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Original Article

Evaluation of Strength and Functional Ability of Soccer Players Two Years After Anterior Cruciate Ligament Reconstruction: A Cross-sectional Study

Konstantinos Chatzilamprinos[1], Eleni Semaltianou[1], Dimitrios Hatzimanouil[1], Dimitrios Lytras[2], Evaggelos Sykaras[1]

[1]Department of Physical Education and Sports Science, Aristotle University of Thessaloniki, Thessaloniki, Greece;
[2]Department of Physiotherapy, Faculty of Health Sciences, International Hellenic University, Sindos, Thessaloniki, Greece

Abstract

Objectives: This study examines the strength and functional capacity of active soccer players two years post anterior cruciate ligament reconstruction (ACLR). **Methods**: Sixteen players, two years post ACLR, participated. Isokinetic tests assessed Peak Torque (PT) for concentric and eccentric contractions, along with conventional (H/Qconv) and functional (H/Qfunc) H/Q ratios at various angular velocities. Functional ability was gauged through hop tests. Paired-Samples T Test compared PT and hop test values, as well as H/Qconv and H/Qfunc ratios between involved and non-involved limbs. Limb symmetry was evaluated using the Limb Symmetry Index (LSI). **Results**: After two years, participants exhibited significant differences in concentric PT between limbs. The non-involved limb demonstrated superior performance at isokinetic speeds. Eccentrically, PT for knee extensors and flexors showed no significant disparities between the operated and non-operated limbs across all velocities tested. Most participants did not achieve LSI 90-110% for knee extensors and flexors. No noteworthy distinctions were observed in H/Qconv, H/Qfunc, and hop tests between limbs. The majority met LSI 90-110% in hop tests, except in the 30-second side hop (37%). **Conclusions**: Two years post ACLR, soccer players still manifest strength and functional deficits, heightening the risk of injury.

Keywords: Anterior Cruciate Ligament Reconstruction, Hop Tests, Isokinetic Test, Return to Sports, Soccer

Introduction

Anterior cruciate ligament (ACL) rupture accounts for 6-14% of injuries that occur in soccer[1,2]. For the return of soccer players to competitive action at the pre-injury level, surgical reconstruction is imperative when this has been jointly decided by the medical and training team as well as the athlete[3,4]. Within the first two years after surgical reconstruction there is a high risk of injury to both the operated and non-operated limb[5]. In the first two years after the initial ACL tear there is also a 24% risk of a second injury upon return to competitive action[6]. Relevant literature reports that 24 months after anterior cruciate ligament reconstruction (ACLR) athletes have a sixfold risk of re-injury[7]. Furthermore, within the first five years after surgery 3-22% of athletes sustained a graft tear, while 3-24% sustained an ACL tear in the healthy limb[8].Muscle deficits involving knee joint extensors and flexors persist up to two years after ACLR[9,10].

Researchers often use isokinetic assessment to determine strength as well as hop tests for functional ability to evaluate athletes for return to competitive action[7]. Hop tests are used in the functional assessment of post-ACLR patients in sports that involve jumping, turning, and changes of direction. Assessment of muscle strength is performed through isokinetic testing of the knee extensors and flexors where muscle deficits are often noted after ACLR[11]. A 10-15% difference between the two limbs for functional testing and

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Corresponding author: Evaggelos Sykaras PT, PhD, Department of Physical Education and Sports Sciences, Aristotle University of Thessaloniki, Thermi, 57001, Thessaloniki Greece
E-mail: sykaras@phed.auth.gr

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Table 1. Participants demographics, time from surgery (months), rehabilitation time (months).

n =16	Range	Minimum	Maximum	Mean	SD
Age	15.00	18.00	33.00	24.62	4.92
Body mass (kg)	23.00	57.00	80.00	67.90	6.83
Height(cm)	25.00	160.00	185.00	175.25	7.11
Time from surgery(months)	3.00	22.00	25.00	23.56	1.03
Rehabilitation time (months)	4.00	6.00	10.00	8.75	1.39

SD= Standard Deviation; kg= Kilogram; cm= centimeters.

strength assessment is considered acceptable[12]. However, some researchers consider a difference of more than 10% between limbs after ACLR for both strength and hop tests unsatisfactory[13]. Athletes that participated in evaluation tests and did not meet the proposed return-to-sport criteria were four times more likely to re-injure (graft rupture)[12].

In the international literature, studies examining functional ability at 24 months after surgery usually use single tests of either strength or functioning or a combination of both[14]. In our study, soccer players were thoroughly assessed two years after ACLR, a critical time point when there is a risk of re-injury. The purpose of the study was to determine the competitive readiness of active soccer players two years after the surgery through isokinetic evaluation indices and hop tests.

Materials and Methods

Design

Our study followed a cross-sectional design and was conducted under the supervision of the Department of Physical Education and Sports Science of the Aristotle University of Thessaloniki. The evaluation protocol of the soccer players who participated in the study meets the criteria of the Principles and Operation Regulation of the Ethics Committee of the Aristotle University of Thessaloniki and the current legislation. Eligibility of participants as well as evaluation assessments took place in the Laboratory of Evaluation of Human Biological Performance.

Participants

Sixteen soccer players voluntarily participated in this study. Participants were level 1 athletes (participating in a sport with twisting movements, jumping, and cutting such as soccer 4-7 times/week)[15] who participated in a national level championship. Their mean age was 24.62±4.92 years, body weight 67.90±6.83kg, and height 175.25±7.11cm, while their mean previous soccer experience was 10.31±4.25 years. Athletes were assessed 23.56±1.03 months after ACLR and during the measurement period had returned to competitive action. Their mean recovery time was 8.75±1.39 months (Table 1).

Inclusion criteria for participation in the study were: (1) men, (2) age 18-35 soccer players (level 1 athletes) active in the last five years, (4) having undergone ACLR 22-25 months ago, and (5) signing a written consent form for their participation in the research. An exclusion criterion was the existence of a musculoskeletal injury in the last six months. The absence of injury during the last six months was recorded through a personal interview during the eligibility screening phase and was confirmed after contact with the training team of the participants.

Procedures

Participants visited the laboratory twice. During their first visit, their history was recorded, they were informed about the evaluation process, and they were given time to familiarize themselves with the laboratory equipment that was to be used during the evaluation. On their second visit, baseline measurements were performed. Before measurements, the athletes did a five-minute warm-up on an exercise bike (100 Watts) and five minutes of dynamic stretching of the lower limbs. All participants performed the same warm-up routine.

