, Mean ± SD (range)	Female, n (%)	LEAP	Medial meniscal lesion, n (%)	Lateral meniscal lesion, n (%)	Follow-up, mo, Mean ±SD (range)
Alm et al. (2020)	RACLR+LEAP: 59	31.4 ± 10.5 (18–54)	28 (47.5)	Modified Lemaire	35 (59.3)	9 (15.3)	26.4 ± 3.3 (24-37)
	RACLR: 14	29.3 ± 10.3 (18–51)	6 (42.9)		9 (64.3)	3 (21.4)	26.4 ± 3.3 (24-37)
Eggeling et al. (2022)	RACLR+LEAP: 23	33.3 ± 12.3 (16–55)	10 (43.5)	Modified Lemaire	11 (47.8)	4 (17.4)	28.7 ± 8.8 (24-67)
	RACLR: 55	31.9 ± 9.9 (16–52)	20 (36.4)		24 (43.6)	12 (21.8)	28.7 ± 8.8 (24-67)
Helito et al. (2022)	RACLR+LEAP: 86	29.8 ± 8.3 (18–56)	20 (23.2)	41: ALLR * 45: Modified Lemaire	27 (62.8)	14 (32.5)	32.8 ± 9.1 (24-60)
	RACLR: 88	31 ± 5.2 (20–48)	11 (12.5)		16 (50)	9 (28.1)	35.3 ± 12.9 (24-84)
Keizer et al. (2022)	RACLR+LEAP: 42	27.6 ± 7.6	9 (37.5)	Modified Lemaire	17 (40.5)	21 (50)	43.9 ± 29.2 (12-192)
	RACLR: 36	31.3 ± 8.9	12 (33.3)		23 (63.9)	13 (36.1)	43.9 ± 29.2 (12-192)
Lee et al. (2019)	RACLR+LEAP: 42	26.8 ± 6.1	9 (21.4)	ALLR with gracilis allograft	n.r.	n.r.	38.2 ± 6.9
	RACLR: 45	27.3 ± 7.6	11 (24.4)		n.r.	n.r.	41.5 ± 8.2
Trojani et al. (2012)	RACLR+LEAP: 84	n.r.	n.r.	n.r.	n.r.	n.r.	44 (24-120)
	RACLR: 79	n.r.	n.r.		n.r.	n.r.	44 (24-120)
Ventura et al. (2021)	RACLR+LEAP: 12	31.4 ± 10.3	2 (16.7)	Modified MacIntosh	n.r.	n.r.	54 (24-84)
	RACLR: 12	29.3 ± 9.5	3 (25)		N.R.	n.r.	54 (24-84)

Yoon et al. (2021)	RACLR+LEAP: 18	32.9 ± 10.8 (18–55)	2 (11.1)	ALLR with tibialis allograft	4 (22.2)	3 (16.7)	24
	RACLR: 21	29.6 ± 10.2 (16–54)	4 (19)		10 (47.6)	2 (9.5)	24

Table 2. Basic characteristics of Included Studies. ALLR, anterolateral ligament reconstruction; LEAP, lateral extra-articular procedure; Mo, months; n, number of patients; n.r., not reported; RACLR, revision anterior cruciate ligament reconstruction; SD, standard deviation
*either autograft or allograft depending on the main graft used for the ACL reconstruction

