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ORIGINAL RESEARCH

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Functional outcome and single hop test results of ACL reconstruction in athletes at a follow-up of 6 and 12 months: modified all-inside versus conventional hamstring autograft

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Abstract

Anterior cruciate ligament (ACL) tears are injuries with a high incidence in athletes, and ACL reconstruction (ACLR) is a surgical treatment orthopedists perform. This study aims to compare the 6 and 12 months post-op results of single leg hop tests (SLHT) performed in multidirectional conventional semitendinosus/gracilis (ST/G) and modified all inside (MAI) ACLR techniques on both sides and the limb symmetry indexes (LSI) of both techniques. This study evaluated a retrospective cohort of 50 male athletes who applied MAI (n = 23) and traditional ACLR ST/G (n = 27) techniques. Functional knee strength of the participants on both sides was measured with different SLHTs at 6 and 12 months postoperatively. The SLHT included medial side (MSTH), triple hop (TH), medial rotation (90°) (MRH), crossover triple (CH) ve the single hop (SH) hop for distance. Both ACLR techniques showed significant improvement in mean Tegner, International Knee Documentation Committee (IKDC) and Lysholm scores preoperatively and at 6 and 12 months postoperatively ($p < 0.05$). For MAI and ST/G techniques, there was no significant difference in the results of SLHTs at 6 and 12 months for both the operated and non-operated sides ($p < 0.05$). Significance was found only in the MRH test of the non-operated side ($p < 0.05$). There was no significant difference in SLHT scores between the operated and non-operated sides at 6 and 12 months postoperatively ($p > 0.05$). There was no difference in LSI scores between techniques ($p < 0.05$). Our study revealed similar LSI rates in ST/G and MAI techniques at 6 and 12 months, suggesting that MAI technique can be used as a functional ACLR technique for athletes.

Keywords

Interference screw; Anterior cruciate ligament reconstruction; Return to sport; Hop test; Cortical suspensory fixation

1. Introduction

An anterior cruciate ligament (ACL) tears usually occur during sports activities involving frequent rotation and jumping [1]. ACL reconstruction (ACLR) is the most common procedure among orthopaedic surgeries realised in sports medicine. It aims to correct the loss of stability and function in the knee while allowing patients to return to pre-injury sports activities (RTS) during the rehabilitation process [2]. The graft types commonly used in ACLR are semitendinosus/gracilis (ST/G), quadriceps, patellar, and hamstring tendons [3]. Graft fixation method is another important condition in ACLR. Proximally, fixation to the femoral cortex provides positive results, while tibial fixation is usually performed with an interference screw [4, 5]. In 2011, a new technique developed by Lubowitz *et al.* [6] (2011) called "all-inside", in which the ST tendon is harvested and grafted in four layers (4ST). Shorter tibial tunnels are drilled retrogradely, thus limiting bone loss and stabilizing the graft with an adjustable fixation system, has also become widespread. Although this technique has advantages, it has disadvantages such as the necessity of using special drills for socket formation, problems encountered in adjusting the socket depth, and the high cost of the technique. Because of these disadvantages, Mahiroğulları *et al.* [7] (2023) developed a new method called the modified all-inside (MAI) technique and presented the results of this method [7, 8]. With this method, the ST tendon is wrapped in four layers and fixed with graft sling fixation over the tibia and femur [9].

Using isokinetic dynamometers to measure strength effectively determines patient readiness for RTS, especially in the athletic population [10, 11]. However, since isokinetic dynamometers and their derivatives are available in a few centers and access is difficult, many alternative functional tests are used [12]. One of them, single leg hop tests (SLHT), is the most frequently used assessment method due to its reliability and validity, ease of application, portability and low cost [8]. SLHTs are widely recommended, especially in rehabilitation processes after ACLR, as they provide the opportunity to determine athletes' functional knee strength status in the lower extremity, reveal functional asymmetries between the operated and non-operated sides, and observe functional strength improvements in the operated limb [13, 14]. Traditionally applied SLHTs mainly consist of movements in the forward direction, a significant limitation [15] because movements during sports activities occur in multiple directions [9]. Therefore, SLHTs performed only in the forward direction may not be sufficient for assessing lower extremity performance, injury prevention, or RTS decisions after surgical operations such as ACLR [16, 17]. Researchers have emphasized that multidirectional tests and conventional forward SLHTs are also crucial in RTS decision-making, especially after injury [18, 19]. In addition, asymmetry rates have been shown to increase in multidirectional testing compared to conventionally applied forward SHLTs [9, 20]. One study reported that decreased quadriceps strength on the surgically treated side after ACLR was associated with shorter distance jump tests [21]. They emphasized this factor's importance in studies examining limb asymmetries after ACLR [21, 22] shows us that the limb asymmetry index (LSI), which is frequently used with SLHT, is also an important parameter. With all these, it can be stated that traditional SLHTs and multidirectional jump tests are critical in determining the rehabilitation process and RTS duration after ACLR [9].

With all this information in mind, the present study focussed on two objectives. The first one is to compare the pre and post-operative knee scores of MAI and ST/G ACLR techniques with the post-operative 6 and 12 SLHT scores, and the second one is to evaluate the limb asymmetries that occur in SLHTs performed in both forward and medial and rotational directions. Our study hypothesized that pre- and post-operative knee and post-operative 6 and 12 SLHT scores of MAI and ST/G ACLR techniques would be similar.

2. Materials and methods

2.1 Approach and patients

The data evaluated in this study were obtained from retrospective institutional records of patients treated for ACL rupture. The included patients underwent MAI (n = 23) and traditional ACLR ST/G (n = 27) techniques between April 2019 and June 2022 by the same surgeon. A retrospective cohort of a total of 50 male athletes was evaluated. Lachman test and magnetic resonance (MR) imaging were primarily used for the diagnosis of ACL rupture in patients admitted to the center with complaints of knee pain, swelling, weakness, atrophy and slippage. The number of subjects was identified by G*Power 3.1 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). According to the results of tests with similar literature [9, 23], it was determined that working with 14 patients for each technique was sufficient (effect size r: 0.87, lower and upper critical p: 0.55, true power: 0.91). The research for the study was completed with a total of 50 patient groups. The data to be used in the study were obtained by examining the records of the patients available at the centre.