Hop tests

After the initial warm-up, the assessment was carried out through the hop tests in the following order: Single hop test for distance (SHD), 6-meter timed hop test (6MTH), triple hop test for distance (THD), crossover hop test for distance (CHD), and 30-second side hop test (SH). Each test was performed first on the healthy limb and then on the affected limb. For all tests participants performed one trial and two normal tests (the average of the two successful tests was calculated) for each limb except for SH where one trial and one normal test was performed for each limb. If an attempt was invalid, then an additional normal attempt was allowed. The downtime between attempts was at least 30 seconds, while between different tests at least two minutes. During the execution of the hop tests, there was no restriction on the movement of the arms. The mean values of time (sec), distance (cm), and number of hops (rep) were compared between the operated and healthy limb to calculate the performance of the athletes[16-18].

Single hop test for Distance (SHD)

In this test, participants were asked to stand with one foot behind the starting line and perform as long as possible a horizontal jump (the maximum distance of the jump in cm was considered for the measurement). The distance measurement was performed at the level of the heel. When landing on the tested leg, subjects had to maintain their balance for two seconds.

6-meter timed hop test (6MTH)

In this hop test, participants were asked to stand on one leg behind the starting line and after the examiner's signal to cover the distance of six meters on one leg as quickly as possible. The time in seconds taken by each participant to cover the distance of six meters was considered, measured with a digital stopwatch hand timer (Amila 44092 Professional Stop watch).

Triple hop test for distance (THD)

In this test, participants were asked to stand on one leg behind the starting line and perform three consecutive horizontal jumps on one leg to achieve as much distance as possible, while in the last jump, upon landing, they had to maintain their balance for two seconds. The maximum hop distance in cm was considered for the measurement. The distance measurement was performed at the level of the heel.

Crossover hop test (CHD)

In this test, participants had to stand with one foot behind the starting line and perform three horizontal cross jumps over a median line (without touching the 15cm thick line). The goal of the test was to cover the longest possible distance without losing their balance and to land firmly on the last jump for two seconds. The maximum distance in cm was considered for the measurement. The distance measurement was carried out at the level of the heel.

30-seconds side hop test (SH)

When performing this test, participants were asked to stand on the examined leg and jump over two parallel lines 40cm apart for 30 seconds without touching them. The goal of the test was to perform the largest possible number of jumps within 30 seconds. A digital stopwatch hand timer was used for the test (Amila 44092 Professional Stopwatch). The number of jumps performed by each examinee in 30 seconds was considered for the measurement. If 25% of the jumps were unsuccessful then the process was repeated.

Isokinetic assessment

After a five-minute break, the isokinetic assessment followed using an isokinetic dynamometer (C.S.M.i., HUMACNORM 770, U.S.A.). The maximum torque of the extensor and flexor muscles of the knee joint with full range of motion was assessed. Participants were assessed at 60°/s, 180°/s, 300°/s concentrically and at 60°/s, 180°/s, 300°/s eccentrically. During the isokinetic assessment, three trials and three normal attempts were performed at each angular velocity for each limb, with a one-min break between the different angular velocities. The measurement was made from the slowest to the fastest velocity. The best effort for each angular velocity was selected from the three normal attempts (peak torque is defined as the maximum torque value from a set of repetitions)[19]. After a five-minute break, the eccentric evaluation was performed. The non-operated limb was evaluated first[17]. A five-minute break was given between the assessment of the two limbs. The researchers provided participants with visual and auditory feedback. The conventional H/Q ratio (H/Qconv) (concentric function of the knee flexors / concentric function of the knee extensors) and the functional H/Qratio (H/Qfunc) (eccentric function of the flexors / concentric function of the knee extensors) of each limb were also calculated.

Statistical analysis

The statistical analysis of the data was carried out using the SPSS version 25 statistical program (IBM Corporation, Armonk, NY). The Shapiro-Wilk test was used to check the normality of the distribution, where the normality of the distribution was established. The Paired-Samples T Test was used to compare the mean values of peak knee extensor and flexor muscles torque between the two limbs, H/Qconv, H/Qfunc during isokinetic assessment, distance in (cm), time in (sec), and the number of jumps during the hop tests. Additionally, the peak torque of knee extensors in three different velocities (60°/s, 180°/s, and 300°/s) was correlated with each hop test score though a Pearson correlation analysis to establish any association between strength and hop test data. Correlation in each participant was measured only for the operated limb. The level of significance was set at $p < .05$. Finally, the limb symmetry index (LSI) for knee extensors and flexors was calculated with the equation {(operated value/non-operated value) × 100} during the isokinetic assessment for concentric contraction, and for the hop tests with the equation {(operated value/non-operated value) × 100}, except for the 6MTH where the equation {(non-operated value/operated value) × 100} was used.

Results

Hop tests

When evaluating the jump tests, it was observed that two years after ACLR, the non-operated limb had better values in terms of the average distance in (cm), time in (sec), and the number of jumps compared to the operated limb, albeit without significant statistical difference (Table 2). Specifically, no significant statistical difference was observed in SHD between the operated and non-operated limb of the

Table 2. Values for five hop tests between operated and unaffected limb.

n =16	SHD (cm)	6MTH (sec)	THD (cm)	CHD (cm)	SH (number of hops)
Operated limb Mean (SD)	194.84±23.96	1.99±0.37	553.28±73.07	511.93±65.23	37.43±10.68
Unaffected limb Mean (SD)	201.37±16.19	1.91±0.29	575.81±56.20	516.28±51.73	39.68±10.07
Sig.operated/ Unaffected limb	p = .095	p = .177	p = .069	p = .698	p = .113

SD= Standard Deviation; SHD= Single Hop for Distance; 6MTH= 6 Meter Timed Hop; THD= Triple Hop for Distance; CHD= Crossover Hop for Distance; SH= Side Hop; cm= centimeters; sec= seconds; Sig= Significance.

