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Isokinetic strength and functional capacity in soccer players 24 months after anterior cruciate ligament reconstruction

Research Article

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Abstract

Study aim: This cross-sectional study aimed to compare inter-limb differences in isokinetic peak torque (PT), hop performance, and dynamic balance in soccer players 24 months post-ACLR, and secondarily to examine associations between PT and functional test performance.
Methods: Twenty-four soccer players who had undergone ACLR 24 months prior were assessed. Isokinetic PT of the knee extensors and flexors was measured at 60, 180, and 300°/s. Functional performance was evaluated using the single hop for distance, the 30 s side hop (SH), and the Y-balance test (YBT). Paired-samples *t*-tests assessed inter-limb differences; Pearson correlation analysis SHD examined associations between PT and functional outcomes.
Results: Significant inter-limb differences were found in knee extensor PT at all velocities and in flexor PT at 60°/s. Mean inter-limb differences ranged from 10.25 to 17.08 Nm for knee extensors and were 7.54 Nm for knee flexors at 60°/s (Cohen's d = 0.45–0.65). No differences were found in hop or YBT scores. A substantial portion of participants did not meet the symmetry threshold for isokinetic strength or SH performance. SH performance was significantly associated with extensor and flexor PT at specific velocities, while extensor PT was also associated with selected YBT directions and the composite score.
Conclusions: In this sample of male soccer players, strength asymmetries may persist 24 months post-ACLR, although group-level differences in hop and YBT performance were not observed. SH and selected YBT outcomes may complement, but not replace, isokinetic evaluation.

Keywords: *Anterior Cruciate Ligament Reconstruction • Isokinetic Test • Hop Tests • Y-Balance Test • Soccer*

1. Introduction

In soccer, one of the most severe injuries is the rupture of the anterior cruciate ligament (ACL). This injury often leads not only to long-term absence from competition but also to early termination of an athletic career and knee joint degeneration (Nawas et al., 2023). Surgical reconstruction is commonly used in young active patients with ACL rupture who wish to return to their pre-injury activity level, although non-operative management may be an appropriate alternative in selected patients (Paschos & Howell, 2016). However, surgical reconstruction does not guarantee a risk-free return to competition, as future knee joint injuries remain a concern (Hui et al., 2011). Graft rupture rates range from 8 to 17%, while contralateral knee injuries are notably high, with a rate of 24% (Hui et al., 2011).

According to the literature, young athletes returning to sport after ACLR may face up to a sixfold higher risk of

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sustaining a second ACL injury within the subsequent 24 months compared to uninjured peers (Paterno et al., 2014). During the first two years postsurgery, strength deficits are commonly observed in both the knee extensors and flexors (Kaplan & Witvrouw, 2019), with persistent quadriceps deficits often exceeding 10% of the contralateral limb and limb symmetry index (LSI) values frequently remaining below the commonly accepted 90% threshold in isokinetic assessments (Lepley, 2015). Functional capacity assessments for return to play (RTP) often utilize hop tests, frequently combined with evaluations of maximum strength in knee extensors and flexors (Ebert et al., 2018). Hop tests are widely used to assess functionality in sports involving rotational movements, directional changes, and jumping. Isokinetic evaluation is employed in various ways to measure strength deficits at different intervals following ACLR (Goes et al., 2020). However, although hop tests and strength assessments are widely used in RTP decision-making, their ability to predict successful RTP or second ACL injury remains incomplete when interpreted in isolation, highlighting the need for a broader and more integrated functional assessment approach (Welling et al., 2020).

The LSI is a key measure of strength and functionality, comparing the operated limb to the nonoperated one (Thomeé et al., 2012). Patients failing to achieve an LSI of at least 90% are at an increased risk of reinjury (Grindem et al., 2016; Kyritsis et al., 2016). Dynamic balance is another important parameter during rehabilitation because it reflects neuromuscular control, sensorimotor function, and the ability to stabilize the lower limb during single-leg tasks commonly encountered in sport (Cervenka et al., 2018). The Y-balance test (YBT) is frequently used to evaluate dynamic balance in lower extremity injuries, such as ACL ruptures (Kim et al., 2022). The YBT is a cost-effective, easy-to-administer test with high reliability, serving as a valuable tool for RTP decisions and as an indicator of neuromuscular training effectiveness (Benis et al., 2016; López-Valenciano et al., 2019). Deficits in dynamic balance may contribute to altered movement mechanics and may be associated with increased vulnerability to a second ACL injury.

Studies have correlated knee extensor strength with hop tests, revealing that the single hop for distance (SHD) test cannot replace assessments of knee extensor strength (Barfod et al., 2019). Additionally, prior research has explored correlations between YBT performance and various parameters, noting that dynamic balance scores are linked to the strength of knee extensors and flexors (Myers et al., 2018).

Although existing studies evaluate functional capacity 24 months post-ACLR, evidence remains limited in active soccer players regarding the combined assessment of lower limb symmetry through extensive strength and functional testing at this time point. Moreover, although previous studies have reported associations between knee strength and hop or Y-balance performance after ACLR, evidence remains limited in active soccer players approximately 24 months post-ACLR, particularly when both extensor and flexor isokinetic torque are examined in relation to a combined battery of hop and dynamic balance tests.

The purpose of this study was to examine the isokinetic strength of knee extensors and flexors, functional capacity through two hop tests, and dynamic balance in active soccer players 24 months post-ACLR. Additionally, the study investigated the associations between isokinetic torque of the knee extensors and flexors and SHD, 30 s side hop (SH), and YBT performance in the operated limb. It was hypothesized that the operated limb would demonstrate lower isokinetic peak torque and lower functional performance compared with the non-operated limb. It was also hypothesized that greater isokinetic peak torque would be positively associated with better performance in hop and dynamic balance tests.