Inclusion criteria were (i) age between 18–35 years, (ii) Isolated ACL rupture alone, without meniscus accompanying osteoarthritis (OA) and without any other ligament injury, (iii) no history of ACLR, (iv) no neuromuscular or musculoskeletal injury other than ACL rupture, (v) no history of surgical procedure or injury in the contralateral knee, and (vi) patients had undergone ACLR with either of the two techniques (MAI or ST/G). Exclusion criteria were (i) not adhering to the rehabilitation program, (ii) not completing knee scores or SLHTs, (iii) experiencing various complications during follow-up, (iv) having a history of ACLR. The study included the Lysholm scale, assessing symptoms of instability in the knee and other areas; the Tegner scale, assessing an individual's activity levels to determine health status for return to regular activity or sports; and the International Knee Documentation Committee (IKDC) scale, evaluating areas such as improvement in functioning, symptoms and RTS [24]. Tegner, IKDC, Lysholm scores (pre-operative, 6th and 12th month post-operative) and performance on five different SLHTs (6th and 12th months post-operative) were determined for all participants. The five different functional SLHTs used in our study were as follows; medial side triple hop for distance (MSTH), triple hop for distance (TH), medial rotation (90°) hop for distance (MRH), single hop for distance (SH), crossover triple hop for distance (CH). All of these tests were performed in a straight line, exhibiting maximum force [8, 25]. All of these tests have been tested in previous studies by test-retesting and yielded reliable results [26].

For these measurements, all patients had four visits to the visiting laboratory, excluding routine check-ups in the clinic. The first visit included the first visit after the diagnosis of ACL tear. During this visit, the subjective questionnaires Tegner, IKDC, Lysholm scales were completed and general information about the study was given. The second visit covered the first six months after ACLR. In this visit, anthropometric data were then obtained and the SLHTs to be applied in the third visit were recognised. After the second visit, 3 days were waited. Then the third visit took place. At this visit, the Lysholm, Tegner and IKDC scales were completed for the second time and the patients' performance on five different SLHTs was assessed. The fourth and final visit (12th month post-operative) included the third completion of the Lysholm, Tegner and IKDC scales and the assessment of the final tests of SLHT performance. By directing the patients to the same rehabilitation program, it was aimed to reduce the external factors that would affect the recovery periods and to ensure that the evaluated results were objective (Fig. 1).

2.2 Surgical treatment

2.2.1 Modified all-inside technique

Patients who underwent Modified—All inside ACLR underwent anatomical single bundle, quadruple folded semitendinosus autograft with adjustable sling fixation. The approximately 28 cm long semitendinosus tendon was quadrupled

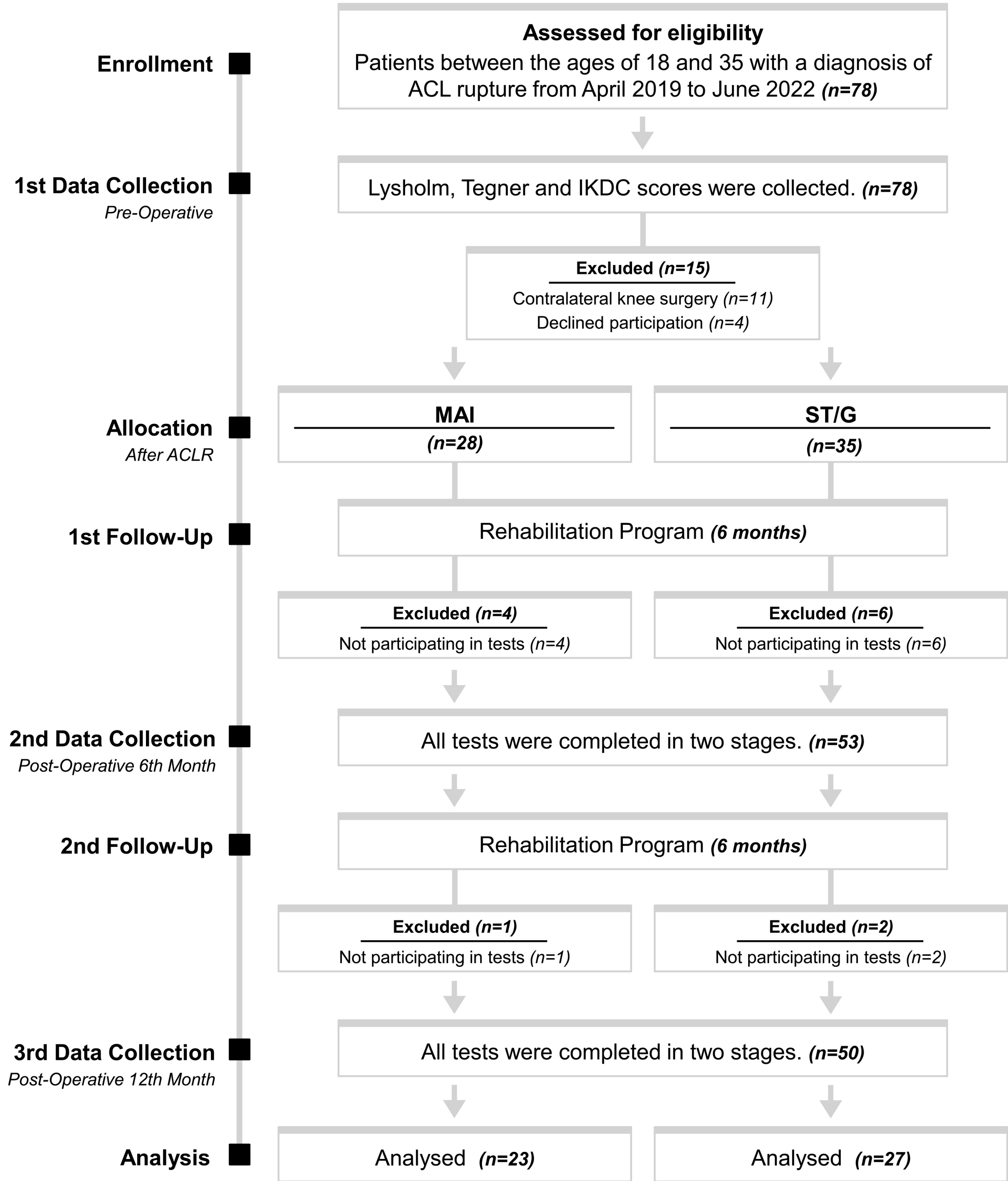

FIGURE 1. Flowchart. MAI: modified all-inside technique; ST/G: semitendinosus/gracilis technique; ACLR: anterior cruciate ligament reconstruction; IKDC: international knee documentation committee.

with a fixed loop button system on the femoral side and an adjustable loop cortical sling fixation method on the tibial side. The fixation system applied on the tibial side consists of a button with a titanium structure with a width of approximately 20 mm and a double loop with a knotless locking mechanism. The titanium button on the femoral side is approximately 10 mm wide and has continuous loops of 15–40 mm in length. The femoral tunnel carved with the anteromedial portal was drilled with a 4.5 mm drill, and a complete tunnel was opened by evaluating the guide pin. The length after the tunnel was determined. Then, a socket with the same lengths as the 4-fold graft was drilled by evaluating an endobutton “flip” travel distance of 6 to 8 mm. A complete tibial tunnel was then drilled, extending from the outside to the inside towards the defined anatomical scar. The 4-folded graft was passed through the articular space to the tibial and femoral tunnels, and then tension was applied at a flexion angle of 20 degrees. The knee was then repeatedly brought to the extension and flexion phases approximately 30 times in a row, and the graft density was evaluated using a probe. After the probe evaluation, tension was applied towards the tibial side and knotted and ligated with a sling fixation system (Fig. 2).