Table 3. Isokinetic values for knee extension and knee flexion peak torque between operated and unaffected limb during concentric contraction.

n=16	Knee extension peak torque 60°/s (Nm)	Knee extension peak torque 180°/s (Nm)	Knee extension peak torque 300°/s (Nm)
Operated limb Mean (SD)	173.37±32.47	133.00±18.32	100.87±11.23
Unaffected limb Mean (SD)	191.25±30.49	146.12±21.36	110.75±11.88
Sig. Operated limb/ Unaffected limb	p = .027	p = .045	p =.031
n=16	**Knee flexion peak torque 60°/s (Nm)**	**Knee flexion peak torque 180°/s (Nm)**	**Knee flexion peak torque 300°/s (Nm)**
Operated limb Mean (SD)	111.68±23.62	87.56 ±15.73	66.93±13.94
Unaffected limb Mean (SD)	119.62±23.07	94.00±16.80	72.06±17.11
Sig. Operated limb/ Unaffected limb	p =.076	p =.102	p =.143

SD= Standard Deviation; Nm= Newton Meter; Sig= Significance.

participants with the non-operated having better results (*p* = .095). For 6MTH, no significant statistical difference was observed between the operated and non-operated limb, with the non-operated limbs having better results (*p* = .177). For THD, no significant statistical difference was observed between the operated and non-operated limb, with the non-operated limb of the participants having better results (*p* = .069). No significant statistical difference was observed between the operated and non-operated limb when evaluating CHD, with the non-operated limb having better outcomes (*p* = .698). For SH, no significant statistical difference was observed in the number of jumps between the operated and non-operated limb of the participants, with the non-operated limb performing better (*p* = .113).

Isokinetic test

Regarding the isokinetic assessment two years after ACLR under conditions of peak torque, when tested at the three angular velocities (60°/s, 180°/s, 300°/s) during concentric function a significant statistical difference was observed regarding the mean of the peak torque between the operated and the non-operated limb for the knee extensors with the non-operated having better values (Table 3). We found no significant statistical differences for the knee flexors in all three angular velocities (60°/s, 180°/s, 300°/s) during concentric function, with the non-operated limb having better values. More specifically, at 60°/s the mean peak torque for the knee extensors between the operated and non-operated limb showed a significant statistical difference, with the non-operated limb having better results (*p* = .027). At 60°/s the mean peak torque for the knee flexors between the operated and non-operated limbs did not show a significant statistical difference, with the non-operated limb having better results (*p* = .076). At 180°/s the mean peak torque for the knee extensors between the operated and non-operated limbs was significantly statistically different with the non-operated limb having better values (*p* = .045). At the same angular velocity for the knee flexors no significant statistical difference was observed between the operated and non-operated limb of the participants, with the non-operated limb having better values (*p* = .102). At 300°/s there was a significant statistical difference in the mean peak torque

Table 4. Isokinetic values for knee extension and knee flexion peak torque between operated and unaffected limb during eccentric contraction.

n=16	Knee extension peak torque 60°/s (Nm)	Knee extension peak torque 180°/s (Nm)	Knee extension peak torque 300°/s (Nm)
Operated limb Mean (SD)	178.00±42.63	177.92±43.42	185.92±38.85
Unaffected limb Mean (SD)	186.14±35.54	199.71±39.52	189.57±61.91
Sig.	p =.515	p =.082	p =.831
N=14	**Knee flexion peak torque 60°/s (Nm)**	**Knee flexion peak torque 180°/s (Nm)**	**Knee flexion peak torque 300°/s (Nm)**
Operated limb Mean (SD)	109.71±27.68	116.50±32.37	125.25±30,27
Unaffected limb Mean (SD)	108.78±25.25	122.64±31.00	116.50±41,05
Sig.	p =.902	p =.461	p =.528

SD= Standard Deviation; Nm= Newton Meter; Sig= Significance.

Table 5. Isokinetic values for H/Q conventional (Hamstring concentric peak torque/Quadriceps concentric peak torque) between operated and unaffected limb.

n=16	H/Q Conv. 60°/s	H/Q Conv. 180°/s	H/Q Conv. 300°/s
Operated limb Mean (SD)	64.68±9.23	66.43±11.44	66.81±14.86
Unaffected limb Mean (SD)	62.87±10.02	65.12±12.15	65.06±14.28
Sig. Operated limb/ Unaffected limb	p =.456	p =.718	p =.678

SD= Standard Deviation; H/Q Conv= Hamstrings/Quadriceps Conventional Ratio; Sig= Significance.

between the operated and non-operated limbs for the knee extensors, with the non-operated limb performing better (p = .031). For the knee flexors there was no significant statistical difference between the operated and non-operated limb, with the non-operated limb having better results (p = .143).

Regarding the eccentric evaluation results, there were no statistically significant differences between the operated and non-operated limb for both knee extensors and flexors for the angular velocities examined (60°/s, 180°/s, 300°/s) (Table 4). Specifically, for the knee extensors at 60°/s the non-operated limb had better values than the operated one without this difference being statistically significant (p = .515). At the same angular velocity, the knee flexors of the operated leg showed better values compared to those of the healthy one without the difference being statistically significant (p = .902). Regarding the results at 180°/s, the values in the healthy leg, although improved compared to the injured one, did not show statistically significant differences neither in the extensors (p = .082) nor in the flexors (p = .461). Finally, at 300°/s the healthy leg showed improved values compared to the operated one for the extensors, while for the knee flexors the operated one showed better values compared to the healthy one. However, none of these differences were statistically significant (p = .831 and p = .528 respectively).

When evaluating H/Qconv two years after surgery, it was observed that there were no significant differences between the operated and non-operated limb at all angular velocities examined (60°/s, 180°/s, 300°/s), with the operated limb having better results (Table 5). More specifically, at 60°/s there was no significant statistical difference between the operated and non-operated limb, with the operated limb having a higher value (p = .456). At 180°/s there was no significant statistical difference between the limbs, with the operated limb having a higher value (p = .718). At 300°/s there was no significant statistical difference between the two limbs for H/Qconv with the operated limb having a higher value (p = .678).

We found no significant statistical differences for H/Qfunc at any of the angular velocities examined (60°/s, 180°/s, 300°/s), with the operated limb having better values (Table 6). Specifically, at 60°/s no significant statistical difference was observed between the two limbs, with the operated limb having a better result (p = .124). At 180°/s for the same index no significant statistical difference was observed between the two limbs, with the operated limb having better results (p = .468). At 300°/s no significant statistical difference was observed between the two limbs, with the operated limb having better results (p = .130).

