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SYSTEMATIC REVIEW

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Hamstring tendon graft with LARS augmentation showed superior short-term clinical efficacy compared to hamstring tendon alone as graft in ACL reconstruction: a systematic review and meta-analysis

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Abstract

Background There have been emerging clinical trials investigating the efficacy of synthetic-graft-augmented autografts in anterior cruciate ligament reconstruction (ACLR) in recent years. Hamstring tendon and Ligament Augmentation and Reconstruction System (LARS) are both widely discussed graft choices for ACLR.

Purpose To compare the clinical efficacy of hamstring tendon grafts with LARS-augmented hamstring tendon grafts in ACLR.

Study Design Systematic review and meta-analysis.

Method A systematic literature search was performed in PubMed, Embase and the Cochrane Library to identify primary evidence related to the comparison of ACLR with a hamstring tendon (HT) versus a hamstring tendon with LARS (HT + LARS). Quality assessment of the included studies was conducted using Newcastle–Ottawa Scale for non-RCTs. Quantitative analysis was conducted with Reviewer Manager 5.4. The primary outcomes compared were the Lysholm scale, Tegnar activity scale, International Knee Documentation Committee (IKDC) evaluation, KT-1000-based laxity, complication/retear rate and rate of return-to-sports. The secondary outcomes were the Knee Injury and Osteoarthritis Outcomes Score (KOOS), Global Rating of Change (GRC) scale, hop tests, isokinetic knee strength tests and radiographic and arthroscopic evaluations.

Results Six cohort studies with 710 participants were included in this study. Compared with the HT group, the HT + LARS group had better Lysholm scores at the 1-year follow-up ($P = 0.0007$) and at the final follow-up ($P = 0.04$). HT + LARS group had better IKDC scores at the 1-year follow-up ($P = 0.003$). The HT + LARS group had a better return-to-sports rate in short term. No significant difference in complications or re-surgery was observed. The secondary results revealed superior or non-inferior outcomes in the HT + LARS group.

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Conclusions As grafts for ACLR, the use of hamstring tendons with LARS augmentation, compared with the use of hamstring tendons alone, in the short term, has significantly superior overall functional results and better early sports participation and non-inferior results in other comparisons. In the long term, the use of hamstring tendon with LARS augmentation demonstrated non-inferior results in terms of functional scores, knee stability, knee strength, complications and re-tear rate, etc.

Keywords Anterior cruciate ligament reconstruction, Artificial/synthetic graft, LARS, Hamstring tendon graft

Introduction

The anterior cruciate ligament (ACL) is pivotal for resisting anterior tibial translation and rotational loads [1], and ACL deficiency usually leads to collateral meniscus and cartilage damage, increasing the long-term risk of knee osteoarthritis [2–4]. Anterior cruciate ligament reconstruction (ACLR) is widely considered a standardized treatment for ACL rupture [5, 6]. The most important purpose of ACLR is to restore the stability and function of the injured knee [7, 8].

One of the primary goals of ACLR is to help patients return to sports, especially young and physically active individuals. People who undergo ACLR usually have high expectation of returning to their pre-injury level of sports activity[9]. One study demonstrated that 81% of people returned to some form of sport after ACLR surgery, 65% returned to their previous level of sport, and 55% returned to competitive sports [10]. Thus, the quality of the reconstructed ligament is highly emphasized, and the function of the operated knee is highly valued. Notably, there is a moderate incidence of failure or re-rupture after ACLR, which requires revision surgery, especially considering the need to return to sports [11–14].

Multiple factors contribute to the failure or re-rupture of the reconstructed ACL, among which graft choice has been widely discussed [15–17]. Traditionally, surgeons tend to use autologous grafts to reconstruct the ACL due to theoretically better biological healing capacity, lower antigenicity, and lower chance of infection or disease transmission [18]. Commonly used autologous grafts include bone-patellar-bone (BTB), quadriceps tendon and hamstring tendon grafts [19]. In recent years, synthetic grafts for ACLR have also been studied worldwide. Compared to autologous grafts, synthetic grafts are believed to possess the advantages of sparing the donor site, providing tensile strength, and allowing for early rehabilitation and accelerated recovery [20, 21]. The Ligament Augmentation and Reconstruction System (LARS) has been the most popular choice for either substituting for an autograft or augmenting an autograft [20, 22–28]. However, there is still hesitation toward the use of synthetic grafts because of the reported higher rate of failure, higher incidence of synovitis and earlier onset of secondary knee osteoarthritis [29–32]. Another way to use synthetic grafts is to augment the autograft, either due to the inadequate size and strength of the autograft or the greater demand for intensive sports. *Man* et al. [33] conducted a meta-analysis evaluating the efficacy of augmented autografts versus autografts alone in ACLR, and found that there was no significant advantage comparing the results at the final follow-up. However, since LARS has been reported to facilitate early recovery, it remains unclear whether there is an advantage in the early rehabilitation stage with LARS-augmented autografts.

This study aims to investigate the clinical outcomes of patients who underwent surgery with either the hamstring tendon alone or the hamstring tendon augmented with LARS at both the early stage and long-term follow-up. With a systematic approach, we strive to provide a comprehensive comparison of subjective patient-reported outcomes (Lysholm scale, Tegnar activity scale, IKDC, etc.), KT-1000-Arthrometer-based stability assessment, return-to-sports rate, isokinetic knee strength tests, hop tests, complications and radiographic and arthroscopic evaluations. This study is intended to bring more attention to the potentials of LARS-augmented autografts in clinical settings.

Methods

Literature review and study selection

This study was conducted according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [34]. Two independent researchers systematically searched and reviewed the studies in PubMed, Embase and the Cochrane Library. The keywords applied in the search were "Anterior cruciate ligament OR ACL" and "LARS OR The Ligament Augmentation and Reconstruction System OR Ligament advanced reinforcement system OR synthetic ligament OR artificial ligament". A manual search and confirmation were also conducted. Differences between researchers were settled by discussion. A senior surgeon was consulted if needed. This meta-analysis review protocol was registered on PROSPERO

(International Prospective Register of Systematic Reviews; Registration Number CRD42024467546).

Inclusion and exclusion criteria

Two researchers independently searched the databases mentioned above. Inclusion criteria:

(1) Participants: Hamstring tendon graft alone and hamstring tendon with LARS artificial ligament for patients with ACL injury; (2) Interventions and comparisons: There were at least two study groups in ACLR with either Hamstring tendon graft or hamstring tendon with LARS, and the type of graft fixation was not limited; (3) Outcome measure: the outcome assessments included at least one of the following measures including patient-reported functional scores, knee stability, complications, return-to-sports rate, knee strength and hop tests [35]; (4) Study design: RCTs, retrospective and prospective cohort studies that compared hamstring tendon alone with hamstring tendon with LARS for ACL reconstruction.

The following studies were excluded: case reports, reviews, editorial letters, expert opinions or non-comparative studies.; studies failing to clearly report the data that met our interest; studies with follow-up time less than 1 year; and biomechanical or animal studies. A study was also excluded if data from the same patients were reported in another study with longer follow-ups.

Data extraction

Two researchers independently conducted these processes and resolved disagreements by discussion. A senior surgeon was consulted if needed. Eligible studies were assessed and data pertaining to demographics, interventions used, surgical techniques, outcome measures used, and results were extracted. Hamstring Tendon with LARS (HT + LARS) was compared with Hamstring Tendon alone (HT). Primary outcomes included Lysholm scores, Tegnar activity scores, the International Knee Documentation Committee (IKDC) evaluation forms, KT-1000-Arthrometer-based knee stability (side-to-side differences, laxity), complications/ retear rates and return-to-sports (RTS) rates. Secondary outcomes included the Knee Injury and Osteoarthritis Outcomes Score (KOOS), isokinetic knee strength, hop tests (single hop distance (SHD), triple hop distance (THD), triple crossover hop/ crossover hop distance (TCHD) and 6-min timed hop (6MTH)) and radiographic and arthroscopic evaluations. The results of the hop tests and isokinetic knee strength tests were reported in the form of Limb Symmetric Indices (LSIs) as a functional comparison between the operated and non-operated knee. The primary follow-up times were 12 months, 24 months, or long-term (more than 2 years) post-operatively. The outcomes were also compared at the final follow-up despite the different lengths of follow-up time in each study. Comparisons were made based on data availability provided by individual studies.