2.2.2 Semitendinosus/gracilis (conventional hamstring autograft) technique

For conventional hamstring autograft, ACLR, ST/G tendons from the same side were used. The tendons were folded in half to form a four-helix graft. A closed socket was drilled into the femur, and an open tunnel was drilled externally into the tibia. Socket and tunneling procedures were performed through the medial arthroscopic portal. Sling fixation was used to stabilize the prepared ST/G graft, and interference screw fixation was used to stabilize the tibial side.

FIGURE 2. Modified all-inside anterior cruciate ligament reconstruction technique procedures. (A) Anatomical preparation and adjustable suspension fixation of a single bundled quadrupled ST tendon autograft, (B) insertion of the system prepared as ST tendon autograft into the knee, (C) fixation of the ST autograft into the tunnel on the tibial side, (D) The ST graft was securely placed in the tibial tunnel using Lift Loop and (E) fixation was performed using a combination of Ultrabutton and Xtendobutton.

2.3 Single leg hop tests procedures

For SLHT assessment, a 6 m long and 15 cm wide tape was placed on the ground. Common to all tests, participants were initially instructed to stand on one leg and land on the same leg. Participants were asked to perform a single hop as far forward as possible in the line direction for SH. For TH, participants were asked to perform three consecutive maximal forward hops. For CH, participants were asked to perform three successive forward cross hops as close to the line as possible but without contact. The distance between the line where the test started and the heel of the patient positioned at the landing place was measured with a tape measure and the jump distance obtained was recorded in centimetres. For the MSTH, participants were asked to stand medially at the starting line and perform three consecutive medially directed hops across the line. For the MSTH, patients jumped sideways three times without stopping. In the third jump, the distance between the medial side of the foot and the starting line was measured at the place of landing on the line. For MRH, participants positioned their foot with the medial side parallel to the baseline. Then, they jumped in the direction of the test line, rotated their foot 90° towards the medial side during the swing phase and landed. Before take-off, the participant was not permitted to rotate the foot in the direction of the test line. The jump distance was measured from the baseline to the toe after landing (Fig. 3). In all tests, only balanced and successful landings after the hop were considered valid, and in cases such as loss of balance and additional hops, the hop was invalidated and repeated.

2.4 Statistical analysis

The analysis of the study was carried out using SPSS 22.00 (IBM Corp, NY, USA) package program. The normality assumption of the data was examined with the Shapiro-Wilk test, and it was determined that the variables were normally distributed ($p > 0.05$). Independent sample t-test was used to compare the techniques regarding demographic information. A paired sample t-test was used to compare the techniques used in the group for the 6 and 12 months. Repeated Measures Mixed Design Analysis of Variance was applied. Sphericity was examined using Mauchly's Sphericity test. The Sphericity Assumed test was used for equal variances ($p > 0.05$). In cases where variances were not equal ($p < 0.05$), epsilon value ($\mathcal{E}$) was examined, and Greenhouse and Geisser tests were used when $\mathcal{E} < 0.75$ and Huynh-Feldt tests were used when $\mathcal{E} > 0.75$. The Bonferroni test was used to determine the differences between groups. Analysis of variance with the factorial design was used to analyze technique, time, side, technique × time, and technique × side interaction. Mean and standard deviation values for the findings obtained and frequency and percentage for demographic characteristics were given as descriptive statistics values.

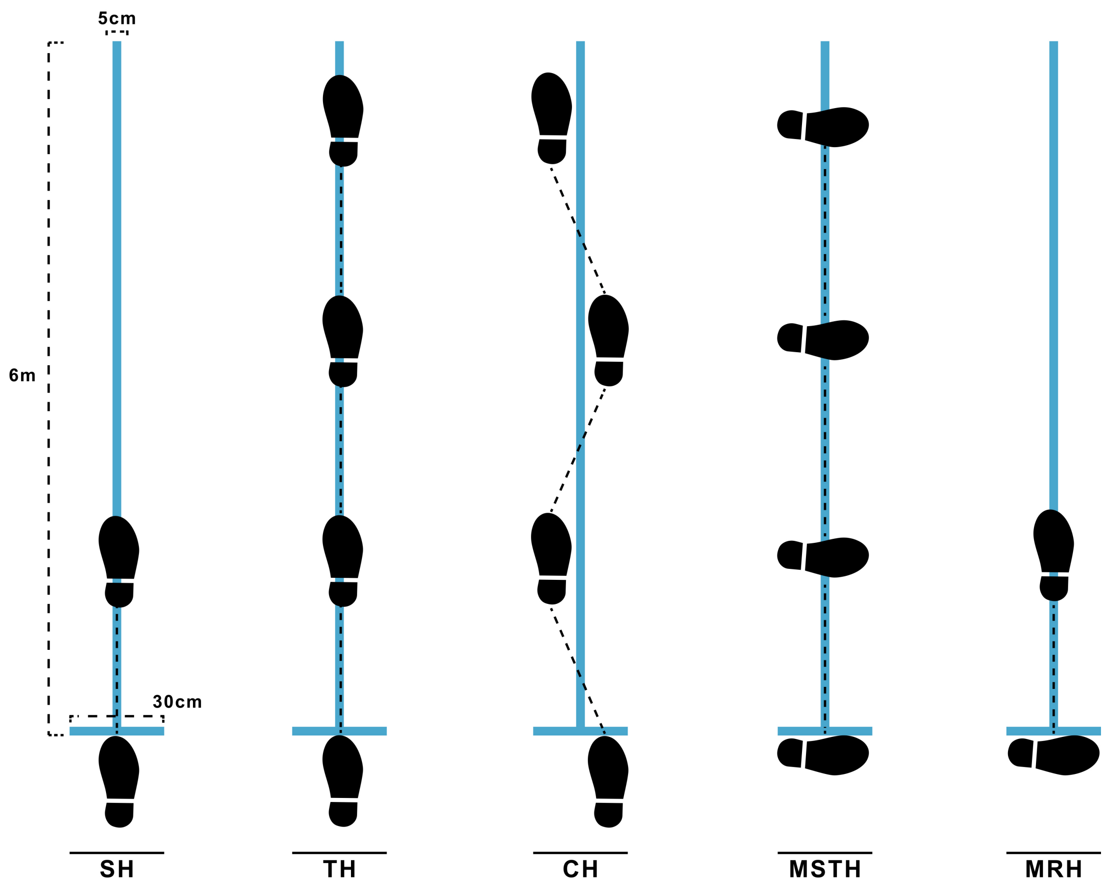

FIGURE 3. Single leg hop tests. CH: crossover triple hop for distance; MSTH: medial side triple hop for distance; SH: single hop for distance; MRH: medial rotation (90°) hop for distance; TH: triple hop for distance.