Table 6. Isokinetic values for H/Q Functional (Hamstring eccentric peak torque/Quadriceps concentric peak torque) between operated and unaffected limb.

n=16	H/Q Func 60°/s	H/Q Func 180°/s	H/Q Func 300°/s
Operated limb Mean (SD)	0.65±0.14	0.89±0.22	1.26±0.28
Unaffected limb Mean (SD)	0.57±0.10	0.85±0.17	1.04±0.36
Sig. Operated limb/ Unaffected limb	p =.124	p =.468	p =.130
SD= Standard Deviation; H/Q Func= Hamstrings/Quadriceps Functional Ratio; Sig= Significance.			

Table 7. Limb symmetry Index percentages of hop tests for 16 semi-professionals soccer players.

Limb Symmetry Index (LSI)	90-110% (LSI)	>110% (LSI)	<90% (LSI)
SHD (cm)	14/16 (87%)	0/16 (0%)	2/16 (13%)
6MTH (sec)	11/16 (69%)	1/16 (6%)	4/16 (25%)
THD (cm)	11/16 (69%)	2/16 (12%)	3/16 (19%)
CHD (cm)	13/16 (81%)	1/16 (6%)	2/16 (13%)
SH number of hops)	6/16 (37%)	3/16 (19%)	7/16 (44%)
LSI= Limb Symmetry Index; SHD= Single Hop for Distance; 6MTH= 6 Meter Timed Hop; THD= Triple Hop for Distance; CHD= Crossover Hop for Distance; SH= Side Hop; cm= centimeters; sec= seconds.			

Table 8. Limb symmetry index percentages for knee extensors and flexors between operated and unaffected limb.

Limb Symmetry Index (LSI)	90-110% (LSI)	>110% (LSI)	<90% (LSI)
Knee extension peak torque 60°/s (Nm)	5/16 (31%)	2/16 (13%)	9/16 (56%)
Knee flexion peak torque 60°/s (Nm)	11/16 (69%)	1/16 (6%)	4/16 (25%)
Knee extension peak torque 180°/s (Nm)	6/16 (37%)	2/16 (13%)	8/16 (50%)
Knee flexion peak torque 180°/s (Nm)	6/16 (37%)	3/16 (19%)	7/16 (44%)
Knee extension peak torque 300°/s (Nm)	9/16 (56%)	1/16 (6%)	6/16 (38%)
Knee flexion peak torque 300°/s (Nm)	6/16 (37%)	3/16 (19%)	7/16 (44%)
LSI= Limb Symmetry Index; Nm= Newton Meter.			

Limb Symmetry Index (LSI) for hop tests

Regarding the assessment of the LSI when performing the hop tests (Table 7), it was observed that for the SHD 14/16 (87%) of the participants achieved the required symmetry of 90-110%, for 6MTH 11/16 (69%) of participants achieved symmetry within 90-110%, for THD 11/16 (69%) achieved the required symmetry, for CHD 13/16 (81%) of participants achieved the required symmetry, while finally for SH only 6/16 (37%) of the participants achieved the required symmetry value.

Limb Symmetry Index (LSI) for isokinetic test

The assessment of limb symmetry during the isokinetic test for the knee extensors and flexors (Table 8) showed that at 60°/s for the knee extensors 5/16 (31%) of the participants achieved the required value within 90 -110%, and for knee flexors at the same angular velocity 11/16 (69%) were within normal limits. At 180°/s for knee extensors 6/16 (37%) and 6/16 (37%) for knee flexors achieved 90-110% symmetry between the two limbs. Finally, at 300°/s the required symmetry was achieved for the extensors by 9/16 (56%) participants, while for the flexors by 6/16 (37%) participants.

Correlations between knee extensors peak torque and hop tests

Regarding the Pearson correlation analysis results between hop tests and all knee extension measurements of the operated limb, a strong positive correlation was found

Table 9. Pearson correlation coefficients for all pairs among hop tests and knee extension peak torque tests for the operated limb.

	Knee extension peak torque 60°/s (Nm)		Knee extension peak torque 180°/s (Nm)		Knee extension peak torque 300°/s (Nm)	
	r	p	r	p	r	p
SHD (cm)	0.250	.350	0.286	.283	0.215	.425
6MTH (sec)	-0.350	.184	-0.266	.319	-0.394	.131
THD (cm)	0,220	.412	0.198	.463	0.296	.314
CHD (cm)	0.156	.564	0.124	.648	0.386	.140
SH (number of hops)	**0.654**	**.006**	**0.635**	**.008**	**0.653**	**.006**

SHD= Single Hop for Distance; 6MTH= 6 Meter Timed Hop; THD= Triple Hop for Distance; CHD= Crossover Hop for Distance; SH= Side Hop; cm= centimeters; sec= seconds, r = Pearson correlation coefficient.

between SH and all different angular velocities of knee extension peak torque (r = 0.635 – 0.654, *p* = .006 - .008). No other significant correlation was detected between all other hop tests with all different angles of knee extension torques (Table 9).

Discussion

Our research found that two years after ACLR soccer players continue to exhibit deficits in knee extensors muscle strength during isokinetic assessment, as well as affected functional ability related to lateral jump. We observed during the isokinetic evaluation of the mean peak torque for the knee extensors a significant difference between the operated and the non-operated limb, with the non-operated limb having better values for the concentric contraction. For the eccentric contraction, we found that the mean peak torque for the knee extensors and knee flexors was not significantly different between the operated and non-operated limb. Furthermore, most participants did not achieve the required 90-110% bilateral symmetry for both knee extensors and flexors.

The evaluation of the hop tests did not reveal any significant difference between the two limbs. Regarding limb symmetry beyond the 30 second side hop in the remaining hop tests, most participants achieved the required symmetry index of 90-110%. The assessment of isokinetic balance indices of the muscles surrounding the knee joint for both H/Qconv and H/Qfunc showed no significant difference between the two limbs at any angular velocity. However, participants were unable to achieve the required ratio values between competing muscles at most angular velocities for both indices.

One of the main findings of the study was the significant difference between the operated and non-operated limb for the knee extensors at the angular velocities tested, which is also verified by the relevant literature. In their review, Nagelli et al.[20] states that quadriceps strength deficits continue to persist for several months to years, with strength recovery lasting beyond the two-year period[20]. Roewer et al.[21] also found that quadriceps strength continues to recover two years after ACLR surgery. In the systematic review by Petersen et al.[22], researchers observed that in many studies strength deficits persisted 12-24 months after surgery. Finally, Karanikas et al.[23] found lower joint torques 12-24 months after ACLR.