2. Materials and methods

2.1 Design

The present study employed a cross-sectional design and was supervised by the Department of Physical Education and Sports Science at Aristotle University of Thessaloniki. The evaluation protocol for the participating soccer players adhered to the guidelines established by the Principles and Operational Regulations of the Ethics Committee of the university, in accordance with current legal standards. Ethical approval for the study was granted by the Department's Ethics Committee (Reference No. EH-63/2021). The eligibility of participants was evaluated at the Laboratory of Evaluation of Human Biological Performance. All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

2.2 Participants

The study involved 24 soccer players who were level 1 athletes (participation in sports involving cutting,

jumping, and twisting movements 4–7 times per week) (Noyes et al., 1989) and played in a national-level championship in Greece. To participate in the study, athletes had to meet the following criteria: (1) male soccer players; (2) aged 18–35 years; (3) level 1 soccer players for the last five years; (4) ACLR performed 22–25 months prior; (5) no history of ACL injury or reconstruction in the contralateral limb; (6) provide written consent for participation. Conversely, soccer players who experienced a lower extremity injury within 6 months or less before the study were excluded. The research team conducted personal interviews to confirm injuries in the last six months, with input from the players' coaches. Additional surgical information, including graft type and concomitant injuries, was collected for descriptive purposes.

2.3 Procedures

The athletes made two visits to the laboratory, separated by a 5-day period. At the initial appointment, participants provided their medical history, were briefed on the evaluation procedure, and were given an opportunity to become acquainted with the laboratory equipment. Information regarding rehabilitation duration was also collected at this visit and was defined as the self-reported total duration (in months) of the formal postoperative rehabilitation period following ACLR. During this first visit, participants were also familiarized with the testing procedures. All baseline measurements were recorded during the subsequent visit. During the second visit, participants completed the functional performance assessments, including the YBT, single hop for distance, and side hop test, followed by the isokinetic assessment. Prior to these measurements, athletes engaged in a 5 min warm-up on an exercise bike at 40–50 revolutions per minute (rpm), followed by 5 min of dynamic lower limb stretching. All participants adhered to the same warm-up protocol. No separate test–retest reliability session was performed.

2.3.1 Y-balance test

Following the initial warm-up, dynamic balance was assessed using the YBT. This test was performed in a single-leg stance where participants aimed to keep one foot fixed at the center of a Y-shaped figure on the floor while reaching the farthest point along the anterior (ANT), posteromedial (PM), and posterolateral (PL) directions with the nonfixed foot. Participants touched the line at maximum reach and returned to the starting position (Gribble et al., 2012). Participants performed the test barefoot, in accordance with the previously published YBT protocols, to standardize testing conditions and minimize the influence of footwear on reach performance (Fältström et al., 2017; Hebert-Losier, 2017). Limb length was measured using a tape measure as the distance from the anterior superior iliac spine to the medial malleolus with the participant in a supine position, in accordance with commonly used YBT normalization procedures (Hebert-Losier, 2017; Kattilakoski et al., 2023).

Participants completed three practice attempts and three formal attempts in each direction, starting with the nonoperated limb. The best result of the three attempts was used for each direction, and scores were normalized to limb length using the equation [(test value/limb length) × 100].The composite score (CS) is calculated for each limb as the average of the three normalized measurements in each direction (Fältström et al., 2017).

2.3.1.1 Hop tests

After a 5 min break, the assessment was conducted using hop tests in the specified sequence: SHD and SH. Each test was performed initially on the nonoperated limb and subsequently on the operated limb (Reid et al., 2007). For the SHD test, participants completed one trial followed by two normal tests, with the average of the two successful trials being calculated for each limb. In the SH test, participants performed one trial followed by one normal test for each limb. In cases of invalid attempts, an additional valid attempt was permitted. The rest period between attempts was a minimum of 30 s, while the rest period between different tests was at least 2 min. The functional tests were performed in a fixed order (YBT, SHD, SH) for all participants to standardize the assessment protocol and to ensure a progression from lower to higher neuromuscular and physical demand, in accordance with the previously published testing procedures (Ebert et al., 2018). Rest intervals between attempts and tests were incorporated to minimize the potential influence of accumulated fatigue. No movement restrictions were imposed during the hop tests (Gokeler et al., 2017; Reid et al., 2007). To assess performance, the mean values for distance (in cm) and number of hops (reps) were compared between the operated and nonoperated limbs.

2.3.1.2 Single hop for distance

In this test, participants were instructed to position one foot behind the starting line and perform the longest possible horizontal jump, with the maximum jump distance (measured in cm) recorded. The measurement was taken at the level of the heel. Upon landing on the tested leg,

participants were required to maintain their balance for a duration of 2 s (Reid et al., 2007).

2.3.1.3 Side hop

In this test, participants were instructed to stand on the examined leg and jump over two parallel lines positioned 40 cm apart for a duration of 30 s, with the objective of avoiding contact with the lines. The aim was to complete the maximum number of jumps within the given time frame. A digital stopwatch (Amila 44092 Professional Stopwatch) was utilized to track the time. The number of successful jumps completed by each participant in 30 s was recorded. If 25% of the jumps were deemed unsuccessful, the test was repeated (Gustavsson et al., 2006).