3. Results

A total of 50 male athletes participated in the study. In the subject group, 23 (46%) underwent the MAI technique, and 27 (54%) underwent the ST/G technique. No statistically significant differences existed between the age, weight, height, body mass index (BMI) and time to RTS (Table 1).

There was no significant difference in technique and technique × time parameters between pre-op, 6th-month and 12th-month Lysholm, IKDC and Tegner scores for both techniques ($p > 0.05$). In the time parameter, a significant difference was observed in all scores ($p < 0.05$) (Fig. 4 and Table 2).

There was no statistically significant difference in the technique parameter between the SLHT scores of both techniques at 6 and 12 months in the operative and non-operative sides ($p > 0.05$). There was a statistically significant difference between all groups in the time parameter ($p < 0.05$). There was a statistically significant difference in technique × time parameter in non-operative MRH scores ($p = 0.002$). However, other test scores in the same parameter did not show a statistically significant difference ($p > 0.05$) (Fig. 5 and Table 3).

Supplementary Table 1 compares 6- and 12-month SLHTs on the operative and non-operative sides in MAI and ST/G techniques. Accordingly, the MAI technique showed favorable results with statistically significant differences in all parameters ($p < 0.05$). In the ST/G technique, except for the non-operative CH parameter ($p > 0.05$), it gave favorable results with a significant difference in all parameters ($p < 0.05$).

At the 6th and 12th months, there was no statistically significant difference between operative and non-operative SLHT scores in both techniques in terms of technique, side, and technique × side parameters ($p > 0.05$) (Fig. 6).

Supplementary Table 2 compares 6- and 12-month SLHTs on operative and non-operative sides in MAI and ST/G techniques. There was no significant difference between the sides in the MAI technique ($p > 0.05$). In the ST/G technique, only in the parameter SH 6th month ($p = 0.033$) a positive result was seen with statistical significance between the sides ($p < 0.05$).

There was no statistically significant difference ($p > 0.05$) in the technique and technique × time parameters in the LSI rates (min = 96.64 and max = 101.25) resulting from SLHTs performed at the 6th and 12th months in MAI and ST/G groups. There was no statistically significant difference in the time parameter in the CH test ($p > 0.05$). However, a statistically significant difference was observed in the same parameter for other tests ($p < 0.05$) (Fig. 7 and Table 4).

Supplementary Table 3 compares SLHTs LSI parameters in MAI and ST/G techniques between 6 and 12 months. MAI technique showed statistically significant differences in SH LSI ($p = 0.011$), TH LSI ($p = 0.030$), MSTH LSI ($p = 0.010$), and MRH LSI ($p = 0.006$). ST/G technique showed significant differences in SH LSI ($p < 0.001$) and MRH LSI ($p = 0.008$) and favorable results.

4. Discussion

Our study aimed to compare the pre-operative, post-operative, 6- and 12-month knee scores and the results of SLHTs performed in multidirectional directions at 6 and 12 months in the conventional ST/G and the recently emerged MAI ACLR techniques. The essential findings aligned with this purpose: The pre-operative and post-operative 6th and 12th month findings were similar regarding Tegner, IKDC and Lysholm scores in ST/G and MAI ACLR techniques. Especially in Tegner activity scores, when the findings at the 12th month were analysed, it was observed that the scores were similar to the preoperative findings. The 6th- and 12th-month results in SH, TH, CH and MSTH tests between sides of the patients were similar in both MAI and ST/G techniques, while only MRH performance was observed to differ in the non-operated sides of the ST/G technique group. Finally, the study results showed that the scores of both techniques, the 6th and 12th month LSI, were similar. Our study is critical as it is the first to evaluate knee scores after the MAI ACLR technique and five different SLHT scores applied in different directions at post-operative 6th and 12th months.

Although there are various test methods, such as isokinetic and isometric tests, for the assessment of lower extremity strength, there are limitations regarding the applicability of these tests, especially in high-risk groups such as individuals with disabilities and individuals with previous surgical procedures on the lower extremities. When evaluated from this point of view, SLHTs are commonly utilized, especially after surgical interventions such as ACLR, as they offer applicability even in various high-risk groups. SLHTs are frequently preferred by researchers for their applicability and objectivity of results. Studies have found that traditional SLHTs measured in the forward direction in healthy athletic populations have 80–85% similarity between the two limbs [27, 28]. To make a RTS decision in athletes after ACLR, the strength difference between the two limbs is expected to be between 10–15% [9]. LSIs have a critical role for return to sport. For this reason, researchers have examined this evaluation criterion after different ACLR techniques and have come up with different findings. A study evaluating short-term (mean 7.8 months) isokinetic knee and CH and SH strengths of soccer players with ACLR detected that LSI results were above 85% for SH and CH but remained 82% on average for isokinetic strengths [29]. However, they stated that the athletes were not in the re-injury risk range in their evaluation based on all of the tests. Barfod *et al.* [12] (2019) reported that the subjects' 6th and 12th month SH values were above 85% in patients with conventional ST/G hamstring autograft [12]. Similar to our study, a study comparing the short-term (mean 6.7 months) results of ST/G and MAI ACLR techniques in athletes did not reveal any significance between both techniques in terms of both jump distances and LSIs. In addition, all of the study's LSI findings were >85% for both techniques [9]. Çerçi *et al.* [30] (2023) compared the 6th month isokinetic knee strength of ST/G and MAI techniques and found that both had similar muscle strength and knee function [30]. Post-operative RTS findings of the MAI ACLR technique generally revealed similar findings compared to other techniques and contralateral sides. However, one study showed a significant functional strength difference between the side with the MAI technique and the healthy contralateral side. Still, when these findings are evaluated for LSI, parameter the results were >85% [31]. Our

TABLE 1. Descriptive statistics.