Quality assessment

Quality assessment of the included studies was conducted using the Newcastle–Ottawa Scale for non-RCT cohort studies (available at https://www.ohri.ca/programs/clinical_epidemiology/oxford.asp). Two researchers independently assessed the included studies and settled disagreements by discussion. A senior surgeon was consulted if needed.

Statistical analysis

The quantitative meta-analysis was performed using Review Manager 5.4 (Cochrane Collaboration). Dichotomous variables were expressed in terms of the risk ratio (RR) and 95% confidence interval (CI), while pooled results for continuous variables were expressed as the mean difference (MD) and 95% CI. Heterogeneity was assessed via the I^2 test ($I^2 > 50\%$ was considered to indicate important heterogeneity). Either a fixed-effects model or random-effects model was applied to outcome data based on heterogeneity. A fixed-effects model was used to demonstrate data of unimportant heterogeneity ($I^2 \leq 50\%$) and a random-effects model was used for data showing important heterogeneity ($I^2 > 50\%$). $P < 0.05$ was considered to indicate statistical significance.

Results

Search results and inclusion

A flow chart is shown in Fig. 1. Overall, 374 results were obtained from the three databases. After the initial screening, 24 articles that required further full-text review were identified. After the exclusion of 18 articles that did not compare HT with HT + LARS, 6 studies with 710 participants were included [20, 24–27, 36] in the final review.

Study characteristics

The 6 studies were published between 2010 and 2023, including 710 participants in total. There were 313 participants in the HT + LARS group, among whom 232 were male (74.1%), while in HT group there were 397 participants, among which 275 were male (69.2%). The age of the participants ranged from 16 to 56 years. The follow-up time ranged from 1 to 10 years, and the time between injury occurrence and surgery ranged from 1 to 34 months. All studies were retrospective or prospective cohort studies and no RCT was available. Four of the studies used the single-bundle technique, one study

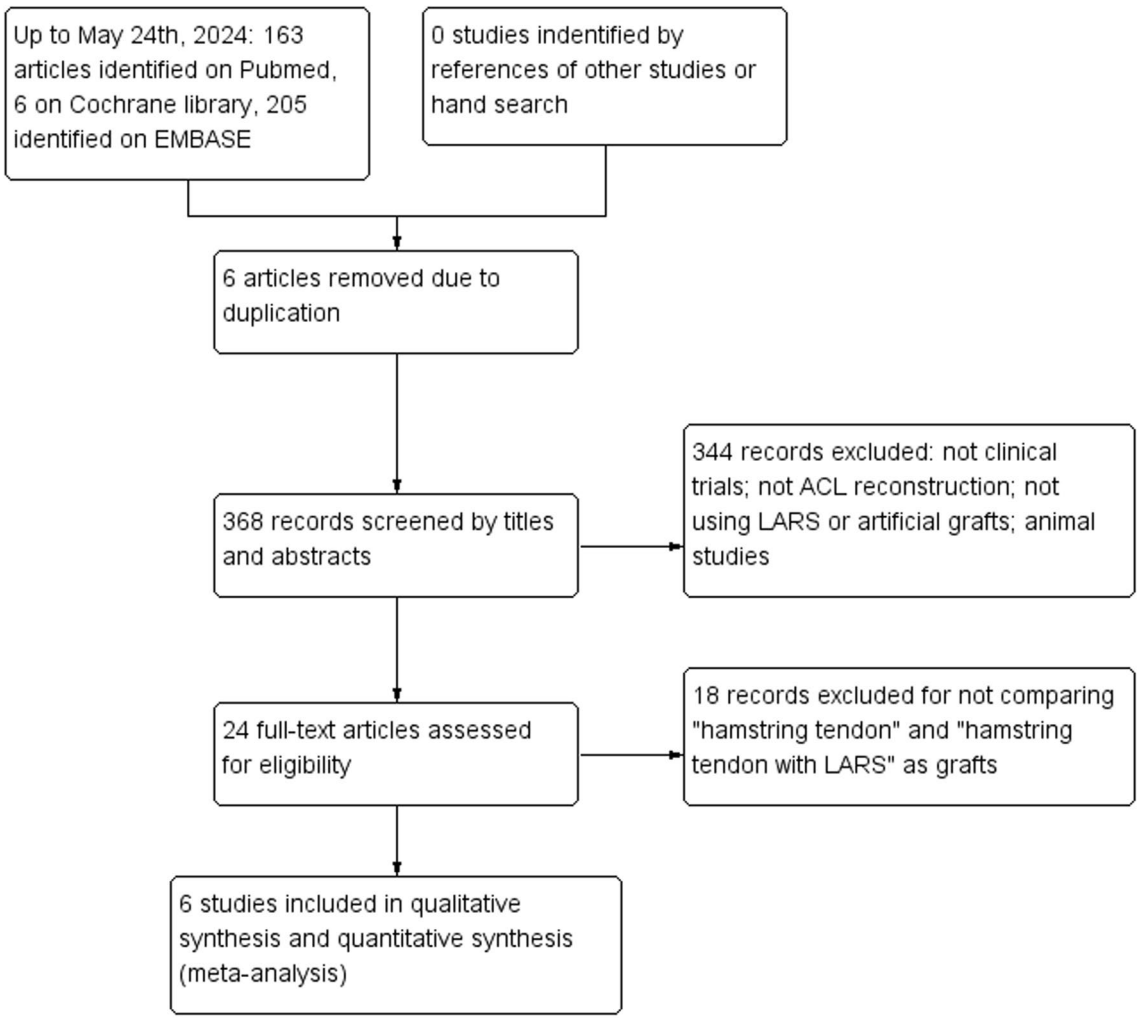

Fig. 1 Study selection flowchart

used the double-bundle technique and one study did not specify the surgical technique used. Four studies were conducted under arthroscopy. Three of the studies mentioned the number of concomitant meniscectomy or meniscus repair procedures, while one study mentioned conducting aforementioned procedures based on arthroscopic evaluation and necessity, with no specific details. The full demographic information is shown in Table 1.

Assessment of risk of bias

Quality assessment of the studies was conducted using the Newcastle–Ottawa Scale (Table 2). All studies had total scores no less than 8.

Primary outcomes

Functional scores

1. Lysholm scores

   Comparisons were made at 1 year (3 studies), 2 years (2 studies) and long-term (3 studies) post-operatively. And a comparison was also made among the results at the final follow-up (6 studies) (Fig. 2). For the Lysholm score, the HT + LARS group showed better results at the 1-year follow-up (WMD 2.45; 95% CI 1.04–3.87; $I^2 = 63\%$; $P = 0.0007$) and at the final follow-up (WMD 1.78; 95% CI 0.11–3.44; $I^2 = 78\%$; $P = 0.04$), and non-inferior results at the 2-year follow-up and long-term follow-up (n.s.).
2. Tegnar activity scores
   Two studies reported Tegnar scores at the 1-year and the 2-year follow-ups, and 3 studies reported long-

Table 1 Characteristics of the included studies

Study	Study type	Surgical technique	Arthroscopy	Fixation	
				Femur	Tibia
Zaid [20]	Prospective (Level II)	Single-bundle	Yes	Endobutton (Smith and Nephew)	Interference screw (Smith and Nephew) and titanium staple (Citieffe)
Ebert [24]	Retrospective (Level III)	Double-bundle	Not specified	Endobutton (Smith and Nephew)	Intra-fix screw and Milagio advance screw (DePuy)
Zhang [36]	Retrospective (Level III)	Single-bundle	Yes	tight cord (Arthrex)	Bioabsorbable screw (Arthrex)
Aujla [25]	Retrospective (Level III)	Single-bundle	Not specified	Endobutton (Smith & Nephew)	Intra-fix screw (DePuy)
Hamido [26]	Retrospective (Level III)	Single-bundle	Yes	Cross-Pin System (Mitek)	Bioabsorbable screw
Liu [27]	Retrospective (Level III)	Not specified	Yes	Interference screw	Interference screw