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Included Studies (Publication Year)	Group	RACLR failures, n (%)	Non-graft rupture related complications
Alm et al. (2020)	RACLR+LEAP: 59	3 (5.1)	n.r.
	RACLR: 14	3 (21.4)	n.r.
Eggeling et al. (2022)	RACLR+LEAP: 23	3 (13)	4 patients complained of lateral pain
	RACLR: 55	6 (11)	0
Helito et al. (2022)	RACLR+LEAP: 86	4 (4.6)	7 complications: - One synovial cyst of the tibial tunnel - One superficial infection in the region of the tibial tunnel - One joint stiffness that required manipulation - One loss of extension of 5 degrees - One case of chronic lateral pain in the region of LEAP - One cyclops lesion One extensive hematoma in the operated leg.
	RACLR: 88	13 (14.7)	5 complications: - One extensive hematoma in the region of the tibial tunnel - One septic arthritis requiring surgical debridement - Two cyclops lesions One superficial infection in the lateral access of the femoral tunnel
Keizer et al. (2022)	RACLR+LEAP: 42	*	n.r.
	RACLR: 36	*	n.r.
Lee et al. (2019)	RACLR+LEAP: 42	0	1 patient required removal of the femoral LET interference screw.
	RACLR: 45	2 (4.4)	0
Trojani et al. (2011)	RACLR+LEAP: 84	6 (7.1)	n.r.
	RACLR: 79	12 (15.2)	n.r.
Ventura et al. (2020)	RACLR+LEAP: 12	n.r.	n.r.
	RACLR: 12	n.r.	n.r.
Yoon et al. (2019)	RACLR+LEAP: 18	2 (11.1)	n.r.
	RACLR: 21	3 (14.3)	n.r.

Table 3. Complications reported in the included studies. LEAP, lateral extra-articular procedure; n, number of patients; n.r., not reported; *failures were excluded from the study and therefore a failure rate was not available, RACLR, revision anterior cruciate ligament reconstruction.

Figure Legends

Fig 1. PRISMA flow chart

Figure 2: Forest plot of failure rates

Figure 1: Forest plot of high-grade (grades 2 & 3) pivot shift

Figure 4: Forest plot of post-operative high-grade Lachman (grade 2 & 3)

Figure 5: Forest plot of side-to-side anteroposterior laxity difference.

Figure 6: Forest plot of return to sport rates

Figure 7: Forest plot of post-operative Tegner activity level

Figure 8: Forest plot of post-operative Lysholm score

Figure 9: Forest plots of post-operative IKDC scores

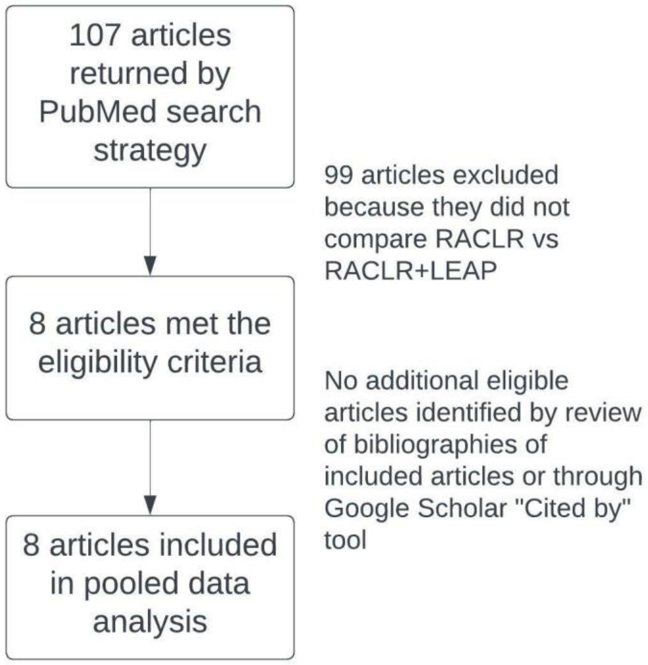
Figure 10a: KOOS symptoms

Figure 10b: KOOS pain

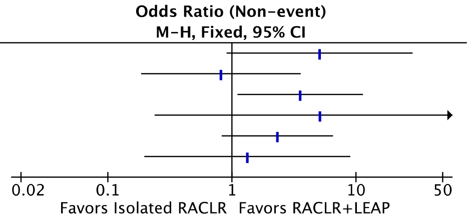
Figure 10c: KOOS ADL

Figure 2d: KOOS Sport

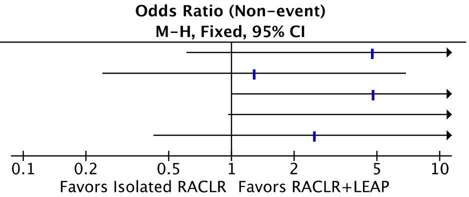
Figure 10e: KOOS QOL


107 articles returned by PubMed search strategy
99 articles excluded because they did not compare RACLR vs RACLR+LEAP
8 articles met the eligibility criteria
No additional eligible articles identified by review of bibliographies of included articles or through Google Scholar "Cited by" tool
8 articles included in pooled data analysis