	MAI Mean ± SD	ST/G Mean ± SD	t	p
Age (yr)	26.25 ± 5.77	24.65 ± 5.36	0.887	0.381
Weight (kg)	80.25 ± 12.20	78.35 ± 8.95	0.532	0.599
Height (cm)	177.56 ± 4.95	179.04 ± 4.67	0.174	0.348
BMI (kg/m^2)	25.75 ± 3.77	24.40 ± 2.54	1.605	0.200
Post-Op Sport	6.75 ± 1.06	6.74 ± 0.91	0.034	0.973
Technique	n		%	
MAI	23		46.0	
ST/G	27		54.0	
Side				
Operative	28		56.0	
Non-Operative	22		44.0	

MAI: modified all-inside technique; ST/G: semitendinosus/gracilis technique; SD: standard deviation; BMI: body mass index; Post-Op: post-operative.

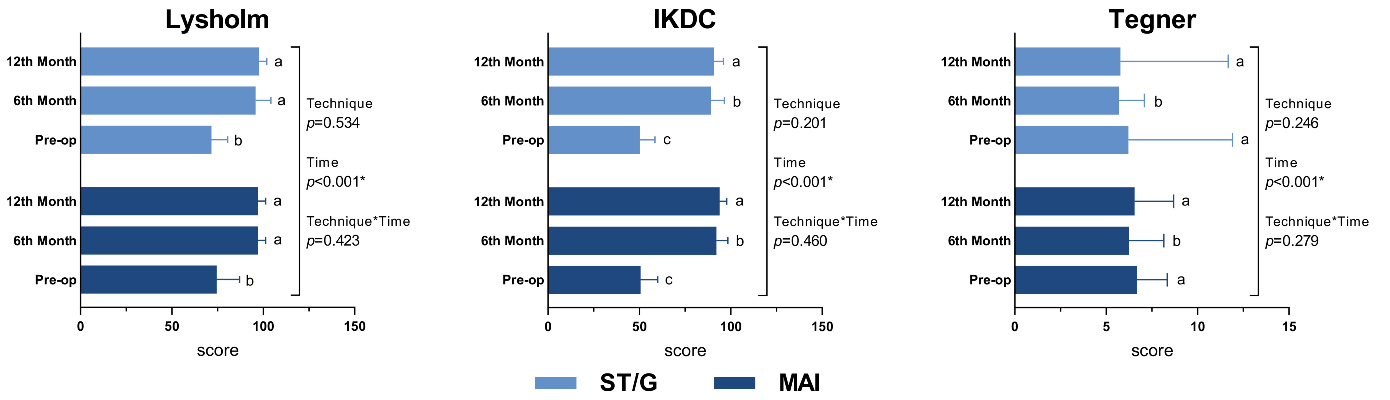

FIGURE 4. Comparison of pre-operative and post-operative 6th and 12th-month Lysholm, Tegner and IKDC scores between techniques. *$p < 0.05$; MAI: modified all-inside technique; ST/G: semitendinosus/gracilis technique; ^{abc}: pairwise comparison for time and time × technique; Pre-op: pre-operative; IKDC: international knee documentation committee.

TABLE 2. Comparison of pre-operative and post-operative 6th and 12th-month Lysholm, Tegner and IKDC scores between techniques.

Technique	Pre-op Mean ± SD	6th month Mean ± SD	12th month Mean ± SD	Technique	Time	Technique × Time
Lynsholm						
MAI	74.50 ± 12.52^b	97.06 ± 4.22^a	97.19 ± 4.15^a	0.534	<0.001*	0.423
ST/G	71.65 ± 8.96^b	95.83 ± 8.36^a	97.52 ± 4.40^a	$\eta_p^2 = 0.011$	$\eta_p^2 = 0.854$	$\eta_p^2 = 0.019$
IKDC						
MAI	50.69 ± 9.39^c	92.19 ± 6.25^b	93.94 ± 3.87^a	0.201	<0.001*	0.460
ST/G	50.30 ± 8.30^c	89.22 ± 7.40^b	90.87 ± 5.16^a	$\eta_p^2 = 0.044$	$\eta_p^2 = 0.942$	$\eta_p^2 = 0.016$
Tegner						
MAI	6.69 ± 1.66^a	6.25 ± 1.91^b	6.56 ± 2.13^a	0.246	<0.001*	0.279
ST/G	6.22 ± 1.20^a	5.70 ± 1.40^b	5.78 ± 1.48^a	$\eta_p^2 = 0.036$	$\eta_p^2 = 0.237$	$\eta_p^2 = 0.033$

**$p < 0.05$; SD: standard deviation; η_p^2: partial eta squared; ^{abc}: pairwise comparison for time and time × technique; IKDC: international knee documentation committee.*