Study	Group	n	Age mean ± SD (Range)	Male n (%)	BMI mean ± SD (Range)	Follow-up time mean ± SD (Range)	Time between injury to surgery mean ± SD (Range)	Concomitant meniscectomy n (%)	Concomitant meniscus repair n (%)
Zaid [20]	HT	89	27.5 ± 5.8	60 (67.4)	25.3 ± 3.0	2 y	2.8 ± 1.4 m	64 (71.9)	20 (22.4)
	HT + LARS	89	28.2 ± 4.7	65 (73.0)	24.8 ± 2.7	2 y	2.4 ± 1.7 m	69 (77.5)	20 (22.4)
Ebert [24]	HT	69	30.8 ± 10.6, (16–49)	44 (63.8)	26.0 ± 3.1, (20.0–34.3)	7.7 ± 0.6, (7–9.5) y	11.6 ± 12.8, (2–52) w	7 (10.1)	16 (23.2)
	HT + LARS	67	31.1 ± 9.3, (16–49)	45 (67.2)	26.2 ± 3.1, (20.3–32.8)	7.9 ± 0.9, (7–10) y	12.8 ± 8.7, (2–52) w	9 (13.4)	16 (23.9)
Zhang [36]	HT	32	33 (21–42)	24 (75)	N/A	12 m	3.6 m (1–8)	N/A	
	HT + LARS	36	27 (17–37)	30 (83.3)		12 m	2.2 m (1–6)		
Aujla [25]	HT	130	27.5 ± 8.6	79 (60.8)	25.3 ± 3.2	2 y	14.2 ± 31.2 w	10 (7.7)	47 (36.2)
	HT + LARS	66	26.8 ± 9.5	44 (66.7)	24.7 ± 3.7	2 y	14.8 ± 21.9 w	8 (12.1)	26 (39.4)
Hamido [26]	HT	45	20 (18–31)	44 (97.8)	N/A	59 m (58–62)	8 m (6–29)	N/A	
	HT + LARS	27	24 (21–35)	27 (100)		59 m (58–62)	7 m (6–31)		
Liu [27]	HT	32	32 (20–56)	24 (75)	N/A	49 m (48–52)	9 m (5–33)	Yes (number not specified)	
	HT + LARS	28	36 (18–54)	21 (75)		49 m (48–52)	8 m (4–34)		

Study	Group	Graft
Zaid [20]	HT	4-strand hamstring tendon graft with semitendinosus and gracilis tendon (4-strand ST/G)
	HT + LARS	4-strand hamstring tendon graft with semitendinosus and gracilis tendon + LARS (4-strand ST/G/ + LARS)
Ebert [24]	HT	Anteromedial bundle: 2-strand semitendinosus tendon; Posterolateral bundle: 2-strand gracilis tendon
	HT + LARS	Anteromedial bundle: 2-strand LARS; Posterolateral bundle: 2-strand gracilis tendon
Zhang [36]	HT	4-strand ST/G
	HT + LARS	2-strand LARS-augmented semitendinosus tendon
Aujla [25]	HT	4-strand ST/G
	HT + LARS	(4-strand ST/G/ + LARS)
Hamido [26]	HT	4-strand ST/G
	HT + LARS	(4-strand ST/G/ + LARS)
Liu [27]	HT	4-strand ST/G
	HT + LARS	(4-strand ST/G/ + LARS)

y, year; m, month; w, week; N/A, not available; HT, hamstring tendon; LARS, ligament augmentation and reconstruction system.

term Tegnar score results. The HT + LARS group showed better results at the 1-year (WMD 1.02; 95% CI 0.67–1.37; $I^2 = 0\%$; $P < 0.0001$) and 2-year (WMD 0.46; 95% CI 0.16–0.76; $I^2 = 0\%$; $P = 0.03$) follow-ups (Fig. 3), and non-inferior result at long-term follow-up (n.s.). Comparing the Tegnar scores at the final follow-up, the HT + LARS group also demonstrated

Table 2 Quality evaluation of observational trials using the Newcastle–Ottawa Scale

Study	Selection	Comparability	Outcome	Total score
Zaid [20]	4	2	3	9
Ebert [24]	4	2	3	9
Aujla [25]	4	2	2	8
Hamido [26]	3	2	3	8
Liu [27]	3	2	3	8
Zhang [36]	4	2	3	9

The Newcastle–Ottawa Scale uses the semiquantitative principle of scoring system to evaluate the quality of literature, with a full score of 9.

better outcomes (WMD 0.48; 95% CI 0.22–0.73; $I^2=44\%$; $P=0.0002$).

3. International Knee Documentation Committee (IKDC) evaluation
   Comparisons were made at the 1-year follow-up (3 studies) and the final follow-up (4 studies) (Fig. 4). HT + LARS showed significantly better results at the 1-year follow-up (WMD 2.22; 95% CI 0.75–3.70; $I^2=60\%$; $P=0.003$) but the difference was no longer statistically significant at the final follow-up (n.s.).

KT-1000-arthrometer-based laxity

Five studies reported KT-1000-based laxity. The results reported were side-to-side differences (mm) and were further categorized as normal (< 3 mm), nearly normal (3–6 mm), abnormal (6–10 mm) or severely abnormal (> 10 mm). Five of the studies reported the number of normal (< 3 mm) participants in the outcome. Both the side-to-side differences and percentage of normal (< 3 mm) individuals were compared (Fig. 5) but there were no significant differences (n.s.). Notably, however, *Hamido* et al. [26] and *Liu* et al. [27] reported numbers of abnormal (6–10 mm) participants in the HT group, which were 4 (8.9%) and 3 (9.4%), respectively. There were no reported severely abnormal (> 10 mm) results in any of the studies.

Complications and revision surgeries

The reported complications (infections, paresthesia, arthrofibrosis, secondary ligament or meniscus injuries and etc.) were listed in Table 3 in detail. Further analysis was shown in Fig. 6. However, there was no significant statistical difference between the groups (n.s.).

Return-to-sports rate

All statistically significant differences were observed within 1 year post-operatively and with HT + LARS group being the superior group (Table 4). *Zaid* et al. [20] reported that at the 6-month follow-up, 75 of 84 patients (89.3%) in the HT + LARS group participated in Noyes [37] level 3 (1–3 times per month) sports, compared to 49 of 84 (58.3%) in the HT group ($P=0.02$). At 12 months, 75 of 80 (93.6%) patients in the HT + LARS group participated in level 1 (4–7 times per week) sports, while 59 of 81 (72.8%) patients in the HT group did ($P=0.03$). However, the difference subsided at 24 months.

Ebert et al. [24] reported that 52 (77.6%) participants in the HT + LARS group returned to pivoting sports after ACLR, compared to 53 (76.8%) in the HT group.

Aujla et al. [25] reported that at 12 months, 54 of 66 (81.8%) patients in the HT + LARS group return to Noyes level 1 (4–7 times per week) or 2 (1–3 times per week) sports, compared to 86 of 130 (66.2%) in the HT group ($P=0.029$). The difference was no longer significant at 24 months.

As for the rate of returning to pre-injury sports, *Zaid* et al.[20] reported that at 24 months, 76 of 78 patients (97.4%) in the HT + LARS group and 71 of 80 (88.8%) in the HT group ($P=0.164$) returned to participate in the sports they played before injury. *Aujla* et al. [25] reported that at 12 months, 34 of 66 (51.5%) participants in the HT + LARS group and 37 of 130 (28.5%) participants in the HT group ($P=0.003$) returned to pre-injury sports, while at 24 months, there was no significant difference. *Aujla* et al. [25] also reported that comparing 24 months with 12 months, HT group had a significant increase in percentage of returning to pre-injury sports ($P=0.001$) while HT + LARS group had no significant improvement (n.s.).