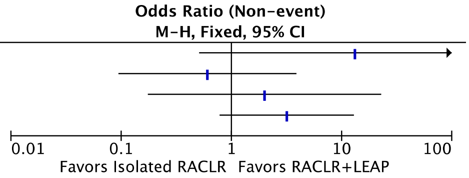
Study or Subgroup	RACLR+LEAP Events	RACLR+LEAP Total	Isolated RACLR Events	Isolated RACLR Total	Odds Ratio (Non-event) M-H, Fixed, 95% CI
Alm 2020	3	59	3	14	5.09 [0.91, 28.60]
Eggeling 2022	3	23	6	55	0.82 [0.19, 3.59]
Helito 2022	4	86	13	88	3.55 [1.11, 11.38]
Lee 2019	0	42	2	43	5.12 [0.24, 109.90]
Trojani 2012	6	84	12	79	2.33 [0.83, 6.54]
Yoon 2021	2	18	3	21	1.33 [0.20, 9.02]



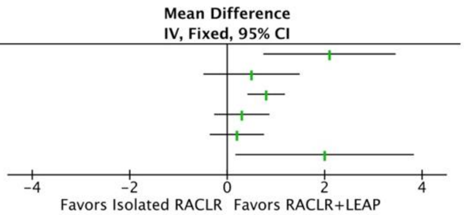
Study or Subgroup	RACLR+LEAP Events	RACLR+LEAP Total	Isolated RACLR Events	Isolated RACLR Total	Odds Ratio (Non-event) M-H, Fixed, 95% CI
Alm 2020	2	59	2	14	4.75 [0.61, 37.14]
Eggeling 2022	2	23	6	55	1.29 [0.24, 6.90]
Helito 2022	2	86	9	88	4.78 [1.00, 22.83]
Lee 2019	0	42	7	43	17.47 [0.96, 316.37]
Yoon 2021	2	18	5	21	2.50 [0.42, 14.83]



Study or Subgroup	RACLR+LEAP Events	RACLR+LEAP Total	Isolated RACLR Events	Isolated RACLR Total	Odds Ratio (Non-event) M-H, Fixed, 95% CI
Alm 2020	0	59	1	14	13.22 [0.51, 342.61]
Eggeling 2022	2	23	3	55	0.61 [0.09, 3.89]
Lee 2019	1	42	2	43	2.00 [0.17, 22.93]
Yoon 2021	4	18	10	21	3.18 [0.78, 12.94]

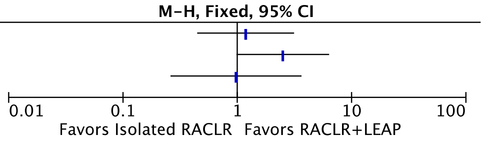


Study or Subgroup	RACLR+LEAP Mean	SD	Total	Isolated RACLR Mean	SD	Total	Mean Difference IV, Fixed, 95% CI
Alm 2020	1.7	1.4	59	3.8	2.5	14	2.10 [0.74, 3.46]
Eggeling 2022	1.3	2	23	1.8	2.1	55	0.50 [−0.49, 1.49]
Helito 2022	1.6	0.9	86	2.4	1.6	88	0.80 [0.42, 1.18]
Lee 2019	1.9	1.3	42	2.2	1.4	45	0.30 [−0.27, 0.87]
Ventura 2021	2.8	0.4	12	3	0.9	12	0.20 [−0.36, 0.76]
Yoon 2021	3.9	3	18	5.9	2.8	21	2.00 [0.17, 3.83]

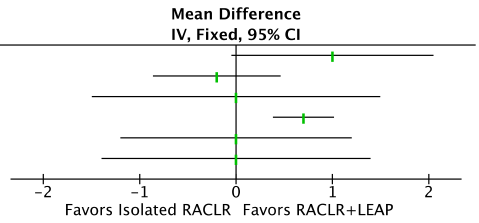


	RACLR+LEAP		Isolated RACLR		Odds Ratio
Study or Subgroup	Events	Total	Events	Total	M–H, Fixed, 95% CI
Eggeling 2022	11	23	24	55	1.18 [0.45, 3.14]
Keizer 2022	22	42	11	36	2.50 [0.98, 6.35]
Lee 2019	37	42	38	43	0.97 [0.26, 3.64]