Opposite results to our study were found by Aglietti et al.[24], where at two years after surgical reconstruction the knee extensor strength of the operated limb was comparable and sometimes greater than that of the non-operated limb. The above study also agrees with Maletis et al.[25], who reports that at two years after surgical reconstruction knee extensor strength was comparable to the healthy opposite limb. In the study by Buckthorpe et al.[26], the importance of regaining knee extensor strength during the rehabilitation period is emphasized, as knee extensor strength deficits are associated to a high risk of re-injury, reduced knee joint functioning, risk of osteoarthritis, and poor biomechanics.

Another important finding of the study was that most participants did not achieve the required symmetry value between the operated and non-operated limb (LSI 90-110%) during the isokinetic assessment for both knee extensors and knee flexors two years after ACLR. The above observation agrees with many studies. Thomeè et al.[27] found that the overall percentage achieving an LSI score ≥ 90% was 48% for the three strength tests (leg press, leg extension, leg flexion) 24 months after surgical reconstruction. In the systematic review by Taifur et al.[28], reported that muscle deficits for the quadriceps and hamstrings are encountered even more than two years after surgery. Xergia et al.[29] found that strength deficits for both extensors and flexors did not resolve two years after surgery. Contrary to the above, Gokeler et al.[30] states that 90% LSI is satisfactory for recreational and non-spinning sports. In contact sports with spinning movements, such as soccer, a 100% LSI is recommended.

Contrariwise, Aune et al.[31] found that 24 months after ACLR during isokinetic assessment of knee extensors and flexors the strength of the operated limb was almost symmetrical with that of the healthy limb regardless of the type of graft used. Moreover, Nagelli et al.[20] report that strength deficits for both knee extensors and flexors resolve two years after surgery. In our study, participants returned to activity without achieving the required limb symmetry for the knee extensors and flexors. It has been found that for every 1% increase in symmetry for the knee extensors there is a 3% reduction in the risk of re-injury[26]. Considering the high risk of re-injury in the two-year period after surgery, the importance of achieving symmetry for the knee extensors and flexors between the operated and non-operated limb can be understood.

The evaluation of the hop tests (SHD, 6MTH, THD, CHD, SH) revealed no significant difference between the operated and non-operated limb for the mean distance in (cm), time in (sec) and number of jumps. Additionally, regarding the limb symmetry index for the hop tests, it was observed that for the four classic hop tests most participants achieved the required symmetry (90-110%), except for SH. This finding is partially in agreement with the existing literature. Abrams et al.[32], in their systematic review, examined functional ability 6-24 months after ACLR. They found that the four most well-known hop tests (SHD, 6MTH, THD, CHD) had an average > 90% LSI at 6-9 months after surgery. However, for more demanding tests such as the 30" SH the results showed a reduction. It is worth noting that there are not many studies in the literature that use endurance hops. Gokeler et al.[16] states that SH requires increased endurance in the operated limb. Of course, as mentioned above, the LSI values for these tests were lower than those of the other hop tests, which could be explained by the fact that in the operated limb there is an increased effect of fatigue that persists for 6-12 months after surgical reconstruction. In our study, the reduced value of those who succeeded in the endurance lateral hop shows that there may be an increased fatigue effect even two years after ACLR on the operated limb, or that the participants were not sufficiently prepared.

Abrams et al.[32] found that these deficits normalize at 24 months after surgical reconstruction as mean limb symmetry is in the mid-90% range. This observation of the above review also agrees with our study as many of the non-successors in the endurance lateral hop were within the mean LSI range of 90%. Davies et al.[33] states that for these more demanding tests the required symmetry index can be reduced so that in turn this results in a higher percentage of passers. However, the same researchers point out that the reduction of the acceptable symmetry index will result in a reduction in the sensitivity of the tests. The participants of our study presented satisfactory symmetry in most of the hop tests, except in the SH test, which shows the importance of the recovery period and the secondary prevention of ACL injury in the intercostal movements as well as the endurance of the operated limb.

Regarding the isokinetic relationship indices of the antagonistic muscles surrounding the knee joint, no significant differences were observed between the two limbs, while in most of the angular velocities examined, the ratios suggested by the literature for both H/Qconv and H /Qfunc were not achieved. It is worth mentioning that the operated limb had higher values than the non-operated limb due to training maladaptation of the non-operated limb during the recovery period which is reported within the literature. Davies et al.[19] states that the non-operated limb presents lower values because of detraining which creates a problem in terms of the image of physiological characteristics of muscle performance.

According to Ruas et al.[34], a very important parameter for a safe return is the isokinetic ratio of knee flexors and extensors (H/Q ratio). The H/Q index is used to detect an imbalance between the knee flexors and extensors. Specifically, for H/Qconv at 60°/s the mean ratio was 64.68±9.23 for the operated limb and 62.87±10.02 for the non-operated limb, which is within the range that the literature suggests. Lehnert et al.[35] states that for H/Qconv at 60°/s the value should be above 0.6. Our results for this angular velocity agree with the proposed value. However, this does not happen for 180°/s and 300°/s where the operated limb had values of 66.43±11.44 and 66.81±14.86 respectively and the non-operated limb had values of 65.12±12.15 and 65.06±14.28 respectively. Therefore, at these two angular velocities for both limbs the required values were not achieved. Davies et al.[19] reports that for 180°/s the H/Qconv index should have a value of 0.70-0.80, while for 300°/s 0.85-0.95, something that was not achieved in our study. In the systematic review by Baroni et al.[36], it was found that for soccer players H/Qconv for slow to intermediate (12°/s -180°/s) angular velocities should be at 60%, while for fast angular velocities (240°/s-360°/s) 70-80% should be achieved.