Secondary outcomes

Knee injury and osteoarthritis outcomes score (KOOS) evaluation

Comparisons were made at the 1-year and the 2-year follow-ups. The HT + LARS group showed prominent superiority at the 1-year follow-up in both the KOOS-Sports/Recreation and KOOS-Quality of Life categories ($P=0.007$ and $P=0.02$, respectively). The other results were not statistically important. The detailed results were shown in Table 5.

Global rating of change (GRC) scale

This scale was used to evaluate patients' self-perceived changes [38] before and after surgery. Only *Aujla* et al. [25] and *Zaid* et al. [20] reported GRC scales at the 1-year and 2-year follow-ups. The HT + LARS group prevailed in both comparisons ($P=0.03$ and $P=0.004$). The detailed results were shown in Table 5.

Hop tests

The single hop distance (SHD), triple hop distance (THD), triple crossover hop/ crossover hop distance (TCHD), and 6-min timed hop (6MTH) results were also reported in the form of LSIs. Comparisons were made at the 1-year follow-up and final follow-up. The results were not significantly different (n.s.). The detailed results were shown in Table 5.

Isokinetic knee strength test

Both knee extensor strength and flexor strength were compared at the 1-year and 2-year follow-ups. The results were shown in the form of LSIs. Both groups

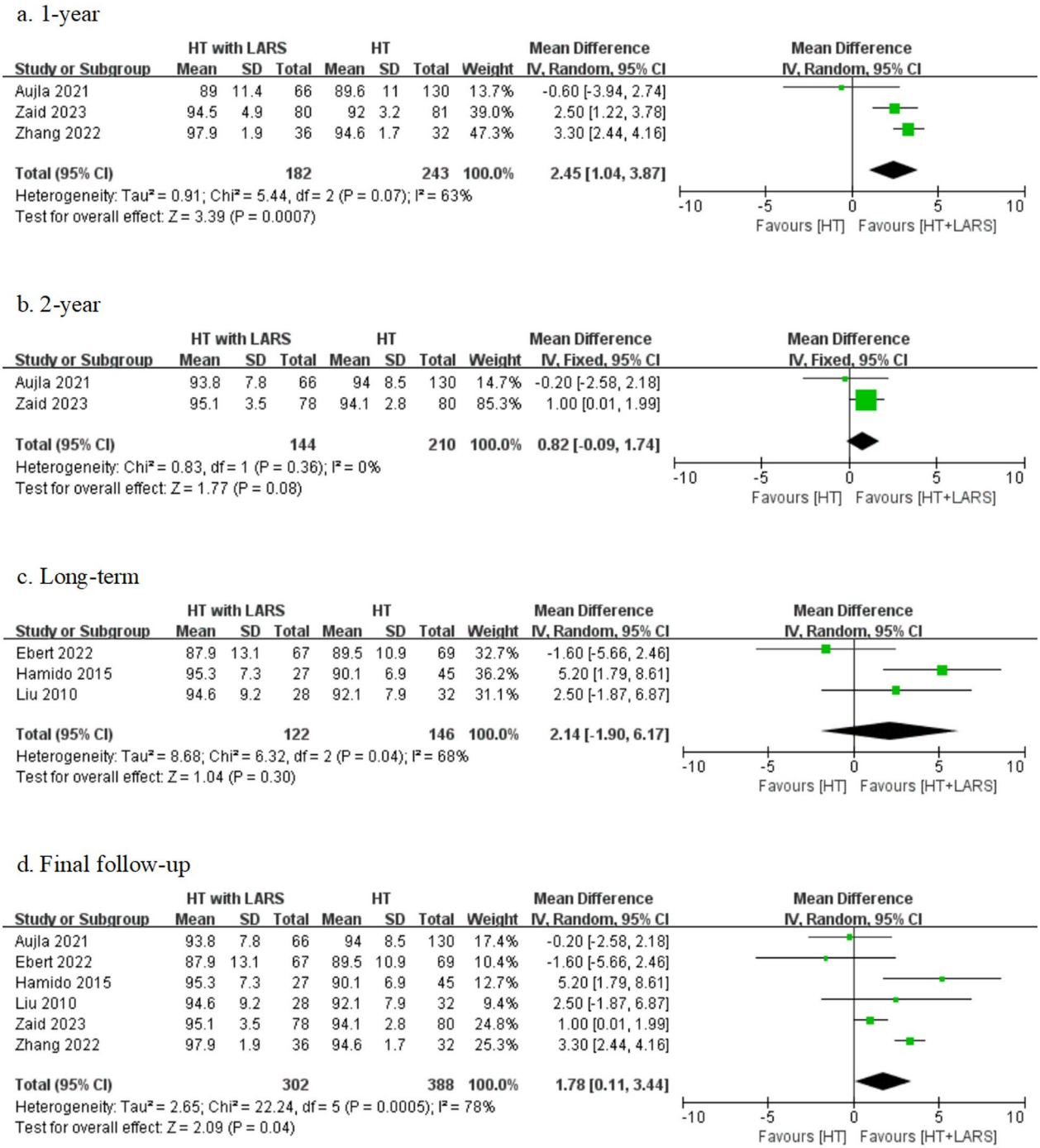

Fig. 2 **a**–**d** show forest plots of Lysholm scores at 1-year, 2-year, Long-term and Final follow-up, respectively. *CI* confidence interval, *IV* inverse variance, *df* degrees of freedom, *SD* standard deviation