2.3.2 Isokinetic test

Following a 5 min rest, an isokinetic assessment was conducted using an isokinetic dynamometer (C.S.M.i., HUMACNORM 770, U.S.A.). Participants were seated in an adjustable chair and stabilized with straps across the trunk, pelvis, and thigh to minimize extraneous movements during testing. The axis of rotation of the dynamometer was aligned with the lateral femoral condyle of the tested knee. The lever arm length and the resistance pad position were individually adjusted for each participant, with the resistance pad placed just above the medial malleolus. The nontested limb remained relaxed and unsupported throughout the assessment. Peak torque of the knee extensors and flexors was measured under isokinetic conditions throughout the full range of motion. Peak torque values were recorded and analyzed as absolute values (Nm) and were not normalized to body mass. Because the primary objective of the study was to examine interlimb differences within the same participants, absolute torque values were considered appropriate for these within-subject comparisons. The range of motion was set from 90° of knee flexion to 0° of full extension. Knee extension started from the flexed position, whereas knee flexion started from full extension. Gravity correction was applied prior to testing. Participants underwent testing at angular velocities of 60, 180, and 300°/s concentrically, as well as eccentrically at the same velocities beginning with the nonoperated limb. For each limb, three trials and three normal attempts were performed at each angular velocity, with a 1 min rest period between different velocities. Testing progressed from the slowest to the fastest angular velocity. The best result from the three normal attempts at each velocity was selected, with peak torque defined as the highest torque value from the set of repetitions (Noyes & Barber-Westin, 2018). Following another 5 min rest, the eccentric evaluation was conducted, beginning with the nonoperated limb (Cvjetkovic et al., 2015). During eccentric testing, movement started from full extension for the assessment of the knee extensors and from knee flexion for the assessment of the knee flexors. Participants were instructed to perform maximal effort throughout the entire range of motion with their arms crossed over the chest. A 5 min rest period was provided between assessments of each limb. Standardized verbal encouragement and visual feedback were provided to all participants during the evaluation. The conventional H/Q ratio (H/Qconv), representing the concentric function of the knee flexors relative to the concentric function of the knee extensors, and the functional H/Q ratio (H/Qfunc), representing the eccentric function of the knee flexors relative to the concentric function of the knee extensors, were calculated for each limb.

2.4 Statistical analysis

The statistical analysis was conducted using SPSS version 25 (IBM Corporation, Armonk, NY). The Shapiro-Wilk test was used to assess normality, confirming a normal distribution of the data. Paired-samples *t*-tests compared mean values of peak knee extensor and flexor torque, H/Qconv, H/Qfunc during isokinetic assessment, distance (cm), number of jumps during hop tests, and normalized ANT, PM, and PL directions. In addition to *p*-values, effect sizes (Cohen's *d* for paired comparisons) and 95% confidence intervals of the mean differences were calculated to facilitate interpretation of the magnitude and precision of between-limb differences. For correlation analyses, Pearson's *r* and corresponding 95% confidence intervals were reported to facilitate interpretation of the magnitude and precision of the observed associations. Before conducting Pearson correlation analyses, scatter plots were visually inspected for each variable pair to assess linearity and identify potential influential outliers. No marked deviations from linearity or extreme outliers were detected. Pearson correlation analysis was used to examine associations between isokinetic strength and functional tests, using operated-limb values only. Correlation coefficients were interpreted according to Cohen as follows: 0.01–0.3 (weak), 0.3–0.5 (moderate), and 0.5–0.99 (strong) (Cohen, 1988). The level of significance was set at $\alpha = 0.05$. Finally, the LSI for isokinetic assessment for knee extensors and flexors, SHD, SH, the three YBT directions, and the CS were calculated as follows: {(operated value/non-operated value) × 100}. A sensitivity power analysis was performed using G*Power (version 3.1.9.7) based on the available sample size ($n = 24$), $\alpha = 0.05$, and power = 0.80. The analysis indicated that

the study was powered to detect effect sizes of approximately d = 0.60 for paired-samples t-tests and r = 0.54 for Pearson correlation analyses. Given the number of paired comparisons and bivariate correlations performed, no formal adjustment for multiple testing was applied. Therefore, the correlation analyses were treated as unadjusted and exploratory, and the results should be interpreted with caution due to the increased risk of type I error.

3. Results

All measurements of the 24 participants were conducted in July 2024. The mean age of participants was 24.70 years, with an average body weight of 69.14 kg, an average height of 175.16 cm, and a mean f (BMI) of 22.52. The soccer players were evaluated 23.79 months post-ACLR, with a mean self-reported rehabilitation duration of 9.79 months (range: 6–18 months) (Table 1). Regarding surgical characteristics, 17 participants had undergone ACLR using hamstring tendon autograft, 5 using bone–patellar tendon–bone autograft, and 2 using allograft. In terms of concomitant injuries, 11 participants presented with medial meniscal injury, 2 with lateral meniscal injury, 1 with O'Donoghue's triad, and 10 had no concomitant injury. Additionally, significant correlations were observed between knee extensor peak torque and selected YBT directions and CS, whereas significant associations with hop performance were observed only for the side hop test. No significant correlations were found between flexor peak torque and YBT outcomes.

3.1 Hop tests

In the evaluation of the two hop tests, it was observed that 24 months post-ACLR, the nonoperated limb showed slightly higher mean values compared to the operated limb for both mean distance in centimeters and number of hops. Specifically, for SHD, the nonoperated limb showed a slightly higher mean value compared to the operated limb, but no significant statistical difference was observed (p = 0.097), with a small effect size (d = 0.35). Regarding SH, the nonoperated limb also showed a slightly higher mean value compared to the operated limb, but again no significant statistical difference was found (p = 0.209) with a small effect size (d = 0.26) (Table 2).