The participants of our study achieved the required value for 60°/s and for 180°/s characterized by slow to intermediate angular velocities at both limbs according to the measurements in soccer players[36]. However, they did not achieve a satisfactory measurement for 300°/s which is characterized as fast, which is probably due to the lack of explosive power training. The above opinion is confirmed by the study of Eniseler et al.[37], where isokinetic values were observed to improve within a soccer season, with the most significant improvements in angular velocity of 500°/s. The authors of the study justified these results as the soccer players performed all strength training at least once a week at the highest speeds, performed additional hamstring strengthening exercises (if weakness was present) to improve H/Qconv, and performed strength training as well as knee extensions and flexions in 1:1 ratio for knee extensors and flexors. Even within the literature, strength training during the recovery period holds an important reference. In the systematic review of Nichols et al.[38], the lack of high intensity in resistance training is highlighted as well as the use of proper restriction with an emphasis on strength training, which is a key feature because it reflects the demands placed on the athlete's neuromuscular system when exerting maximal effort.

Buckthorpe et al.[39] emphasizes the importance of plyometric training during rehabilitation, which includes the stretch-shortening cycle and is used to optimize the explosive performance of athletes. Plyometric training, according to the authors, shows superior results than resistance training in terms of explosive performance of the lower limbs. According to studies, it has been found that the application of plyometric training can improve the H/Q index[40-42]. Finally, it is recommended to use training speeds that simulate the speed of movement of the sports activity[43]. Based on the above findings, it is understood that the training process should be simulated as much as possible in the antagonistic movements.

Another isokinetic index used in our study was H/Qfunc. Lehnert et al.[35] states that H/Qconv identifies muscle imbalances, while H/Qfunc identifies the ability of the knee flexors to slow knee extension. In their systematic review, Kellis et al.[44] states that when the quadriceps produce force concentrically, the hamstrings act antagonistically and contract eccentrically so the use of H/Qfunc is suggested. The above description occurs during knee extension. Ruas et al.[34] reports that H/Qfunc better represents the functional ability of muscles in sports in actions such as running and kicking, while Islam et al.[45] states that in most interval sports, such as soccer, H/Qfunc is more important as it represents the fatigue caused in the sport.

In our study, it was found that soccer players two years after ACLR do not show significant differences between the two limbs, with the operated limb having better results. For 60°/s, the operated limb had an average value of 0.65±0.14, while the non-operated limb had an average value of 0.57±0.10. Both values are not within normal limits. Lehnert et al.[35] states that at 60°/s H/Qfunc should have a ratio of 1.0, which demonstrates satisfactory stability of the knee joint. Baroni et al.[36], in their systematic review, found that for the above index the value of 1.0 is hardly achieved at the angular speed of 60°/s, so they suggest a ratio of 0.8. The relationship suggested by the literature was also not achieved for 180°/s for both limbs with values of 0.89 (0.22) and 0.85 (0.17) for the operated and non-operated limb respectively. According to Baroni et al.[36], for intermediate to fast angular velocities a ratio of 1.0-1.3 should be achieved. Failure to achieve satisfactory relationships for the angular velocities of 60°/s and 180°/s is due to the training process not emphasizing hamstring eccentric training. Islam et al.[45] suggests the use of the Nordic Hamstring to improve the eccentric strength of the hamstrings. Other exercises that can contribute to this are the single leg dead lift, the Swiss ball curl, and the foam roller bridge.

On the contrary, for the angular velocity of 300°/s, satisfactory values were achieved for both limbs. The mean value was 1.26 (0.28) and 1.04 (0.36) for the operated and non-operated limb respectively. Kellis et al.[44] states that for the functional index at angular velocities >240°/s the values must exceed 1.0. This contrast is probably because soccer players due to training and the fast nature of the sport have adapted and do not show a bad ratio in this velocity.

Bogdanis et al.[46] reports that elite soccer players develop velocities during kicking of 1200-1900°/s, while Kellis et al.[44] states that speeds of about 500-800°/s are developed during sprinting.

In our research, we investigated a possible correlation between the performance of the hop tests and the strength of the knee extensors. Our focus was based on previous studies that have also tried to correlate the strength of the knee extensors during the isokinetic test with the performance in the hop tests[47,48]. However, from the results of our research no correlation was observed between knee extensor strength at all angular velocities examined (60°/s, 180°/s, 300°/s) with any of the widely used hop tests (SHD, 6MTH, THD, CHD) for the operated limb, which agrees with the existing literature data. Barford et al.[48] attempted to correlate knee extensor strength with SHD six and 12 months after ACLR and found that SHD cannot replace knee extensor strength testing. Herrington et al.[49] evaluated the relationship of knee extensor strength and functional jump test performance in 15 professional soccer players at the time of returning to play and found that 80% of participants failed to reach ≥ 90% LSI for knee extensors while during functional jump tests 75% of patients achieved the required values. On the other hand, the main finding of our correlation concerns the fact that the muscle performance of the knee extensors showed a significant positive correlation at all angular velocities (60°/s, 180°/s, 300°/s) with the performance in SH for the operated limb, suggesting that the higher the strength of the knee extensors the better the SH performance. A corresponding correlation between knee extensors and SH has not yet been widely examined in the literature. Consequently, SH can be used if it is not possible to evaluate the knee extensors on the isokinetic dynamometer when examining the readiness of the athlete after ACLR. In any case, a test battery with a combination of both strength and functional measurements should be implemented, so that rehabilitation specialists can be led to a complete, valid, and safe conclusion about the functional status of the athlete when evaluating their return to competitive action.

Several limitations are present in our study. The small number of participating soccer players and their semi-professional status do not allow for the results to apply to the entire range of soccer categories.

Conclusions

Two years after ACLR, soccer players continue to show deficits in both strength and functional performance. During the isokinetic evaluation, significant deficits were identified in the operated limb compared to the healthy one in terms of peak torque for the knee extensors, while a large percentage of participants did not achieve the required symmetry (90-110%) for the knee extensors and flexors between the two limbs. Regarding the isokinetic indexes H/Qconv and H/Qfunc there were no significant differences between the operated and the non-operated limb, with most of the indexes not being within the acceptable values. In the hop tests, a significant percentage was not found to achieve the required LSI in the SH, which points to the existence of a lateral hop deficit and a risk of re-injury. Moreover, SH performance may be used as an indirect assessment of knee extensor strength. More studies need to be implemented in the future that will examine why soccer players continue to have deficits in strength as well as function two years after ACLR. The evaluation of the performance should be based on the requirements of the sport, while finally, in addition to the quantitative evaluation, a qualitative evaluation of the movement (motor and kinematic assessment) should be applied to correct the wrong movement patterns.