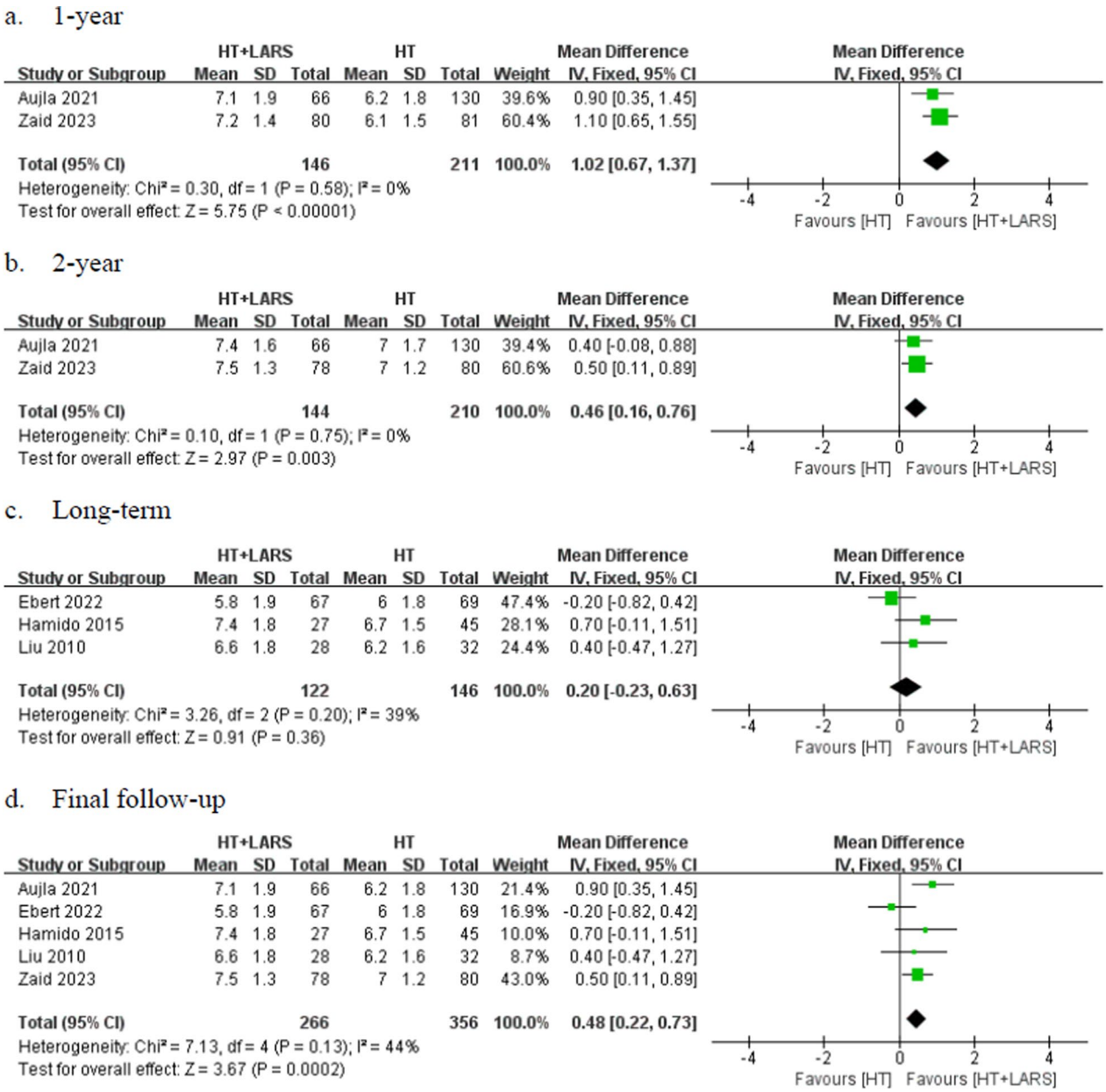

Fig. 3 **a**–**d** show forest plots of Tegnar scores at the 1-year, 2-year, Long-term and Final follow-ups, respectively. *CI* confidence interval, *IV* inverse variance, *df* degrees of freedom, *SD* standard deviation

had similar results in all comparisons. The detailed results were shown in Table 5.

Radiographic and arthroscopic evaluation

Both *Zaid* et al. [20] and *Ebert* et al. [24] used MRI to evaluate patients at follow-up. *Zaid* et al. [20] reported Signal Noise Quotient (SNQ) to represent the signal intensity of the reconstructed ACL, where *SNQ=(signal of the ACL graft—signal of the quadriceps tendon)/signal of the background*, aiming to assess the maturity of the graft. The results showed no significant difference at 3 months, 6 months, 12 months or 24 months (n.s.). *Ebert* et al. [24] used the Whole Organ Magnetic Resonance Imaging Score (WORMS) to evaluate the post-operative knee status. WORMS was applied to the medial tibiofemoral joint (MTFJ), the lateral tibiofemoral joint (LTFJ), the patellofemoral joint (PFJ), and the S region (region of the tibia beneath the tibial spine) to evaluate adverse effects on the cartilage, bone, meniscus, etc. The results demonstrated that both adverse features and WORMS

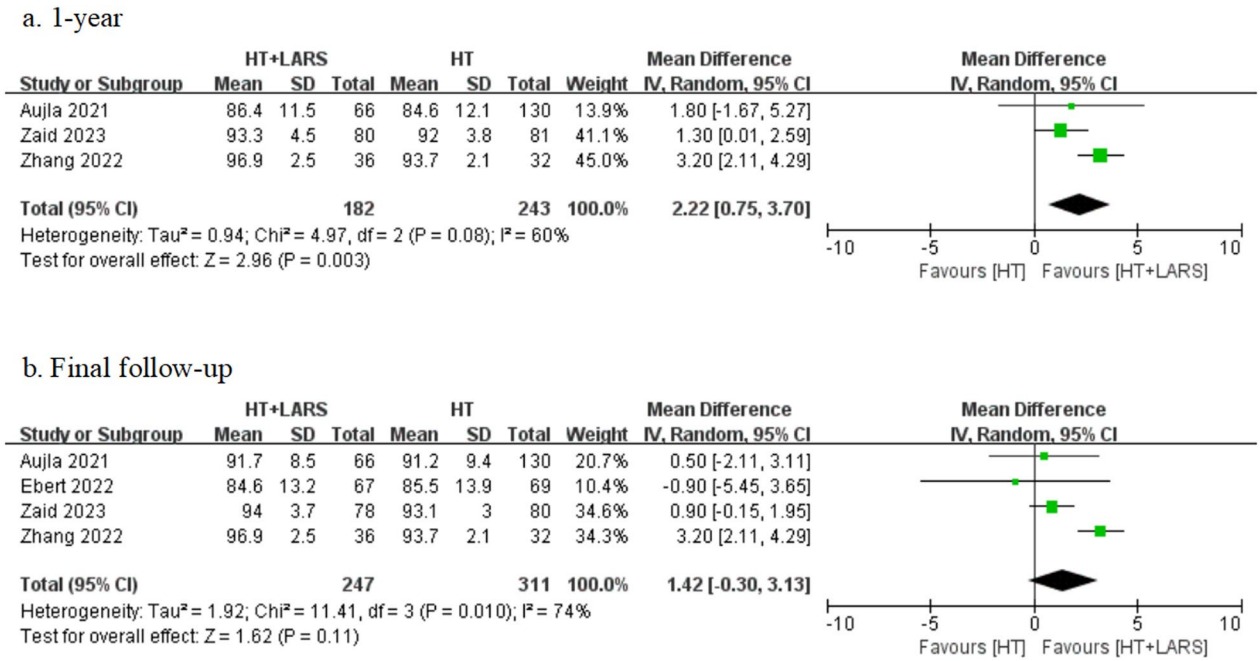

Fig. 4 **a**, **b** show forest plots of IKDC scores at the 1-year follow-up and Final follow-up. *CI* confidence interval, *IV* inverse variance, *df* degrees of freedom, *SD* standard deviation

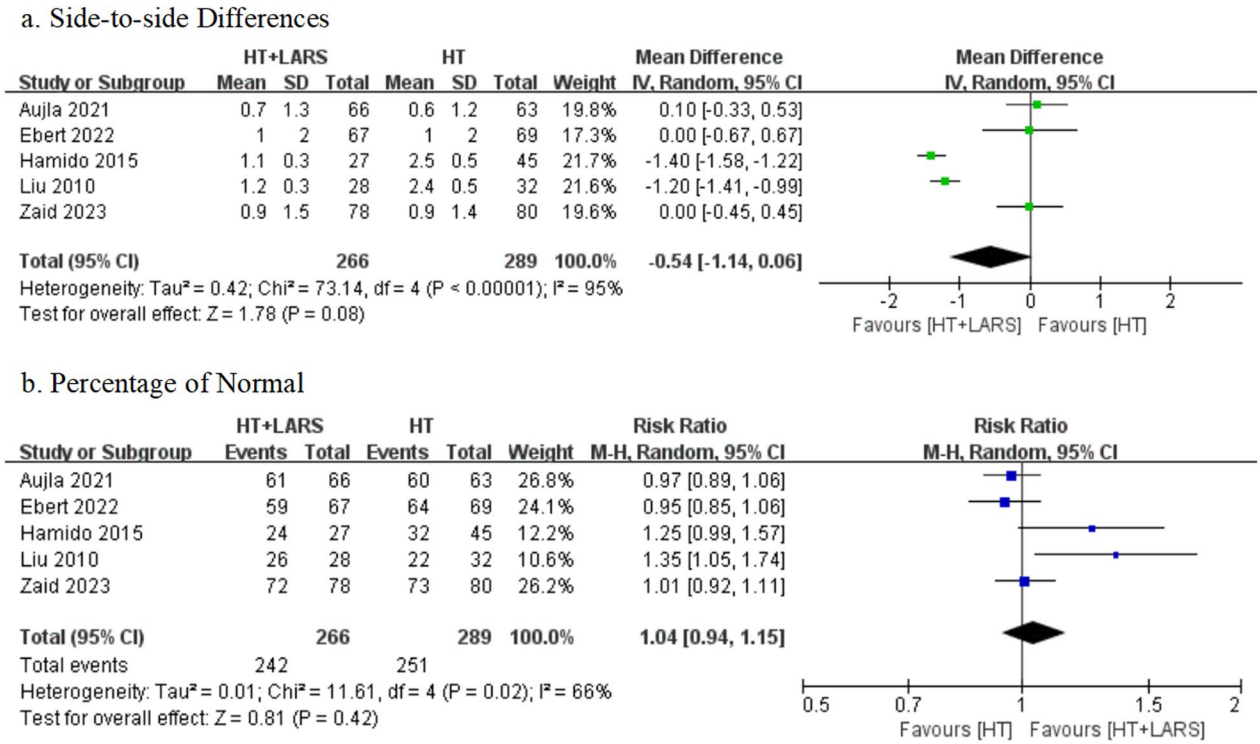

Fig. 5 KT-1000-based-laxity evaluations. **a** Side-to-side differences; **b**: percentage of Normal (laxity < 3 mm). *IV* inverse variance, *CI* confidence interval, *SD* standard deviation, *df* degrees of freedom, *M-H* Mantel–Haenszel