3.2 Isokinetic test

In the isokinetic evaluation, 24 months post-ACLR, the nonoperated limb showed higher peak torque values at all angular velocities for both knee extensors and flexors compared to the operated limb (Table 3). Specifically, at 60°/s for both knee extensors and flexors, the nonoperated limb showed significantly higher peak torque values compared to the operated limb (p = 0.004 for extensors and p = 0.036 for flexors), with a medium effect size for knee extensors (d = 0.65) and a small effect size for knee flexors (d = 0.45). At 180°/s, the nonoperated limb had higher values than the operated limb for extensors with a significant statistical difference (p = 0.012) and a medium effect size (d = 0.55), while for flexors, no significant difference was observed (p = 0.173) with a small effect size (d = 0.29). At 300°/s, the nonoperated limb again showed higher values for knee extensors, with a significant statistical difference (p = 0.004) and a medium effect size (d = 0.65), while for knee flexors, the nonoperated limb had higher values compared to the operated limb, but no significant difference was observed (p = 0.059), with a small effect size (d = 0.41).

In the assessment of H/Qconv, the operated limb showed slightly higher mean values compared to the nonoperated limb at all angular velocities, although these differences were not statistically significant (Table 4). Specifically, at 60°/s, the operated limb showed a numerically higher mean value than the nonoperated limb; however, the observed difference was not statistically significant

Table 1. Demographics characteristics of participants

Measure	Mean ± SD	Minimum	Maximum	Range
Age (years)	24.70 ± 4.35	18.00	33.00	15.00
Body mass (kg)	69.14 ± 8.18	57.00	85.00	28.00
Height (cm)	175.16 ± 6.98	160.00	185.00	25.00
BMI (kg/m^2)	22.52 ± 2.67	20.06	31.60	11.54
Time from surgery (months)	23.79 ± 0.93	22.00	25.00	3.00
Rehabilitation time (months)	9.79 ± 3.24	6.00	18.00	12.00

Source: Author's contribution.

Table 2. Values for hop tests

Parameter	Operated limb (mean ± SD)	Nonoperated limb (mean ± SD)	Mean difference (95% CI)	Effect size (Cohen's *d*)	Significance (*p*-value)
Single hop for distance (cm)	176.00 ± 34.10	181.07 ± 32.79	5.07 (−0.99 to 11.13)	0.35	$p = 0.097$
Side hop (number of hops)	38.75 ± 10.06	40.45 ± 9.10	1.70 (−1.026 to 4.44)	0.26	$p = 0.209$

Source: Author's contribution.

($p = 0.398$), with a small effect size ($d = -0.18$). At 180°/s, the operated limb also showed a slightly higher mean value than the nonoperated limb with no significant differences observed ($p = 0.498$), with a small effect size ($d = -0.14$). At 300°/s, the operated limb again showed a numerically higher mean value than the nonoperated limb with no significant differences observed ($p = 0.499$) and a small effect size ($d = -0.14$).

For H/Qfunc, the operated limb showed slightly higher mean values across all evaluated angular velocities with no significant statistical differences observed (Table 4). At 60°/s, the operated limb showed a numerically higher mean value compared to the nonoperated limb, although no statistically significant differences were found ($p = 0.120$), with a small effect size ($d = -0.35$). At 180°/s, the operated limb also showed a slightly higher mean value than the nonoperated limb, with no significant differences observed ($p = 0.905$) and a small effect size ($d = -0.03$). Similarly, at 300°/s, the operated limb showed a numerically higher mean value than the nonoperated limb, but again, these differences were not statistically significant ($p = 0.088$) and were associated with a small effect size ($d = -0.39$).

3.3 YBT

In the YBT evaluation, no significant statistical differences were observed between the operated and the nonoperated limbs for all three directions or the CS (Table 5). Specifically, for the ANT direction, the nonoperated limb showed a slightly higher mean value than the operated limb, but no significant statistical difference was observed ($p = 0.238$) with a small effect size ($d = 0.25$). For the PM direction, the operated limb showed a slightly higher mean value than the nonoperated limb, but again no significant difference was found ($p = 0.148$), with small effect size ($d = -0.31$). For the PL direction, the operated limb had higher values than the nonoperated limb without a significant difference ($p = 0.247$) and small effect size ($d = -0.24$). Regarding the CS, no significant statistical difference was observed between the two limbs, with the operated limb showing a slightly higher mean value ($p = 0.497$), with a small effect size ($d = -0.14$).

3.4 LSI

The percentage of athletes achieving the acceptable symmetry of LSI 90–110% is presented in Table 6. Specifically, at 60°/s, 11/24 (46%) and 15/24 (62%) of participants achieved 90–110% symmetry for knee extensors and flexors, respectively. At 180°/s, 12/24 (50%) and 9/24 (37%) achieved acceptable symmetry for extensors and flexors,

Table 3. Isokinetic values for knee extension and knee flexion peak torque between operated and nonoperated limb

Parameter	Operated limb, mean (SD)	Nonoperated limb, mean (SD)	Mean difference (95% CI)	Effect size (Cohen's *d*)	Significance (*P*-value)
			Knee extension peak torque (Nm)		
60°/s	179.04 ± 31.64	196.12 ± 35.35	17.08 (6.02 to 28.14)	0.65	0.004
180°/s	139.50 ± 19.99	151.29 ± 22.21	11.79 (2.80 to 20.77)	0.55	0.012
300°/s	107.04 ± 14.26	117.29 ± 14.26	10.25 (3.61 to 16.88)	0.65	0.004
			Knee flexion peak torque (Nm)		
60°/s	112.79 ± 23.14	120.33 ± 21.26	7.54 (0.52 to 14.55)	0.45	0.036
180°/s	90.16 ± 15.09	94.87 ± 16.40	4.70 (−2.22 to 11.64)	0.29	0.173
300°/s	69.20 ± 12.90	73.95 ± 15.53	4.75 (−0.19 to 9.69)	0.41	0.059

Source: Author's contribution.