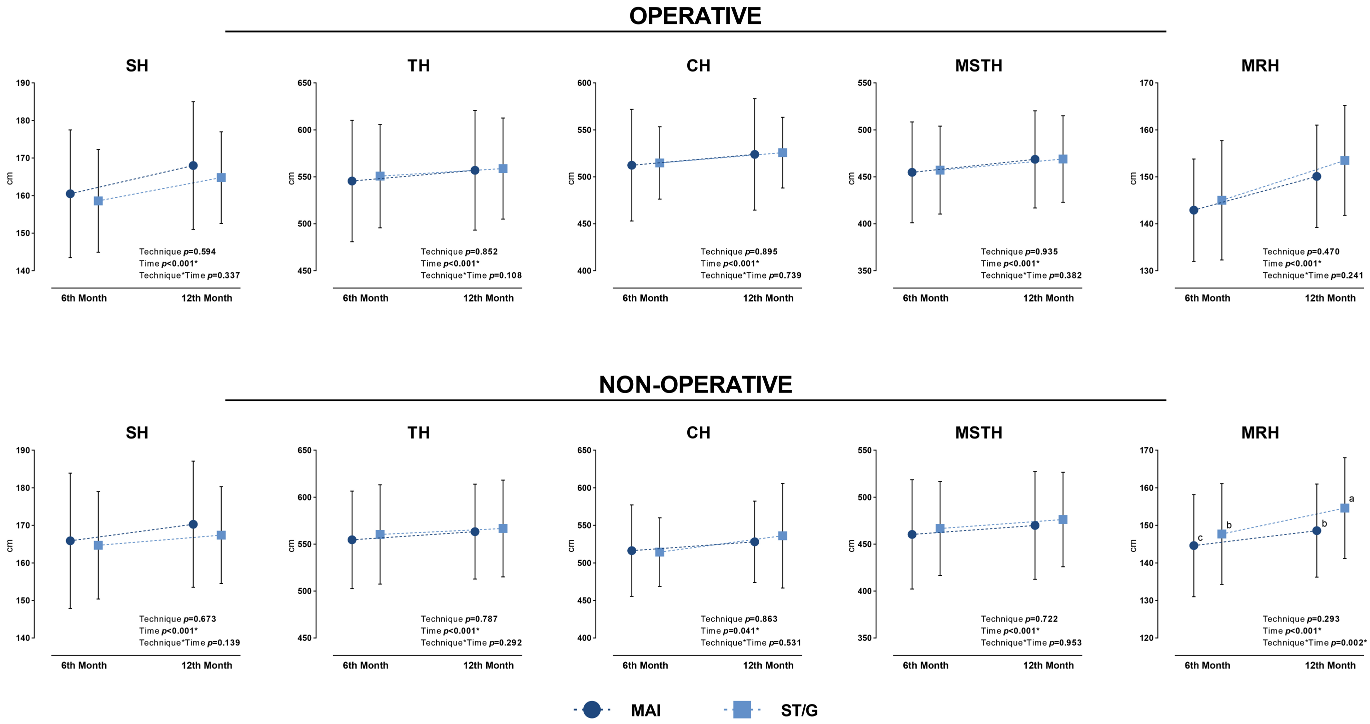

FIGURE 5. Comparison of operative and non-operative SLHT results between the 6th and 12th months in both techniques. *$p < 0.05$; MAI: modified all-inside technique; ST/G: semitendinosus/gracilis technique; SH: single hop for distance; TH: triple hop for distance; CH: crossover triple hop for distance; MSTH: medial side triple hop for distance; MRH: medial rotation (90°) hop for distance.

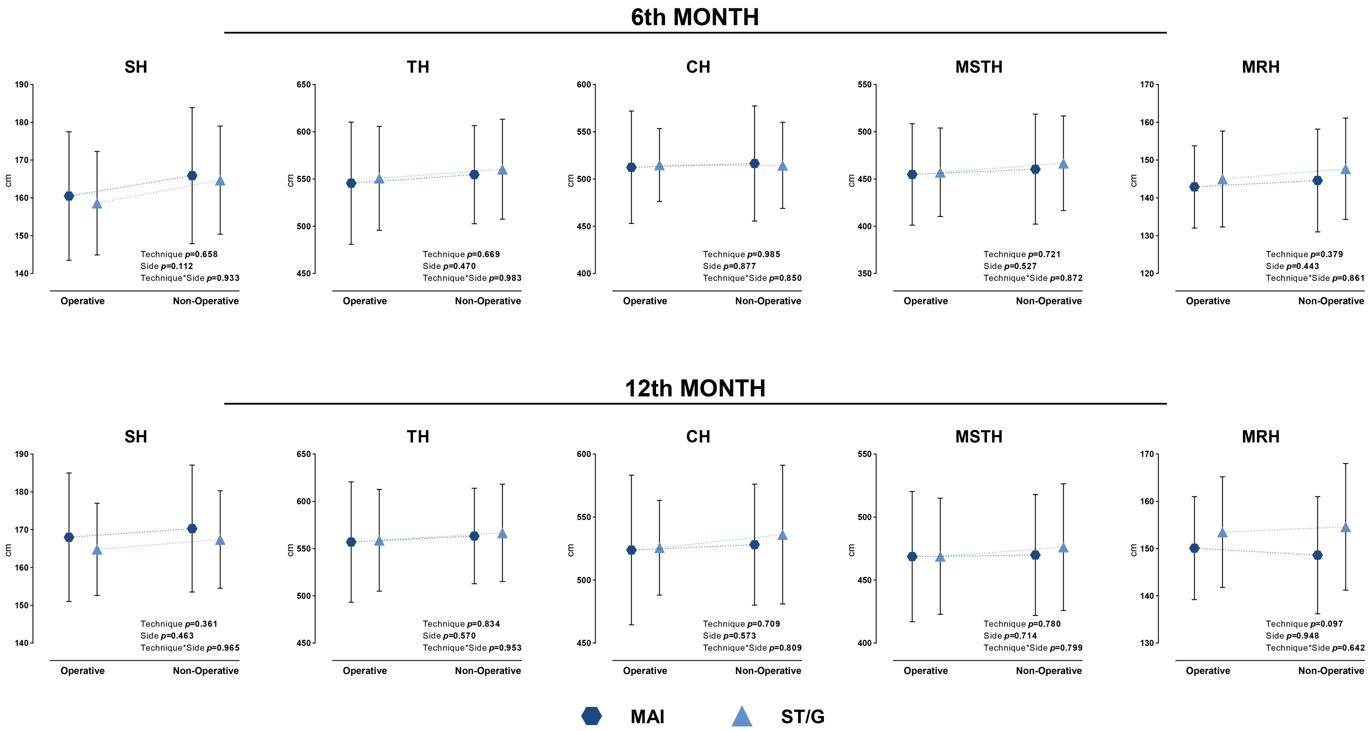

FIGURE 6. Comparison of SLHT results at 6 and 12 months in both techniques between operative and non-operative sides. *$p < 0.05$; MAI: modified all-inside technique; ST/G: semitendinosus/gracilis technique; SH: single hop for distance; TH: triple hop for distance; CH: crossover triple hop for distance; MSTH: medial side triple hop for distance; MRH: medial rotation (90°) hop for distance.

TABLE 3. Comparison of operative and non-operative SLHT results between 6th and 12th months in both techniques.