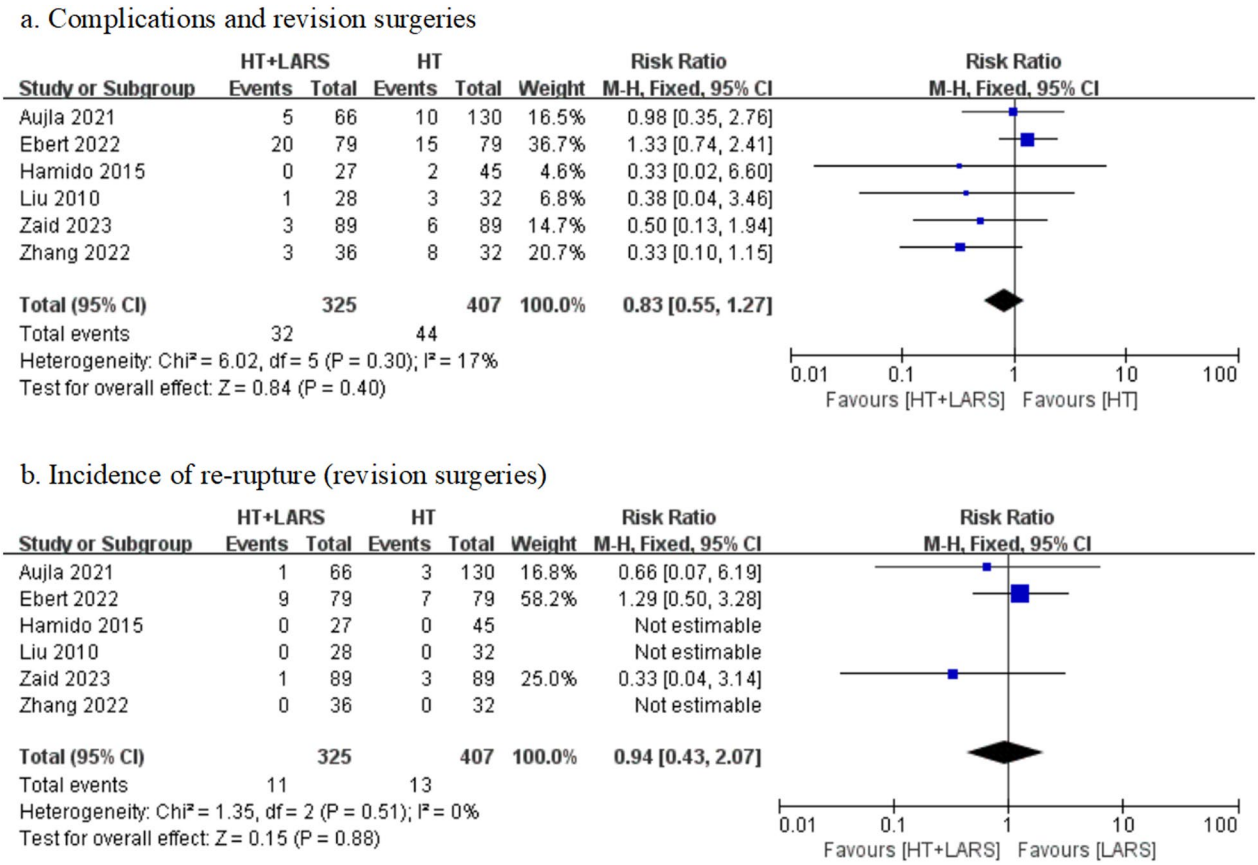

Fig. 6 Forest plots of complications and revision surgeries in each study (**a**) and incidence of ACL re-rupture requiring revision surgery (**b**). *IV* inverse variance, *CI* confidence interval, *SD* standard deviation, *df* degrees of freedom, *M-H* Mantel–Haenszel

Table 3 Complications reported in each study

Study	HT + LARS				HT			
	Patients at FU n	Complications n	Percentage of complications	Description of complications	Patients at FU n	Complications n	Percentage of complications	Description of complications
Zaid [20]	89	3	3.4%	2 infections, 1 revision surgery	89	6	6.7%	3 infections, 3 revision surgeries
Ebert [24]	79	20	25.3%	11 non-ACL surgeries, 9 revision surgeries	79	15	19.0%	8 non-ACL surgeries, 7 revision surgeries
Zhang [36]	36	3	8.3%	2 crepitus, 1 infection	32	8	25.0%	6 crepitus, 2 loss of ROM
Aujla [25]	66	5	7.6%	1 infection, 3 non-ACL surgeries, 1 revision surgery	130	10	7.7%	1 infection, 6 non-ACL surgeries, 3 revision surgeries
Hamido [26]	27	0	0.0%	none	45	2	4.4%	1 paresthesia, 1 arthrofibrosis
Liu [27]	28	1	3.6%	1 pain with screw	32	3	9.4%	2 loss of ROM, 1 arthrofibrosis

ACL anterior cruciate ligament, *FU* follow-up, *ROM* range of motion, *HT* hamstring tendon, *LARS* ligament augmentation and reconstruction system.

"Non-ACL surgeries" means that patients experienced complications that required surgery but not ACL revision surgery.

Table 4 Return-to-sports comparisons

Study	Follow-up time	Level of Sports	Percentage of participation		*P*
			HT + LARS (%)	HT (%)	
Zaid [20]	6 months	Noyes Level 3	89.3	58.3	0.020
Zaid [20]	12 months	Noyes Level 1	93.6	72.8	0.030
Aujla [25]	12 months	Noyes Level 1 or 2	81.8	66.2	0.029
Aujla [25]	12 months	Pre-injury Sports	51.5	28.5	0.003

HT hamstring tendon, *LARS* ligament augmentation and reconstruction system.

Table 5 Summary of secondary outcomes

Comparison	Subgroups	Included studies	Test of homogeneity		Fixed-effects model or Random-effects model*		Test of effect	Favored group
			P	I^2 (%)	Mean Difference	95% CI	*P*	
KOOS-Pain	1-year	2	0.22	33	−0.92	−2.84, 0.99	n.s	
	2-year	2	0.44	0	0.19	−1.2, 1.98	n.s	
KOOS-Symptoms	1-year	2	0.07	70	−0.5*	−4.31, 3.31*	n.s	
	2-year	2	0.28	14	−0.1	−1.73, 1.52	n.s	
KOOS-Activity of Daily Life	1-year	2	0.04	76	0.12*	−3.30, 3.54*	n.s	
	2-year	2	0.68	0	−1.95	−3.86, −0.04	n.s	
KOOS-Sports/ Recreation	1-year	2	0.66	0	4.77	1.31, 8.23	0.007	HT + LARS
	2-year	2	0.18	45	0.18	−2.40, 2.76	n.s	
KOOS-Quality of Life	1-year	2	0.40	0	3.71	0.65, 6.77	0.02	HT + LARS
	2-year	2	0.39	0	1.69	−0.58, 3.95	n.s	
GRCs	1-year	2	0.65	0	0.49	0.06, 0.92	0.03	HT + LARS
	2-year	2	0.47	0	0.39	0.12, 0.66	0.004	HT + LARS
Single Hop Distance	1-year	2	0,87	0	0.12	−2.28, 2.51	n.s	
	Final follow-up	3	0.06	65	−0.38*	−2.92, 2.21*	n.s	
Triple Hop Distance	1-year	2	0.97	0	−0.65	−3.18, 1.87	n.s	
	Final follow-up	3	0.09	58	0.37*	−2.07, 2.82*	n.s	
Triple Crossover Hop Distance	1-year	2	0.49	0	−0.08	−2.64, 2.69	n.s	
	Final follow-up	3	0.04	68	−1.15*	−4.0, 1.69*	n.s	
6-min Timed Hop	1-year	2	0.48	0	1.27	−1.25, 3.79	n.s	
	Final follow-up	3	0.11	54	−0.02*	−0.28, 0.25*	n.s	
Knee Extension	1-year	2	0.93	0	0.77	−2.45, 3.99	n.s	
	Final follow-up	3	0.40	0	0.47	−1.40, 2.33	n.s	
Knee Flexion	1-year	2	0.76	0	0.08	−3.10, 3.26	n.s	
	Final follow-up	3	0.41	0	−0.62	−3.06, 1.81	n.s	