Table 4. Isokinetic values for H/Q conventional (Hamstring concentric peak torque/quadriceps concentric peak torque) and for H/Q Functional (Hamstring eccentric peak torque/quadriceps concentric peak torque) between operated and nonoperated limb

Parameter	Operated limb, mean (SD)	Nonoperated limb, mean (SD)	Mean difference (95% CI)	Effect size (Cohen's *d*)	Significance (*P*-value)
			H/Q conventional ratio (Conv)		
60°/s	63.37 ± 8.86	61.79 ± 9.12	−1.58 (−5.38 to 2.21)	−0.18	0.398
180°/s	65.29 ± 10.39	63.45 ± 11.22	−1.83 (−7.34 to 3.68)	−0.14	0.498
300°/s	65.29 ± 13.24	63.33 ± 12.28	−1.95 (−7.85 to 3.93)	−0.14	0.499
			H/Q functional ratio (Func)		
60°/s	0.66 ± 0.12	0.61 ± 0.11	−0.05 (−0.13 to 0.01)	−0.35	0.120
180°/s	0.87 ± 0.21	0.86 ± 0.17	−0.006 (−0.11 to 0.10)	−0.03	0.905
300°/s	1.20 ± 0.26	1.03 ± 0.30	−0.16 (−0.34 to −0.02)	−0.39	0.088

Source: Author's contribution.

respectively. At 300°/s, 14/24 (58%) and 12/24 (50%) of participants achieved the acceptable symmetry index for knee extensors and flexors, respectively. Regarding SHD, 19/24 (79%) of participants achieved LSI 90–110%. For SH, 10/24 (42%) achieved the acceptable symmetry value. For YBT, 23/24 (96%) achieved the acceptable LSI for the ANT direction, 24/24 (100%) for the PM direction, 23/24 (96%) for the PL direction and 24/24 (100%) for the CS.

3.5 Correlations between peak torque and YBT

The results of the correlation analysis are presented in Table 7. Specifically, weak and nonsignificant correlations were observed between knee extensor peak torque and the ANT direction at 60°/s (r = −0.023, p = 0.915) and 180°/s (r = 0.049, p = 0.821) with confidence intervals

Table 5. Operated and nonoperated limb values for ANT, PM, and PL directions and composite score, expressed as % of limb length

Parameter	Operated limb mean (SD)	Nonoperated limb mean (SD)	Mean difference (95% CI)	Effect size (Cohen's *d*)	Significance (*P*-value)
Anterior reach	75.32 ± 6.77	76.20 ± 7.37	0.87 (−0.62 to 2.38)	0.25	0.238
Posteromedial reach	126.16 ± 10.23	125.17 ± 9.22	−0.98 (−2.35 to 0.37)	−0.31	0.148
Posterolateral reach	117.70 ± 7.57	116.43 ± 6.64	−1.27 (−3.48 to 0.94)	−0.24	0.247
Composite score	106.42 ± 5.81	106.03 ± 4.93	−0.39 (−1.56 to 0.078)	−0.14	0.497

Source: Author's contribution.

including zero. Strong significant correlations were observed between knee extensor peak torque and the PM direction at both 60°/s (r = 0.581, p = 0.003) and 180°/s (r = 0.531, p = 0.008). Similarly, a strong significant correlation was observed between knee extensor peak torque at 60°/s and the PL direction (r = 0.577, p = 0.003), while a moderate significant correlation was observed at 180°/s (r = 0.417, p = 0.043). Strong significant correlations were also observed between knee extensor peak torque and the CS at both 60°/s (r = 0.582, p = 0.003) and 180°/s (r = 0.505, p = 0.012), with confidence intervals not crossing zero. No significant correlations were observed between knee flexor peak torque and YBT outcomes.

3.6 Correlations between peak torque and hop tests

The results of the correlation analysis are presented in Table 8. No significant correlations were observed between knee extensor or flexor peak torque and SHD performance, whereas significant associations with hop performance were observed only for the side hop test at selected angular velocities. Specifically, for knee extensors at 60 and 180°/s and SHD, weak nonsignificant negative correlations were observed (r = −0.073, p = 0.736) and (r = −0.270, p = 0.202), respectively. For knee extensors at 300°/s and SHD, a moderate non-significant negative correlation was observed (r = −0.397, p = 0.055; 95% CI [−0.692, 0.006]). For knee extensor peak torque at 60, 180, and 300°/s and SH, moderate significant correlations were observed at 60 and 300°/s (r = 0.480, p = 0.018; 95% CI [0.180, 0.723]) and (r = 0.416, p = 0.043; 95% CI [0.048, 0.731]), respectively, while a moderate nonsignificant correlation was observed at 180°/s (r = 0.366, p = 0.078; 95% CI [−0.051, 0.715]). For knee flexors at 60 and 180°/s and SHD, weak nonsignificant negative correlations were observed (r = −0.036, p = 0.868) and (r = −0.258, p = 0.224), respectively, while for 300°/s and SHD, a moderate nonsignificant negative correlation was observed (r = −0.318, p = 0.129). For knee flexors at 60°/s and SH, a moderate with strong significant correlation was observed (r = 0.510, p = 0.011; 95% CI [0.098, 0.817]). For knee flexors at 180°/s and SH, a moderate significant correlation was observed (r = 0.414, p = 0.044; 95% CI [−0.049, 0.761]). For knee flexors at 300°/s and SH, a moderate nonsignificant correlation was observed (r = 0.401, p = 0.052; 95% CI [−0.032, 0.681]).