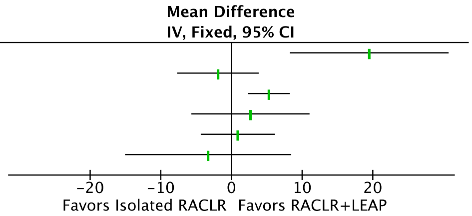
Odds Ratio
M–H, Fixed, 95% CI



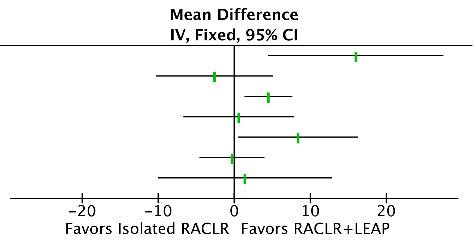
Study or Subgroup	RACLR+LEAP Mean	RACLR+LEAP SD	RACLR+LEAP Total	Isolated RACLR Mean	Isolated RACLR SD	Isolated RACLR Total	Mean Difference IV, Fixed, 95% CI
Alm 2020	7	1.3	59	6	1.9	14	1.00 [−0.05, 2.05]
Eggeling 2022	5.7	1.3	23	5.9	1.5	55	−0.20 [−0.86, 0.46]
Keizer 2022	6	2.2	22	6	2	11	0.00 [−1.50, 1.50]
Lee 2019	7	0.8	42	6.3	0.7	45	0.70 [0.38, 1.02]
Ventura 2021	6	1.5	12	6	1.5	12	0.00 [−1.20, 1.20]
Yoon 2021	4	1.7	18	4	2.7	21	0.00 [−1.40, 1.40]



Study or Subgroup	RACLR+LEAP Mean	RACLR+LEAP SD	RACLR+LEAP Total	Isolated RACLR Mean	Isolated RACLR SD	Isolated RACLR Total	Mean Difference IV, Fixed, 95% CI
Alm 2020	95	10.8	59	75.5	20.8	14	19.50 [8.26, 30.74]
Eggeling 2022	81.9	14.2	42	83.8	14.5	55	−1.90 [−7.66, 3.86]
Helito 2022	87.9	8.7	86	82.6	11.1	88	5.30 [2.34, 8.26]
Lee 2019	90.2	19.4	42	87.5	20.4	45	2.70 [−5.66, 11.06]
Ventura 2021	88.7	6.1	12	87.8	7	12	0.90 [−4.35, 6.15]
Yoon 2021	58.7	16.1	18	62	21.3	21	−3.30 [−15.06, 8.46]



Study or Subgroup	RACLR+LEAP Mean	SD	Total	Isolated RACLR Mean	SD	Total	Mean Difference IV, Fixed, 95% CI
Alm 2020	90	10.7	59	74	21.4	14	16.00 [4.46, 27.54]
Eggeling 2022	77.5	16.2	23	80.1	14.9	55	−2.60 [−10.30, 5.10]
Helito 2022	83.6	9.4	86	79.1	11.7	88	4.50 [1.35, 7.65]
Keizer 2022	81.7	11.8	42	81.1	19.5	36	0.60 [−6.70, 7.90]
Lee 2019	84.3	18.5	42	75.9	19.2	45	8.40 [0.48, 16.32]
Ventura 2021	84.8	6	12	85.1	4.6	12	−0.30 [−4.58, 3.98]
Yoon 2021	57.8	15.7	18	56.4	20.7	21	1.40 [−10.04, 12.84]