A fixed-effects model was used to demonstrate data of unimportant heterogeneity ($I^2 \leq 50\%$) and a random-effects model (marked with *) was used for data showing important heterogeneity ($I^2 > 50\%$). $P < 0.05$ was considered with statistical significance. *KOOS* Knee injury and Osteoarthritis Outcome Score, *GRCs* Global Rate of Change scales, *HT* hamstring tendon, *LARS* ligament augmentation and reconstruction system, *CI* confidence interval, *n.s.* not significant ($P \geq 0.05$).

scores were similar between the HT and HT + LARS groups with no statistically significant differences.

Zaid et al. [20] employed an arthroscopic second-look for 49 (55.1%) participants in the HT + LARS group and 46 (51.7%) in the HT group. The study reported no significant intergroup differences regarding graft tension, graft tears, or synovial coverage. Menisci were mostly healed in both groups similarly.

Discussion

In this systematic review and meta-analysis, we found that, as grafts for ACLR, the HT + LARS group, in the short term, had superior overall functional outcomes, better early sports participation and non-inferior results in other comparisons. In the long term, HT+LARS group demonstrated non-inferior results in terms of functional

scores, knee stability, knee strength, complications, re-tear rate and radiographic/arthroscopic evaluation.

Using the LARS ligament as a graft has been proven to facilitate accelerated recovery compared with the use of autografts in previous studies [22, 28]. However, *Man* et al. [33] reported in a 2023 meta-analysis that at the final follow-up (at least 2 years after surgery), there was no advantage of using autografts with synthetic graft augmentation, including LARS, compared to no augmentation in ACL reconstruction. In this study, we found similar results in long-term (more than 2 years after surgery) comparisons between the groups. However, at the early stage of recovery (within 2 years), we found that the HT+LARS group demonstrated overall superior functional scores. For return-to-sports, all individual studies that discussed this outcome reported better percentage of return-to-sports at any level of sports activity in the HT+LARS group, but only at the early stage. The Global Rating of Change scale outcomes showed that patients in the HT+LARS group experienced more notable improvement in knee function compared to pre-surgery, which combined with the results of early KOOS-Sports/Recreation outcomes and reported early sports participation, indicated that patients who underwent HT + LARS reconstruction had more confidence and self-perceived capability to participate in sports shortly after surgery. This led us to believe that LARS-augmented hamstring tendon grafts preserved the advantage of the LARS ligament, which benefited fast recovery.

According to previous studies, compared to autografts, synthetic grafts such as LARS were believed to cause a greater rate of failure, a greater incidence of synovitis and earlier onset of secondary knee osteoarthritis [29–32]. In this study, we found that the use of the LARS for hamstring tendon graft augmentation, compared to the use of the hamstring tendon alone, showed non-inferior outcomes in the long-term comparison of complications. Interestingly, in the KT-1000-based laxity evaluation, although there was no statistically significant difference in the quantitative comparison, relative laxity (side-to-side difference > 6 mm) was only reported in the HT group. For complications and revision surgeries, there was no statistically significant difference between HT and HT + LARS, but all studies except for *Ebert* et al. [24] reported a greater incidence in the HT group. Considering *Ebert* et al. [24] was the only study that specified the use of the double-bundle technique, the heterogenous results might need more researches regarding the different surgical techniques applied. MRI evaluation and arthroscopic second-look revealed that no significant difference related to cartilage degradation, osteophytes, meniscal degradation, synovial coverage, graft tension or graft tears between the two groups. These results showed that the use of the LARS to augment hamstring tendon grafts did not cause more severe long-term complications than the use of the hamstring tendon alone.

Preserving the advantages while improving the previously believed disadvantages of synthetic ligament grafts, using LARS to augment hamstring tendon grafts showed promising efficacy in facilitating early recovery and return-to-sports with a low long-term incidence of complications after ACL reconstruction.

There were some limitations to this review. First, only 6 studies were included and none of them were randomized controlled trials. This led to a rather small sample size and a considerable possibility of biases. Second, due to limited clinical trials available, it was hard to make sub-group analysis based on different surgical techniques or different types of fixations, both of which might contribute to heterogeneity of the results. Third, the outcomes reported in these studies vary, which made it difficult to compare certain outcomes across all studies. The follow-up time differed from 1 to 10 years in each study when comparing different outcomes. Due to the different lengths of follow-up time, however, the final follow-up might be at 1 year or 10 years, which led to unfair comparisons among participants. Hopefully, there will be more high-quality clinical studies with comprehensive outcomes in the future.

This study indicated that for ACLR patients who seek fast recovery to a rather competitive sports, but worry about more severe complications caused by using LARS alone, LARS-augmented hamstring tendon graft can be a good alternative to consider.

Conclusion

As grafts for ACLR, the use of hamstring tendons with LARS augmentation, compared with the use of hamstring tendons alone, in the short term, has significantly superior overall functional results and better early sports participation and non-inferior results in other comparisons. In the long term, the use of hamstring tendon with LARS augmentation demonstrated non-inferior results in terms of functional scores, knee stability, knee strength, complications and re-tear rate, etc.

Abbreviations

ACL	Anterior cruciate ligament
ACLR	Anterior cruciate ligament reconstruction
CI	Confidence interval
df	Degrees of freedom
GRCs	Global rating of change scale
HT	Hamstring tendon graft
HT + LARS	Hamstring tendon graft with LARS augmentation
IKDC	International knee documentation committee
IV	Inverse variance
KOOS	Knee injury and osteoarthritis outcomes score
LARS	Ligament augmentation and reconstruction system
M-H	Mantel-Haenszel
n.s.	Not significant ($P \geq 0.05$)

PRISMA	Preferred reporting items for systematic reviews and meta-analyses
SD	Standard deviation
VAS	Visual analog scale
WMD	Weighted mean difference

Authors' contribution
ZTW has participated in the conception and design of the study, the acquisition, analysis and interpretation of data and drafted manuscript. ZKB has participated in the interpretation of data and revision of the manuscript. FWL and LJ performed the final manuscript revision. All authors read and approved the final manuscript.