Technique	6th month Mean ± SD	12th month Mean ± SD	Technique	Time	Technique × Time
Operative SH					
MAI	160.5 ± 17.0	168.0 ± 17.0	0.594	<0.001*	0.337
ST/G	158.6 ± 13.7	164.8 ± 12.2	$\eta_p^2 = 0.008$	$\eta_p^2 = 0.731$	$\eta_p^2 = 0.025$
Non-operative SH					
MAI	165.9 ± 18.0	170.3 ± 16.8	0.673	<0.001*	0.139
ST/G	164.7 ± 14.3	167.4 ± 12.9	$\eta_p^2 = 0.005$	$\eta_p^2 = 0.539$	$\eta_p^2 = 0.058$
Operative TH					
MAI	545.5 ± 64.6	556.9 ± 63.7	0.852	<0.001*	0.108
ST/G	550.7 ± 55.0	558.8 ± 53.8	$\eta_p^2 = 0.001$	$\eta_p^2 = 0.714$	$\eta_p^2 = 0.068$
Non-operative TH					
MAI	554.6 ± 51.9	563.3 ± 50.5	0.787	<0.001*	0.292
ST/G	560.3 ± 52.9	566.7 ± 51.5	$\eta_p^2 = 0.002$	$\eta_p^2 = 0.550$	$\eta_p^2 = 0.030$
Operative CH					
MAI	512.4 ± 59.5	523.9 ± 59.4	0.895	<0.001*	0.739
ST/G	514.8 ± 38.5	525.7 ± 37.6	$\eta_p^2 = 0.000$	$\eta_p^2 = 0.762$	$\eta_p^2 = 0.003$
Non-operative CH					
MAI	516.4 ± 60.9	528.1 ± 54.1	0.863	0.041*	0.531
ST/G	514.4 ± 45.6	536.1 ± 69.6	$\eta_p^2 = 0.001$	$\eta_p^2 = 0.108$	$\eta_p^2 = 0.011$
Operative MSTH					
MAI	454.8 ± 53.7	468.6 ± 51.7	0.935	<0.001*	0.382
ST/G	457.1 ± 46.8	468.9 ± 46.1	$\eta_p^2 = 0.000$	$\eta_p^2 = 0.769$	$\eta_p^2 = 0.021$
Non-operative MSTH					
MAI	460.4 ± 58.2	469.9 ± 57.4	0.722	<0.001*	0.953
ST/G	466.6 ± 50.1	476.2 ± 50.3	$\eta_p^2 = 0.003$	$\eta_p^2 = 0.816$	$\eta_p^2 = 0.000$
Operative MRH					
MAI	142.9 ± 10.9	150.1 ± 10.9	0.470	<0.001*	0.241
ST/G	145.0 ± 12.7	153.5 ± 11.7	$\eta_p^2 = 0.014$	$\eta_p^2 = 0.842$	$\eta_p^2 = 0.037$
Non-operative MRH					
MAI	144.6 ± 13.6^c	148.6 ± 12.4^b	0.293	<0.001*	0.002*
ST/G	147.7 ± 13.4^b	154.6 ± 13.4^a	$\eta_p^2 = 0.030$	$\eta_p^2 = 0.808$	$\eta_p^2 = 0.237$

**p* < 0.05; SD: standard deviation; η_p^2: partial eta squared; ^{abc}: pairwise comparison for time and time × technique; SH: single hop for distance; TH: triple hop for distance; CH: crossover triple hop for distance; MSTH: medial side triple hop for distance; MRH: medial rotation (90°) hop for distance; MAI: modified all-inside technique; ST/G: semitendinosus/gracilis technique.*

study shows that the 6- and 12-month post-operative LSI rates in athletes with MAI and ST/G ACLR techniques are >90%.

Although some of the studies have emphasised that LSIs alone are not associated with quadriceps strength after ACLR and that the results alone are not an evaluation criterion for RTS [29], the general comments and research results on this subject have found that LSIs applied in two or more different directions can give significant results for RTS [8, 15]. Dingenen *et al.* [8] (2019) found >90% LSI in all subjects in traditional SLHTs in their study, while only 68.8% of subjects achieved this rate in MSTH and MRH tests, and reported and although there were no statistically significant differences in LSIs, there may be differences in clinical decision-making due to thresholds [8]. In a study, SLHTs were evaluated on a group of healthy athletes and no limb asymmetry was observed in traditional SLHTs, whereas asymmetric proportions were found in MSTH [32]. Clinically, it is important to evaluate conventional SLHTs as well as multidirectional tests for RTS because ≥90% LSI is usually for TH and SH should be considered for RTS [15]. In contrast, medial and rotation tests alone may result in low asymmetry rates, prolonging the duration of RTS. Studies have shown that SLHTs applied in different directions produce asymmetric ratios compared to those applied in the forward direction, a result that is still unclear and open to debate [8, 9]. However, researchers have emphasized that the biomechanics of the lower extremities may vary not only according to the