Study or Subgroup	RACLR+LEAP Mean	RACLR+LEAP SD	RACLR+LEAP Total	Isolated RACLR Mean	Isolated RACLR SD	Isolated RACLR Total	Mean Difference IV, Fixed, 95% CI
Alm 2020	100	9.7	59	87.6	20.8	14	12.40 [1.23, 23.57]
Eggeling 2022	87.6	15.4	23	87.3	14.8	55	0.30 [−7.11, 7.71]
Keizer 2022	60.7	13.4	42	60.7	20.5	36	0.00 [−7.83, 7.83]

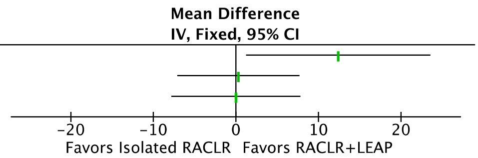


Figure 10a: KOOS symptoms

Study or Subgroup	RACLR+LEAP Mean	RACLR+LEAP SD	RACLR+LEAP Total	Isolated RACLR Mean	Isolated RACLR SD	Isolated RACLR Total	Mean Difference IV, Fixed, 95% CI
Alm 2020	97	6	59	93.2	17	14	3.80 [−5.24, 12.84]
Eggeling 2022	87.9	14.6	23	87.9	14.1	55	0.00 [−7.03, 7.03]
Keizer 2022	91.7	11.8	42	94.4	15.2	36	−2.70 [−8.81, 3.41]

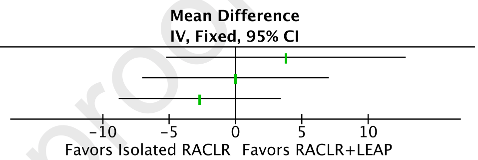


Figure 10b: KOOS pain

Study or Subgroup	RACLR+LEAP Mean	RACLR+LEAP SD	RACLR+LEAP Total	Isolated RACLR Mean	Isolated RACLR SD	Isolated RACLR Total	Mean Difference IV, Fixed, 95% CI
Alm 2020	100	4.1	59	94.3	12.2	14	5.70 [−0.78, 12.18]
Eggeling 2022	95.2	8.2	23	93	10	55	2.20 [−2.07, 6.47]
Keizer 2022	98.5	9.5	42	98.5	17.2	36	0.00 [−6.31, 6.31]

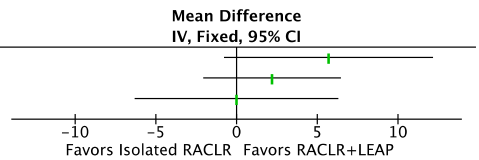


Figure 10c: KOOS ADL

Study or Subgroup	RACLR+LEAP Mean	RACLR+LEAP SD	RACLR+LEAP Total	Isolated RACLR Mean	Isolated RACLR SD	Isolated RACLR Total	Mean Difference IV, Fixed, 95% CI
Alm 2020	95	16.1	59	80	26.3	14	15.00 [0.62, 29.38]
Eggeling 2022	72.6	25.9	23	76	22.7	55	−3.40 [−15.57, 8.77]
Keizer 2022	75	20	42	70	25	36	5.00 [−5.16, 15.16]

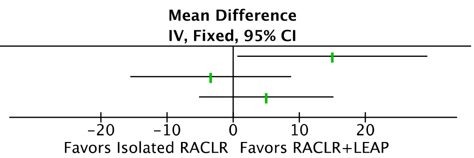


Figure 1d: KOOS Sport

Study or Subgroup	RACLR+LEAP Mean	RACLR+LEAP SD	RACLR+LEAP Total	Isolated RACLR Mean	Isolated RACLR SD	Isolated RACLR Total	Mean Difference IV, Fixed, 95% CI
Alm 2020	68.8	17.7	59	56	24.6	14	12.80 [−0.85, 26.45]
Eggeling 2022	63.8	18.9	23	58.4	19.7	55	5.40 [−3.91, 14.71]
Keizer 2022	53.1	14	42	56.3	18.7	36	−3.20 [−10.63, 4.23]

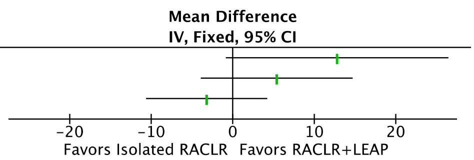


Figure 10e: KOOS QOL