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References

1. Duthon VB, Barea C, Abrassart S, Fasel JH, Fritschy D, Menetrey J. Anatomy of the anterior cruciate ligament. Knee Surg Sports Traumatol Arthrosc. 2006;14(3):204–13.
2. Michalitsis S, Vlychou M, Malizos KN, Thriskos P, Hantes ME. Meniscal and articular cartilage lesions in the anterior cruciate ligament-deficient knee: correlation between time from injury and knee scores. Knee Surg Sports Traumatol Arthrosc. 2015;23(1):232–9.
3. Giordano L, Maffulli N, Carimati G, Morenghi E, Volpi P. Increased time to surgery after anterior cruciate ligament tear in female patients results in greater risk of medial meniscus tear: a study of 489 female patients. Arthroscopy. 2023;39(3):613–22.
4. Ramjug S, Ghosh S, Walley G, Maffulli N. Isolated anterior cruciate ligament deficiency, knee scores and function. Acta Orthop Belg. 2008;74(5):643–51.
5. Shea KG, Carey JL, Richmond J, Sandmeier R, Pitts RT, Polousky JD, et al. The American Academy of Orthopaedic Surgeons evidence-based guideline on management of anterior cruciate ligament injuries. J Bone Joint Surg Am. 2015;97(8):672–4.
6. Piedade SR, Leite Arruda BP, de Vasconcelos RA, Parker DA, Maffulli N. Rehabilitation following surgical reconstruction for anterior cruciate ligament insufficiency: what has changed since the 1960s?-State of the art. J ISAKOS. 2023;8(3):153–62.
7. Maffulli N. The early versus late anterior cruciate ligament reconstruction debate: history teaches us that we cannot use reason and evidence to fight and win against conviction. Arthroscopy. 2018;34(9):2524–5.
8. Maffulli N, Osti L. ACL stability, function, and arthritis: what have we been missing? Orthopedics. 2013;36(2):90–2.
9. Ptasinski AM, Dunleavy M, Adebayo T, Gallo RA. Returning athletes to sports following anterior cruciate ligament tears. Curr Rev Musculoskelet Med. 2022;15(6):616–28.
10. Ardern CL, Taylor NF, Feller JA, Webster KE. Fifty-five per cent return to competitive sport following anterior cruciate ligament reconstruction surgery: an updated systematic review and meta-analysis including aspects of physical functioning and contextual factors. Br J Sports Med. 2014;48(21):1543–52.
11. Lord L, Cristiani R, Edman G, Forssblad M, Stålman A. One sixth of primary anterior cruciate ligament reconstructions may undergo reoperation due to complications or new injuries within 2 years. Knee Surg Sports Traumatol Arthrosc. 2020;28(8):2478–85.
12. Wiggins AJ, Grandhi RK, Schneider DK, Stanfield D, Webster KE, Myer GD. Risk of secondary injury in younger athletes after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. Am J Sports Med. 2016;44(7):1861–76.
13. Liukkonen RJ, Ponkilainen VT, Reito A. Revision rates after primary ACL reconstruction performed between 1969 and 2018: a systematic review and metaregression analysis. Orthop J Sports Med. 2022;10(8):23259671221110190.
14. Li X, Yan L, Li D, Fan Z, Liu H, Wang G, et al. Failure modes after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. Int Orthop. 2023;47(3):719–34.
15. Duchman KR, Lynch TS, Spindler KP. Graft selection in anterior cruciate ligament surgery: Who gets What and Why? Clin Sports Med. 2017;36(1):25–33.
16. Samitier G, Marcano AI, Alentorn-Geli E, Cugat R, Farmer KW, Moser MW. Failure of anterior cruciate ligament reconstruction. Arch Bone Jt Surg. 2015;3(4):220–40.
17. Yao S, Yung PSH, Lui PPY. Tackling the challenges of graft healing after anterior cruciate ligament reconstruction-thinking from the endpoint. Front Bioeng Biotechnol. 2021;9: 756930.
18. Lin KM, Boyle C, Marom N, Marx RG. Graft selection in anterior cruciate ligament reconstruction. Sports Med Arthrosc Rev. 2020;28(2):41–8.
19. Reinhardt KR, Hetsroni I, Marx RG. Graft selection for anterior cruciate ligament reconstruction: a level I systematic review comparing failure rates and functional outcomes. Orthop Clin North Am. 2010;41(2):249–62.
20. Zaid HHG, Chenwei N, Xu H, Yang G, Li X. Clinical and arthroscopic outcomes of single-bundle anterior cruciate ligament reconstruction using autologous hamstrings augmented with ligament augmentation and reconstruction systems compared with four-strand hamstring tendon grafts alone. Int Orthop. 2023;47(1):151–64.
21. Rittweger J, Maffulli N, Maganaris CN, Narici MV. Reconstruction of the anterior cruciate ligament with a patella-tendon-bone graft may lead to a permanent loss of bone mineral content due to decreased patellar tendon stiffness. Med Hypotheses. 2005;64(6):1166–9.
22. Smith C, Ajuied A, Wong F, Norris M, Back D, Davies A. The use of the ligament augmentation and reconstruction system (LARS) for posterior cruciate reconstruction. Arthroscopy. 2014;30(1):111–20.
23. Ebert JR, Annear PT. ACL reconstruction using autologous hamstrings augmented with the ligament augmentation and reconstruction system provides good clinical scores, high levels of satisfaction and return to sport, and a low retear rate at 2 years. Orthop J Sports Med. 2019;7(10):2325967119879079.
24. Ebert JR, Nairn R, Breidahl W, Annear PT. Double-bundle anterior cruciate ligament reconstruction using autologous hamstrings with LARS augmentation demonstrates comparable outcomes to hamstrings alone, without evidence of synovitis or early osteoarthritis. Knee Surg Sports Traumatol Arthrosc. 2022;30(7):2320–8.
25. Aujla RS, Ebert JR, Annear PT. Anterior cruciate ligament reconstruction using autologous hamstrings augmented with the ligament augmentation and reconstruction system versus hamstrings alone: a comparative cohort study. Orthop J Sports Med. 2021;9(10):23259671211046630.
26. Hamido F, Al Harran H, Al Misfer AR, El Khadrawe T, Morsy MG, Talaat A, et al. Augmented short undersized hamstring tendon graft with LARS artificial ligament versus four-strand hamstring tendon in anterior cruciate ligament reconstruction: preliminary results. Orthop Traumatol Surg Res. 2015;101(5):535–8.
27. Liu ZT, Zhang XL, Jiang Y, Zeng BF. Four-strand hamstring tendon autograft versus LARS artificial ligament for anterior cruciate ligament reconstruction. Int Orthop. 2010;34(1):45–9.

28. Newman SD, Atkinson HD, Willis-Owen CA. Anterior cruciate ligament reconstruction with the ligament augmentation and reconstruction system: a systematic review. Int Orthop. 2013;37(2):321–6.
29. Kdolsky RK, Gibbons DF, Kwasny O, Schabus R, Plenk H Jr. Braided polypropylene augmentation device in reconstructive surgery of the anterior cruciate ligament: long-term clinical performance of 594 patients and short-term arthroscopic results, failure analysis by scanning electron microscopy, and synovial histomorphology. J Orthop Res. 1997;15(1):1–10.
30. Makisalo SE, Visuri T, Viljanen A, Jokio P. Reconstruction of the anterior cruciate ligament with carbon fibres: unsatisfactory results after 8 years. Knee Surg Sports Traumatol Arthrosc. 1996;4(3):132–6.
31. Tiefenboeck TM, Thurmaier E, Tiefenboeck MM, Ostermann RC, Joestl J, Winnisch M, et al. Clinical and functional outcome after anterior cruciate ligament reconstruction using the LARS™ system at a minimum follow-up of 10 years. Knee. 2015;22(6):565–8.
32. Tulloch SJ, Devitt BM, Porter T, Hartwig T, Klemm H, Hookway S, et al. Primary ACL reconstruction using the LARS device is associated with a high failure rate at minimum of 6-year follow-up. Knee Surg Sports Traumatol Arthrosc. 2019;27(11):3626–32.
33. Man Q, Gao Y, Wang H, Ma Y, Meng Q. There is no difference in the efficacy of anterior cruciate ligament reconstruction using autograft combined with or without ligament augmentation: a systematic review and meta-analysis. Knee Surg Sports Traumatol Arthrosc. 2023;31(12):5524–34.
34. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group T. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ. 2009;339:b2535.
35. Papalia R, Franceschi F, Tecame A, D'Adamio S, Maffulli N, Denaro V. Anterior cruciate ligament reconstruction and return to sport activity: postural control as the key to success. Int Orthop. 2015;39(3):527–34.
36. Zhang B, Xiang P, Bian S, Wang Y, Ma Y. Early clinical outcomes of ACL reconstruction using semitendinosus tendon combined with LARS synthetic. Comput Math Methods Med. 2022;2022:2845114.
37. Barber-Westin SD, Noyes FR. Assessment of sports participation levels following knee injuries. Sports Med. 1999;28(1):1–10.
38. Kamper S. Global rating of change scales. Aust J Physiother. 2009;55(4):289.

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