4. Discussion

This study found that, 24 months after ACLR, the operated limb of active soccer players demonstrated lower knee extensor and flexor strength compared with the nonoperated limb. However, these between-limb differences should be interpreted with caution, as the contralateral limb (nonoperated limb), may also exhibit residual deconditioning or neuromuscular deficits after ACLR and therefore may not represent a fully normal reference. Regarding the H/Qconv and H/Qfunc ratios, functional hop tests, and dynamic balance, no significant differences were observed between the operated and nonoperated limbs. Furthermore, concerning the LSI, a significant number of participants did not meet the required range

Table 6. Limb symmetry index percentages for isokinetic test, SHD, SH, and YBT

Parameter	90–110% (LSI)	>110% (LSI)	<90% (LSI)	Percentage of failure
Knee extension peak torque 60°/s (Nm)	11/24 (46%)	2/24 (8%)	11/24 (46%)	54%
Knee flexion peak torque 60°/s (Nm)	15/24 (62%)	3/24 (13%)	6/24 (25%)	26%
Knee extension peak torque 180°/s (Nm)	12/24 (50%)	2/24 (8%)	10/24 (42%)	50%
Knee flexion peak torque 180°/s (Nm)	9/24 (37%)	5/24 (21%)	10/24 (42%)	63%
Knee extension peak torque 300°/s (Nm)	14/24 (58%)	1/24 (4%)	9/24 (38%)	42%
Knee flexion peak torque 300°/s (Nm)	12/24 (50%)	3/24 (12%)	9/24 (38%)	50%
Single hop for distance (cm)	19/24 (79%)	1/24 (4%)	4/24 (17%)	17%
Side hop (number of hops)	10/24 (42%)	5/24 (21%)	9/24 (37%)	58%
Anterior reach (normalized to leg length)	23/24 (96%)	0/24 (0%)	1/24 (4%)	4%
Posteromedial reach (normalized to leg length)	24/24 (100%)	0/24 (0%)	0/24 (0%)	0%
Posterolateral reach (normalized to leg length)	23/24 (96%)	1/24 (4%)	0/24 (0%)	4%
Composite score (normalized to leg length)	24/24 (100%)	0/24 (0%)	0/24 (0%)	0%

Source: Author's contribution.

Table 7. Correlation between isokinetic peak torque of extensors and flexors and Y-balance reaches and composite score

	Knee extension peak torque 60°/s (Nm), *r* (95% CI)	*p*	Knee extension peak torque 180°/s (Nm), *r* (95% CI)	*p*
Anterior reach	−0.023 (−0.418 to 0.316)	0.915	0.049 (−0.476 to 0.496)	0.821
Posteromedial reach	0.581 (0.319 to 0.741)	0.003	0.531 (0.165 to 0.744)	0.008
Posterolateral reach	0.577 (0.206 to 0.790)	0.003	0.417 (0.011 to 0.699)	0.043
Composite score	0.582 (0.228 to 0.778)	0.003	0.505 (0.054 to 0.750)	0.012
	Knee flexion peak torque 60°/s (Nm), *r* (95% CI)	*p*	Knee flexion peak torque 180°/s (Nm), *r* (95% CI)	*p*
Anterior reach	−0.073 (−0.427 to 0.268)	0.735	−0.108 (−0.552 to 0.319)	0.617
Posteromedial reach	0.378 (0.090 to 0.608)	0.068	0.170 (−0.118 to 0.525)	0.426
Posterolateral reach	0.169 (−0.158 to 0.459)	0.429	0.029 (−0.298 to 0.322)	0.892
Composite score	0.275 (−0.015 to 0.502)	0.194	0.072 (−0.257 to 0.397)	0.737

Source: Author's contribution.

Table 8. Correlation between isokinetic peak torque of extensors and flexors and hop tests

Parameter	SHD (*r*)	*p*-value	95% CI	SH (*r*)	*p*-value	95% CI
Knee extension peak torque 60°/s	−0.073	0.736	[−0.454, 0.373]	0.480	0.018	[0.180, 0.723]
Knee extension peak torque 180°/s	−270	0.202	[−0.622, 0.186]	0.366	0.078	[−0.051, 0.715]
Knee extension peak torque 300°/s	−0.397	0.055	[−0.692, 0.006]	0.416	0.043	[0.048, 0.731]
Knee flexion peak torque 60°/s	−0.036	0.868	[−0.411, 0.434]	0.510	0.011	[0.098, 0.817]
Knee flexion peak torque 180°/s	−0.258	0.224	[−0.596, 0.159]	0.414	0.044	[−0.049, 0.761]
Knee flexion peak torque 300°/s	−0.318	0.129	[−0.598, 0.041]	0.401	0.052	[−0.032, 0.681]

Source: Author's contribution.

of 90–110% during the isokinetic evaluation for both the extensors and flexors, as well as for the SH test. Significant correlations were observed between knee extensor peak torque and performance in the YBT, as well as between both knee extensors and flexors and the SH test.

More specifically, 24 months after ACLR, soccer players demonstrated significant differences in extensor strength at all evaluated angular velocities, while significant differences for the flexors were observed only at 60°/s. These findings align with the existing literature. Petersen et al. (2014) reported that muscle deficits persist up to 2 years post-ACLR. Xergia et al. (2011) noted that strength deficits in the knee extensors and flexors remain unresolved 2 years after ACLR. Buckthorpe et al. (2019) highlighted the critical role of restoring extensor strength, pointing out its correlation with an elevated risk of re-injury, knee osteoarthritis, and altered joint biomechanics.