Ethics approval

Ethical approval was granted by the Ethics Committee of the Department of Physical Education and Sports Science, Aristotle University of Thessaloniki, Greece (No. EH-63/2021).

References

1. Tamalet B, Rochongar P. Epidemiology and prevention of anterior cruciate ligament rupture of the knee. Rev Rum Mongr 2016;83(2):103-7.
2. Gilchrist J, Mandelbaum BR, Melancan H, Ryan GW, Silvers HJ, Griffin LY, Watanabe DS, Dick RW, Djorek J. A randomized controlled trial to prevent non contact anterior cruciate ligament injury in female collegiate soccer players. Am J Sports Med 2008;36(8):1476-83.
3. Della Villa S, Boldrini L, Ricci M, Danelon F, Snyder-Mackler L, Nanni G, Roi GS. Clinical Outcomes and Return to Sports Participation of 50 soccer players after Anterior Cruciate Ligament Reconstruction through a Sports-Specific Rehabilitation protocol. Sports Health 2012;4(1):17-24
4. Koh BT, Sayampanathan AA, Bin Abd Razak HR, Chong HC, Tan HC. Injury patterns in patients presenting with recurrent anterior cruciate ligament tear following primary reconstruction. Ann Transl Med 2016;4(12):232.
5. Leister I, Mattiasich G, Kindermann H, Ortmaier R, Barthofer J, Vasvary I, Katzensteiner K, Stelzhammer C, Kulnik ST. Reference values for fatigued versus non- fatigued limb symmetry index measured by newly designed single led hop test battery in health subjects: a pilot study. Sports Sci Health 2018;14(1):105-113.
6. Schmitt L, Paterno MV, Hewett T. The Impact of Quadriceps Femoris Strength Asymmetry on Functional Perfomance at Return to Sport Following Anterior Cruciate Ligament Reconstruction. J Orthop Sports Phys Ther 2012;42(9);750-9.
7. Ebert JR, Edwards P, Curie J, Smith A, Joss B, Ackland T, Buelow JU, Hewitt B. Comparison of the back in action test battery to standard hop tests and isokinetic knee dynamometry in patients following anterior cruciate ligament reconstruction. Int J Sports Phys Ther 2018;13(3):389-400.
8. Van Melick N, Van Cingel REH, Brooijmans F, Neeter C, Van Tiensen T, Hullegie W, Nijhuis-van der Sanden MWG. Evidence-based clinical practice update: practice guidelines for anterior cruciate ligament rehabilitation based on systematic review and multidisclipinary consensus. Br J Sports Med 2016;50(24):1506-1515.
9. Grindem H, Snyder-Mackler L, Moksnes H, Engebretsen L, Risberg MA. Simple decision rules after ACL reconstruction: the Delaware-Oslo ACL cohort study. Br J Sports Med 2016;50:804-808.
10. Kaplan V, Witvrouw E. When is it safe to return to sport after ACL reconstruction? Reviewing the criteria. Sports Health 2019;11(4):301-305.
11. Goes RA, Cossich V, Franca BR, Campos ALS. Return to play after anterior cruciate ligament reconstruction. Revista Brasileira de Medicina do Esporte 2020;26(6):478-486.
12. Kyritsis P, Bahr R, Landreau P, Miladi R, Witvrouw E. Likehood of ACL graft rupture: not meeting six clinical discharge criteria before return to sport is associated with four times greater risk of rupture. Br J Sports Med.2016;50(15):946-51.
13. Thomeè R, Kaplan Y, Kvist J, Myklebust G, Risberg MA, Theisen D, Tsepis E, Werner S, Wondrasch B, Witvrouw E. Muscle strength and hop performance criteria prior to return to sports after ACL reconstruction. Knee Surg Sports TraumatolArthrosc 2011;19(11):1798-805.
14. Reinke EK, Splindler KP, Lorring D, Jones MH, Schmitz L, Flanigan DC, Qi An A, Quiram AR, Preston E, Martin M, Schroeder B, Parker RD, Kaeding CC, Borzi L, Pedroza A, Huston LJ, Harrell FE Jr, Dunn WR. Hop tests correlate with IKDC and KOOS at minimum 2 years after primary ACL reconstruction. Knee Surg Sports TraumatolArthrosc 2011;19(11):1806-1816.
15. Noyes F, Barber SD, Mooar LA. A rationale for assessing sports activity levels and limitations in knee disorders. Clin Orthop Relat Res 1989;(246):238-49.
16. Gokeler A, Welling W, Benjaminse A, Lemmik K, Seil R, Zaffagnini S. A Critical Analysis of Limp Symmetry Indices of Hop Tests in Athletes after Anterior Cruciate Ligament Reconstruction: A case Control study. OrthopTraumatol Surg Res 2017;103(6):947-951.
17. Reid A, Birmingham TB, Stratford PW, Alcork GK, Griffin JR. Hop Testing Provides a Reliable and Valid Outcome Measure During Rehabilitation After Anterior Cruciate Ligament Reconstruction. Phys Ther 2007;87(3):337-49.
18. Noyes FR, Barber SD, Mangine RE. Abnormal lower limb symmetry determined by function hop tests after anterior cruciate ligament rupture. Am J Sports Med 1991;19(5):513-8.
19. Davies GJ, Riemann BL, Ellenbecker T. Role of Isokinetic Testing and Training After ACL Injury and Reconstruction: Causes, Impacts, and Conditioning Programs. Causes, Impacts, and Conditioning Programs. In: ACL Injuries in the female Athlete. Editors Noyes FR, Barber Westin S. Springer;2018 pp 567-588.
20. Nagelli C, Hewett T. Should Return to Sport be Delayed Until 2 years After Anterior Cruciate Ligament Reconstruction? Biological and Functional Considerations. Sports Med 2017;47(2):221-232.
21. Roewer BD, Di Stasi SL, Snyder-Mackler L. Quadriceps