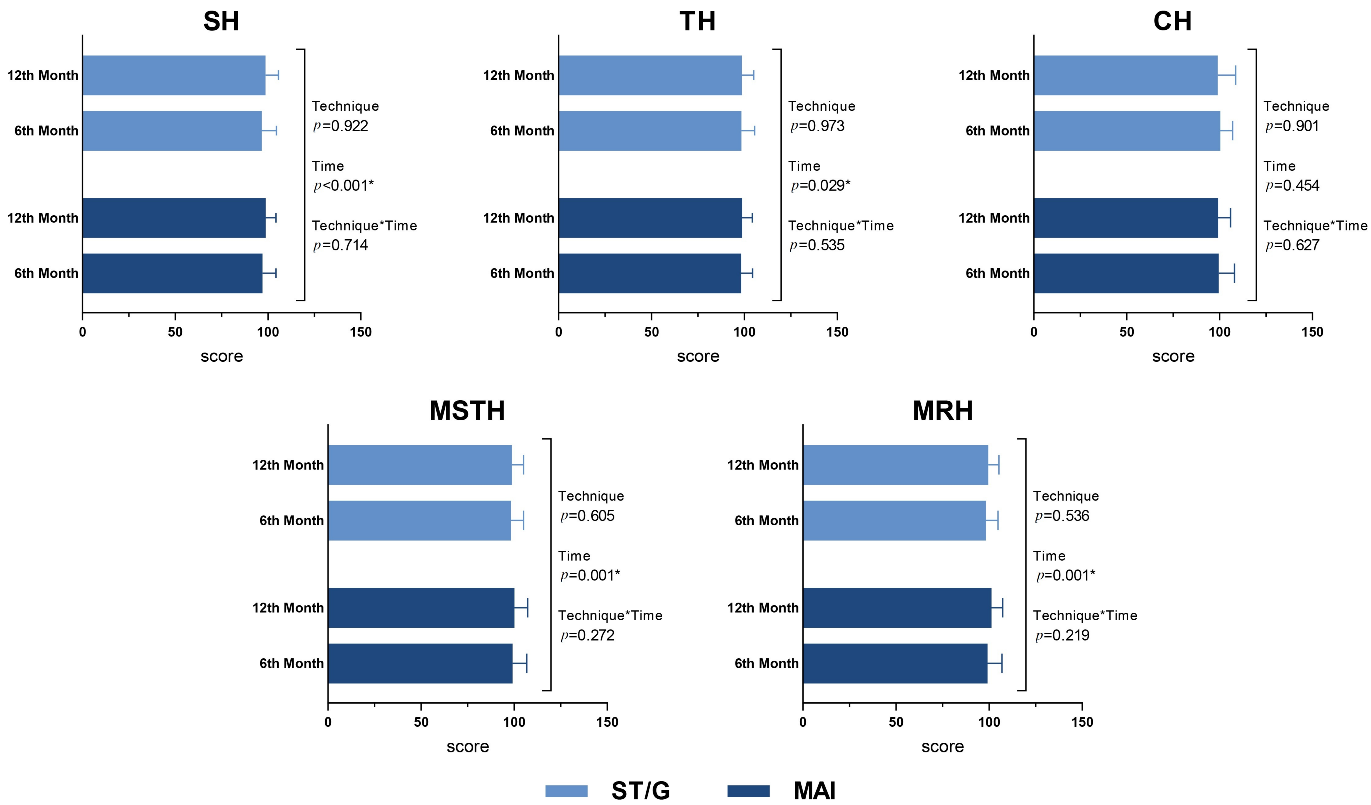

FIGURE 7. Comparison of LSI rates resulting from SLHT between post-operative 6th and 12th months. *$p < 0.05$; MAI: modified all-inside technique; ST/G: semitendinosus/gracilis technique; SH: single hop for distance; TH: triple hop for distance; CH: crossover triple hop for distance; MSTH: medial side triple hop for distance; MRH: medial rotation (90°) hop for distance.

TABLE 4. Comparison of LSI rates resulting from SLHT between post-operative 6th and 12th months.

Technique	6th month Mean ± SD	12th month Mean ± SD	Technique	Time	Technique × Time
SH					
MAI	97.01 ± 7.34	98.78 ± 5.54	0.922	<0.001*	0.714
ST/G	96.64 ± 7.96	98.70 ± 7.01	$\eta_p^2 = 0.000$	$\eta_p^2 = 0.390$	$\eta_p^2 = 0.004$
TH					
MAI	98.30 ± 6.10	98.77 ± 5.58	0.973	0.029*	0.535
ST/G	98.47 ± 7.07	98.74 ± 6.26	$\eta_p^2 = 0.000$	$\eta_p^2 = 0.122$	$\eta_p^2 = 0.010$
CH					
MAI	99.58 ± 8.42	99.29 ± 6.63	0.901	0.454	0.627
ST/G	100.41 ± 6.68	99.04 ± 9.65	$\eta_p^2 = 0.000$	$\eta_p^2 = 0.015$	$\eta_p^2 = 0.006$
MSTH					
MAI	99.24 ± 7.56	100.17 ± 7.14	0.605	0.001*	0.272
ST/G	98.30 ± 6.82	98.78 ± 6.33	$\eta_p^2 = 0.007$	$\eta_p^2 = 0.248$	$\eta_p^2 = 0.033$
MRH					
MAI	99.20 ± 7.68	101.25 ± 6.01	0.536	0.001*	0.219
ST/G	98.36 ± 6.47	99.52 ± 5.75	$\eta_p^2 = 0.010$	$\eta_p^2 = 0.354$	$\eta_p^2 = 0.040$

**$p < 0.05$; SD: standard deviation; η_p^2: partial eta squared; SH: single hop for distance; TH: triple hop for distance; CH: crossover triple hop for distance; MSTH: medial side triple hop for distance; MRH: medial rotation (90°) hop for distance.*

direction of jumping and landing but also according to dynamic postural stability [33, 34]. Due to hip abduction during descent from multidirectional SLHTs (MSTH and MRH), medial rotation and knee valgus limit movement, which can lead to knee injuries [26, 35]. For these reasons, multidirectional tests such as MSTH and MRH are important to obtain valid and reliable information after ACLR and any knee injury.

In terms of surgical technique, it is thought that removing a single tendon (ST) from the hamstring muscle instead of removing both hamstring tendons (ST/G) will have less detrimental effect on flexion movement of the knee [7]. Previous studies evaluated the removal of the hamstring tendon in ACLR and reported no significant difference in knee extension and flexion strength [36]. In addition, with the advent of objective measurement methods such as isokinetic dynamometers, some significant differences in knee-deep flexion torque have been found. When the force curves were evaluated, it was observed that the peak of the curve shifted to the left after the ST/G hamstring harvest. This revealed that ST/G muscles are essential deep flexors for knee torque [37, 38]. After these findings, only the semitendinosus muscle is autografted, and the gracilis muscle is preserved. It was determined that knee flexion function improved with the protection of the Gracilis muscle [39]. Although this difference is not evident in studies evaluating SLHTs after different ACLR techniques, as in our current study, the results can be assessed more clearly with strength curves in isokinetic dynamometers, which are more objective methods.

Our study has limitations at various levels. The main limitation is the retrospective nature of the study. Although the patients were subjected to the same physical therapy in the standard procedure, the content of the physical therapy and how regularly the patients stayed in this treatment were not noted. In addition, our study did not evaluate parameters such as, agility, strength, balance and quickness, which should be applied to RTS in addition to SLHTs. In future studies, evaluating LSI ratios at certain fatigue levels may be important in ensuring the participation of athletes, especially those with a history of ACLR, in physical activity with maximum effort. Since the main hypothesis of our study focused on similar post-operative findings between the MAI technique and ST/G, the limitations mentioned above were ignored.

5. Conclusions

Our results revealed similar LSI ratios between ST/G and MAI techniques in SLHTs applied in different directions, which led us to think that the MAI technique is a functional ACLR technique that can be used in athletes. Therefore, it is essential to compare the MAI technique with other techniques by evaluating factors such as isokinetic strength tests, radiological evaluations, electromyographic analyses and some performance components instead of evaluating SLHTs alone in patients with different ACLR techniques.

AVAILABILITY OF DATA AND MATERIALS

Data are available for research purposes upon reasonable request to the corresponding author.

AUTHOR CONTRIBUTIONS

BY, AKY, CY, EA, BA, MDB, ASG and LK—conceptualization, methodology, writing–original draft preparation, writing–review and editing, funding acquisition; EA, BA, MDB, ASG and LK—software; BY, MDB, ASG and LK—validation; MDB, ASG and LK—formal analysis; CY, EA, BA, MDB and ASG—investigation; BY, AKY, CY, EA and BA—resources; BY, AKY, CY, EA and LK—data curation; EA and BA—visualization; BY and AKY—supervision, project administration. All authors have read and agreed to the published version of the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was approved by the Clinical Research Ethics Committee of Gümüşhane University (approval number: E-95674917-108.99-239804) and conducted according to the Declaration of Helsinki. The data evaluated in this study were obtained from retrospective institutional records of patients treated for ACL rupture. Informed consent forms were obtained from all participants.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at https://oss.jomh.org/files/article/1803326865326129152/attachment/suplementary%20material.docx.

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