Regarding the symmetry index (LSI), a significant proportion of participants failed to meet the commonly used thresholds during isokinetic testing for both the extensors and flexors. This observation is consistent with other studies. Tayfur et al. (2021) found that deficits in flexors and extensors persist beyond 2 years post-ACLR. Högberg et al. (2024) suggested that full recovery of hamstring strength requires 2 years. A 1% increase in extensor symmetry is associated with a 3% reduction in the risk of knee re-injury (Buckthorpe et al., 2019). Nichols et al. (2021) highlighted the lack of high-intensity resistance training and improper periodization, emphasizing the importance of strength-focused training. Although the 90% LSI threshold is widely used as a return-to-play benchmark after ACLR, its clinical sufficiency remains debated. A limb may achieve acceptable symmetry despite persistent bilateral weakness, particularly if the contralateral limb is also deconditioned. Therefore, LSI should be interpreted alongside other criteria, such as absolute strength capacity, strength normalized to body mass, and normative or sport-specific reference values. Had such complementary criteria been available in the present study, the interpretation of recovery status may have been more conservative.

When evaluating the two hop tests, no significant differences were observed between the operated and nonoperated limbs. However, a large number of participants did not achieve the required LSI of 90–110% for SH, a result

not observed in SHD. The apparent discrepancy between the absence of significant between-limb differences in functional test performance and the proportion of athletes failing to meet LSI thresholds likely reflects the distinction between group-level and individual-level analyses. Group mean comparisons may suggest overall symmetry at the sample level, whereas symmetry-based thresholds can still identify clinically relevant deficits in individual athletes. Therefore, the absence of significant mean differences should not be interpreted as evidence that all participants had fully restored function.

Abrams et al. (2014) found that for commonly used hop tests (SHD, THD, CHD, 6MTH), patients typically achieve a 90% LSI within 6–9 months, though rates are lower for more demanding tests like SH. Chatzilamprinos et al. (2024) also found that a substantial proportion of participants failed to meet the symmetry requirement for SH. This may be because SH is an endurance-based test, requiring increased endurance capacity from the operated limb (Gokeler et al., 2017). Thomeé et al. (2012) observed that only 50% of participants achieved the required LSI for SH compared to 85% for single hop tests. Stitelmann et al.(2024) noted difficulties maintaining rhythm during SH on the operated limb. Davies et al. (2020) suggested lowering the required LSI threshold for such demanding tests, though this would reduce test sensitivity.

In dynamic balance evaluation using the YBT, no significant differences were observed between limbs in all three directions or in the CS. Contrary to our findings, Cervenka et al. (2018) reported better results in all directions and the CS for the nonoperated limb. Clagg et al. (2015) noted reduced ANT direction performance in ACLR groups compared to controls. Delahunt et al. (2013), 2.9 ± 2.8 years post-ACLR, reported reduced normalized values for PL and PM directions but not for ANT direction between ACLR and control groups. Regarding limb symmetry, participants in this study achieved the required LSI of 90–110% for all directions and the CS. Clagg et al. (2015) found similar results, with 97% symmetry in the ANT direction, falling within the normal range at RTP. Fälström et al. (2017) also reported similar findings, with participants achieving normal symmetry values for all directions and CS at an average of 18 months postsurgery. Deficits in dynamic stability, proprioception, and neuromuscular control often persist after ACLR and have been identified as predictors of knee re-injury (Paterno et al., 2010). It is noteworthy that participants in this study demonstrated satisfactory symmetry for dynamic balance 24 months post-ACLR. However, the absence of between-limb differences in the YBT should be interpreted with caution. It may reflect true recovery of dynamic balance; however, it may also be explained by bilateral neuromuscular adaptations or residual deficits affecting both limbs after ACLR. In addition, the sensitivity of the YBT to detect subtle or sport-specific deficits remains a matter of debate. Recent evidence suggests that not all YBT components are equally informative and that different reach directions may reflect different underlying physical capacities after ACLR (Kim et al., 2022; Rodrigues et al., 2024). Therefore, the lack of significant between-limb differences in the present study does not necessarily indicate full restoration of dynamic balance capacity.

Isokinetic evaluations use ratios of antagonistic knee joint muscles (H/Q), particularly in high-risk sports like soccer (Ruas et al., 2018). These ratios are categorized as “conventional” and “functional,” calculated using isokinetic concentric and eccentric peak torque (Ruas et al., 2015). No significant differences were observed between the operated and nonoperated limbs for H/Qconv or H/Qfunc, with soccer players not consistently reaching the commonly cited reference values across all tested angular velocities. However, the operated limb showed higher values for both indices compared to the nonoperated limb, which may be influenced by the lower concentric quadriceps peak torque observed in the operated limb. Chatzilamprinos et al. (2024) reported similar results in soccer players 2 years post-ACLR.

For H/Qconv, values around 0.6 at 60°/s and progressively higher values at faster angular velocities have been historically proposed as reference benchmarks in the literature (Daneshjoo et al., 2013). In this study, participants met these commonly cited values for 60 and 180 but not for 300°/s. Baroni et al. (2020) recommended values of 0.6 for slow/intermediate angular velocities (12–180°/s) and 0.7–0.8 for fast velocities (220–360°/s). Soccer activities, such as kicking and running, occur at angular velocities of 730°/s to 860–1720°/s (Nunome et al., 2002). Training during rehabilitation and injury prevention should mimic these speeds. Nevertheless, the clinical interpretation of H/Qconv should remain cautious, as recent evidence questions the use of H/Q ratios as independent predictors of ACL or hamstring injury risk. Therefore, H/Qconv may provide supportive information regarding muscle balance, but should not be interpreted as a stand-alone indicator of knee stability or return-to-sport readiness.