strength and weight acceptance strategies continue to improve two years after anterior cruciate ligament reconstruction. J Biomech 2011;44(10):1948-53.
22. Petersen W, Taheri P, Forkel P, Zantop T. Return to play following ACL reconstruction: a systematic review about strength deficits. Arch OrthopTrayma Surg 2014;134:1417-1428.
23. Karanikas K, Arampatzis A, Brüggemann GP. Motor task and muscle strength followed different adaptation patterns after anterior cruciate ligament reconstruction. Eur J Phys Rehabil Med 2009;45(1):37-45.
24. Aglietti P, Giron F, Buzzi R, Biddau F, Sasso F. Anterior cruciate ligament reconstruction: bone-patellar tendon-bone compared with double semitendinosus and gracilis tendon grafts. A prospective randomized clinical trial. J Bone Joint Surg Am 2004;86-A:2143-2155.
25. Maletis GB, Cameron SL, Tengan JJ, Burchette RJ. A prospective randomized study of anterior cruciate ligament reconstruction: a comparison of patellar tendon and quadruple-strand semitendinosus/gracilis tendons tendons fixed with bioabsorbable interference screws. Am J Sports Med 2007;35:384-394.
26. Buckthorpe M, De La Rosa G, Della Villa F. Restoring knee extensor strength after Anterior Cruciate Ligament Reconstruction: A Clinical Commentary. Int J Sports Phys Ther 2019;14(1):159-172.
27. Thomeè R, Neeter C, Gustavsson A, Thomeè P, Augustsson J, Ericson B, Karlsson J. Variability in leg muscle power and hop performance after anterior cruciate ligament reconstruction. Knee Surg Sports TraumatolArthrsc 2012;20(6):1143-51.
28. Tayfur B, Charuphongsa C, Morrissey D, Miller SC. Neuromuscular Function of the Knee Joint Following Knee Injuries: Does It Ever Get Back to Normal? A Systematic Review with Meta-Analyses. Sports Med 2021;51(2):321-338.
29. Xergia SA, McClelland JA, Kvist J, Vasiliadis HS, Georgoulis AD. The influence of graft choice on isokinetic muscle strength 4-24 months after anterior cruciate ligament reconstruction. Knee Surg Sports TraumatolArthrosc 2011;19(5):768-80.
30. Gokeler A, Dingenen B, Hewett TE. Rehabilitation and Return to Sport Testing After Anterior Cruciate Ligament Reconstruction: Where Are We in 2022? Antthrosc Sports Med Rehabil 2022;4(1):e77-e82.
31. Aune AK, Holm I, Risberg MA, Jensen HK, Steen H. Four-strand hamstring tendon autograft compared with patellar tendon-bone autograft for anterior cruciate ligament reconstruction. A randomized study with two-year follow-up. Am J Sports Med 2001;29(6):722-28.
32. Abrams GD, Harris JD, Gupta AK, McCormick FM, Bush-Joseph CA, Verma NN, Cole BJ, Bach Jr B. Functional Performance Testing After Anterior Cruciate Ligament Reconstruction: A Systematic Review. Orthop J Sports Med 2014;2(1):2325967113518305.
33. Davies WT, Myer GD, Read PJ. Is It Time We Better Understood the Tests We are Using for Return to Sport Decision Making Following ACL Reconstruction? A Critical Review of the Hop Tests. Sports Med 2020; 50(3):485-495.
34. Ruas CV, Pinto MD, Brown LE, Minozzo F. The association between conventional and dynamic control knee strength and dynamic control knee strength ratios in elite soccer players. Isokinetics and Exercise Science 2015;23(1):1-12.
35. Lehnert M, Xenerova Z, De Ste Croix M. Changes in muscle strength in U19 soccer players during an annual training cycle. J Hum Kinet 2014;42:175-85.
36. Baroni BK, Ruas CV, Ribeiro-Alcarez JB, Pinto RS. Hamstring-to-Quadriceps Torque Ratios of Professional Male Soccer Players: A Systematic Review. J Strength Cond Res 2020;34(1):281-293.
37. Eniseler N, Şahan C, Vurgun H, Mavi HF. Isokinetic Strength Responses to Season-long Training and Competition in Turkish Elite Soccer Players. J Hum Kinet 2012;31:159-168.
38. Nichols ZW, O' Brien D, White SG. Is resistance training adequately prescribed to meet the demands of returning to sport following anterior cruciate ligament repair? A Systematic review. BMJ Open Sport Exerc Med 2021;7(3):e001144.
39. Buckthorpe M, Della Villa F. Recommendations for Plyometric Training after ACL Reconstruction – A Clinical Commentary. Int J Sports Phys Ther 2021;16(3):879-895.
40. Hewett TE, Stroupe AL, Noyes FR. Plyometric training in female athletes. Decreased impact forces and increased hamstring torques. Am J Sports Med 1996;24(6):765-73.
41. Myer GD, Ford KR, Brent JL, Hewett TE. The effects of plyometric vs Dynamic stabilization and balance training on power, balance, and landing force in female athletes. J Strength Cond Res 2006;20(2):345-53.
42. Wilkerson GB, Colston MA, Short NI, Neal KL, Hoewischer PE, Pixley JJ. Neuromuscular Changes in Female Collegiate Resulting From a Plyometric Jump-Training Program. J Athl Train 2004;39(1):17-23.
43. Tsang KKW, DiPasquale AA. Improving Q:H strength ratio in women using plyometric exercises. J Strength Cond Res 2011;25(10):2749-5.
44. Kellis E, Sahinis C ,Baltzopoulos V. Is hamstrings-to-quadriceps torque ratio useful for predicting anterior cruciate ligament and hamstring injuries? A systematic and critical review. J Sport Health Sci 2023;12(3):343-358.
45. Islam MS, De A. Functional Hamstring to Quadriceps Strength Ratio (H:Q) and Hamstring Injury of Soccer Players: A Qualitative Analysis. Orthopaedis and Sports Medicine 2018 doi:10.324741OSMo AJ.2018.0200133.
46. Bogdanis GC, Kalapothakos VI. Knee Extension Strength and Hamstrings-to-Quadriceps Imbalances in Elite Soccer Players. Int J Sports Med 2016;37(2):119-24.
47. Greenberger HB, Paterno MV. Relationship of knee

extensor strength and hopping test performance in assessment of lower extremity function. J Orthop Sports Phys Ther 1995; 22(5):202-6.
48. Barford KW, Feller JA, Hartwig T, Deritt BM, Webster KE. Knee extensor strength and hop performance following anterior cruciate ligament reconstruction. Knee 2019; 26(1):149-154.
49. Herrington L, Ghulam H, Comfort P. Quadriceps Strength and Functional Performance After Anterior Cruciate Ligament Reconstruction in Professional Soccer Players at Time to Return to Sport. J Strength Cond Res 2018; 35(3):769-775.