H/Qfunc is considered more functionally relevant for sports like soccer, as it incorporates the eccentric action of the hamstrings in relation to concentric quadriceps function during tasks such as running and kicking (Ruas et al., 2018). However, despite its greater sport-specific relevance, recent evidence suggests that H/Q ratios – including the functional ratio – have limited value as independent

predictors of ACL or hamstring injury and should therefore be interpreted alongside other strength, functional, and biomechanical measures (Kellis et al., 2023). In this study, participants did not consistently reach the commonly cited reference values across evaluated angular velocities except for 300°/s. For 60°/s, values around 1.0 have often been proposed as a reference target, reflecting the capacity of the hamstrings to counteract anterior tibial translation (Lehnert et al., 2014). Since this value is challenging to achieve at 60°/s, lower but still acceptable reference ranges have also been discussed in the literature, with values around 0.8 reported at 60°/s, whereas ranges of 1.0–1.3 have been suggested for intermediate to high velocities (Baroni et al., 2020). Although muscle force-generating capacity decreases at increasing concentric shortening velocities, eccentric peak torque appears to remain relatively stable as movement velocity increases (Baroni et al., 2020). This may partly explain why the commonly cited H/Qfunc reference threshold was more easily achieved at 300°/s in the present study. However, as with H/Qconv, these values should not be interpreted as absolute markers of dynamic knee stability. Recent literature suggests that H/Q ratios alone have limited predictive value for ACL or hamstring injury, and therefore, the present findings should be interpreted as descriptive indicators of relative muscle function rather than definitive markers of joint protection or injury risk.

The correlation analysis between knee extensor and flexor torque with SHD and SH revealed moderate correlations for SH with 60°/s and 300°/s knee extensors, and a strong correlation for SH with knee flexor torque at 60°/s, whereas only a weak correlation was observed at 180°/s. Conversely, no significant correlations were observed for SHD. These findings align with the literature. Barfod et al. (2019) found no correlation between knee extensors and SHD at 6 or 12 months post-ACLR. Another study found correlations between knee extensors and SH but not SHD or other hop tests (Chatzilamprinos et al., 2024).

The present study also examined the associations between knee torque and YBT performance. Significant moderate to strong correlations were observed between knee extensor torque at 60°/s and 180°/s and PM, PL directions, and CS, but not ANT direction. No significant correlations were found for flexors. Kim et al. (2022) reported weak to moderate correlations for extensor and flexor torque with PM, PL, and CS, excluding ANT. Myers et al. (2018) found similar correlations across directions. The lack of correlation with ANT may reflect its reliance on ankle dorsiflexion rather than knee extensor strength (Nakagawa & Petersen, 2018).

The correlation findings of the present study should be interpreted with caution, as the observed associations were based on unadjusted bivariate correlations and do not account for potentially relevant confounding factors such as body mass, time since surgery, rehabilitation duration, or training exposure. Therefore, these relationships should not be interpreted as causal.

5. Limitations

This study had several limitations. First, the sample size was relatively small, which may limit the generalizability of the findings. Second, the cross-sectional design does not allow causal inferences regarding recovery status, rehabilitation duration, training quality, or the relationships observed between muscle strength and functional performance, nor does it permit conclusions about recovery trajectories over time. Third, comparisons were based on the contralateral limb, which may also exhibit residual deconditioning or neuromuscular deficits after ACLR and therefore may not represent a fully normal reference. As a result, symmetry-based indices such as LSI may overestimate recovery status in some cases. Fourth, the correlation analyses were based on unadjusted bivariate associations and did not account for potentially relevant confounding variables such as body mass, time since surgery, rehabilitation duration, or training exposure. In addition, no direct measures of muscular endurance or fatigue-related performance were included, and therefore, interpretations regarding the endurance demands of the side hop test remain indirect. Finally, the study focused primarily on knee extensor and flexor function and did not include broader assessments of other joints or biomechanical variables that may also influence post-ACLR functional performance.

6. Conclusion

The findings of this study suggest that, in this sample, soccer players 24 months post-ACLR exhibit significant deficits in knee extensor and flexor strength during isokinetic evaluations relative to the contralateral limb. A significant proportion of participants were unable to achieve the commonly used symmetry thresholds for knee extensors and flexors, as well as for the SH test. Regarding the H/Q ratios, most participants did not meet the commonly cited reference values. Finally, significant but velocity- and direction-specific associations were observed between isokinetic peak torque and selected functional tests, particularly between knee extensor and flexor torque and SH

performance, and between knee extensor torque and selected YBT components. These findings suggest that SH and YBT may offer useful complementary functional information, but they should not be interpreted as equivalent to or substitutes for isokinetic strength testing. However, these findings should be interpreted in light of the relatively small, male-only sample and the absence of a healthy control group, which limit the external validity of the results.

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Author contributions

Conception and design of the study were done by K. Chatzilamprinos, E. Semaltianou, D. Lytras, and E. Sykaras; acquisition of data was done by K. Chatzilamprinos, E. Semaltianou, D. Lytras, and E. Sykaras; analysis and/or interpretation of data was done by K. Chatzilamprinos, E. Semaltianou, D. Lytras, and E. Sykaras; Drafting the paper was done by K. Chatzilamprinos, D. Lytras, and E. Semaltianou; revising the paper critically for important intellectual content was done by D. Lytras, K. Chatzilamprinos, V. Geoorgoulas, I. Algiounidis. All authors were involved in the approval of the paper to be published.

Generative AI declaration

No generative AI or AI-assisted technologies were used in the writing of this manuscript.

Conflict of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

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