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Comparison of Performance Parameters of Professional Football Players with Unilateral Anterior Cruciate Ligament Reconstruction to the Contralateral Extremity

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Abstract

BACKGROUND/AIMS: Anterior cruciate ligament (ACL) injury and reconstruction can lead to persistent neuromuscular deficits and impaired athletic performance. However, the extent of inter-limb asymmetry in professional football players after unilateral ACL reconstruction (ACLR) remains unclear. This study aimed to compare reaction time, knee proprioception, isometric muscle strength, and vertical jump performance between the operated limb and the contralateral healthy limb in professional football players with a history of unilateral ACLR.

MATERIALS AND METHODS: In this cross-sectional, paired-design study, 15 professional football players were evaluated. All assessments were performed by a single experienced physiotherapist. Simple reaction time was measured using the Nelson Foot Reaction Test. Knee proprioception was assessed using a validated smartphone inclinometer application. Isometric muscle strength of the quadriceps, hamstrings, gluteus maximus, and gluteus medius was measured bilaterally using a calibrated hand-held dynamometer. Vertical jump performance was evaluated with a VertiMetric device using the squat-jump protocol; mean jump height (cm) and power (W) were recorded.

RESULTS: There were no statistically significant differences between the operated and contralateral limbs for any outcome ($p>0.05$). The operated limb showed small, nonsignificant deficits in reaction time, hamstring and gluteal strength, and vertical jump performance compared with the healthy limb. Quadriceps strength was effectively symmetrical. Proprioceptive differences were inconsistent and non-significant across angles.

CONCLUSION: Clinically, ~6 years after unilateral ACLR, professional footballers in our cohort demonstrated largely restored limb symmetry in reaction time, proprioception, isometric strength, and squat-jump performance; small residual hamstring/gluteal and jump deficits-though not statistically significant-support continued targeted strengthening and limb symmetry monitoring during return to sport follow-up.

Keywords: Anterior cruciate ligament reconstruction, football, limb symmetry, reaction time, proprioception, vertical jump, return to sport

INTRODUCTION

The anterior cruciate ligament (ACL) is a proprioception-rich structure that plays a critical role in maintaining knee joint stability and proper kinematics.[1] ACL injuries most commonly result from mechanical stress during sudden pivoting or directional changes while the foot is planted, or from direct trauma to the knee.[2] ACL insufficiency alters joint biomechanics, leading to abnormal loading of the menisci and articular cartilage, which may predispose the knee to osteoarthritic changes.[3]

Beyond structural consequences, ACL deficiency can compromise both functional capacity and athletic performance.[4] A substantial proportion

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of athletes fail to return to their pre-injury levels of performance, with contributing factors including lower-extremity muscle asymmetries, muscle strength deficits, and sport-specific biomechanical alterations.[5] Psychological barriers, such as kinesiophobia, are frequently observed after an injury and can further impede rehabilitation and delay the return to sport (RTS).[5]

Strength asymmetry between the operated and contralateral limbs has emerged as a critical factor in assessing readiness to RTS. While some studies have reported no significant differences in limb symmetry indices for muscle strength, notable disparities in jump performance have been consistently observed between the operated and non-injured limbs.[6] Although balance measures may not differ significantly, asymmetries in muscle strength and jump performance between limbs have been documented.[7] Moreover, while most research has focused on the adaptation of the operated limb, cohort studies indicate that the contralateral healthy limb may also experience functional impairments, thereby emphasizing the need to assess core musculature and other body segments.[8,9]

Despite these insights, discrepancies between the operated and contralateral limbs and their effects on sports performance following ACL reconstruction (ACLR) remain incompletely understood. Therefore, the aim of the present study was to evaluate and compare athletic performance outcomes between the operated and the healthy limbs in athletes who had undergone unilateral ACLR.

MATERIALS AND METHODS

Study Design and Subjects

In this cross-sectional paired-design study, fifteen professional football players who have undergone unilateral ACLR within the past five years and who are currently active in the Turkish Republic of Northern Cyprus Super League were included. Ethical approval for the study was obtained from the Cyprus International University Scientific Research and Publication Ethics Committee (approval number: TBF.00.0-020-8152, date: 23.06.2021). Prior to study initiation, all participants were thoroughly informed about the study procedures and written informed consent was obtained from each participant. The inclusion criteria were as follows: participants had to be between 18 and 40 years of age (inclusive), hold a valid football license, have undergone ACLR within the last five years, be actively engaged in their sports careers, and have received unilateral reconstruction. Exclusion criteria included a history of bilateral knee reconstruction or the presence of any pathology in the same knee other than an ACL injury. All assessments in the study were performed by the same physiotherapist.

Sample Size

The sample size for the present study was determined based on previous research with a similar design and participant characteristics.[10] A total of 15 professional football players who had undergone unilateral ACLR were included in the study, and all injuries involved the dominant limb. All measured parameters in our study were compared between the operated and non-operated sides of the same participants.

Procedures

Nelson Foot Reaction Test

Lower limb reaction time was assessed using the Nelson Foot Reaction Test in accordance with established protocols. During the test, each participant removed their shoes and was seated with the tip of the foot positioned 2.5 cm from the wall and the heel 5 cm from the wall. The examiner held the reaction-time ruler vertically against the wall, with the base of the ruler aligned with the participant's big toe. Participants were instructed to focus on the concentration line and, after the command "be ready", to catch the falling ruler by pressing its end against the wall with the tip of their foot as quickly as possible. This procedure has been recognized in recent literature as a valid and practical method for evaluating neuromuscular response and reaction time in both clinical and athletic populations.[11,12]

Measurement of Proprioception

A smartphone inclinometer application was used to assess proprioception in professional athletes.[13] For the measurement, participants were seated upright with back support and knees flexed at 90°, ensuring that their feet did not touch the ground. With eyes open, the tibial crest was marked on the proximal region of the leg, the lateral side of the smartphone was placed on this mark, and the device was secured with a transparent band during the measurement. While the knee was slowly extended from 90° of flexion, the movement was paused for 10 seconds at each of 40°, 20°, and 5° of flexion, and these target angles were taught to the participant. After the participant had learned to perceive the three different knee extension positions (40°, 20°, and 5°), the knee was returned to 90° flexion without changing the sitting position. The participant was then asked to close their eyes and reproduce the target angles. This procedure was performed on both the operated knee and the contralateral healthy knee, with three repetitions each; the mean angular deviation in degrees (°) was recorded.[14]

Isometric Muscle Strength Measurement

Isometric muscle strength was assessed using a Lafayette hand-held dynamometer (Model 01165; Lafayette Instrument®, USA). The digital dynamometer was calibrated prior to each assessment. The isometric muscle strength of the quadriceps, hamstrings, gluteus maximus, and gluteus medius was assessed using procedures described elsewhere for knee and hip strength measurements obtained with a hand-held dynamometer. To assess quadriceps strength, participants were seated with the hips and knees flexed to approximately 90°, and the dynamometer was placed just proximal to the ankle on the anterior aspect of the leg while the examiner provided counterpressure. For hamstring strength, participants were positioned prone with the knee flexed to approximately 90°, and the dynamometer was positioned over the posterior aspect of the distal leg. Gluteus maximus strength was measured with the participant prone, the hip in neutral position; the dynamometer was applied to the posterior aspect of the distal thigh while the participant attempted hip extension. Gluteus medius strength was assessed with the participant in the side-lying position on the contralateral side, with the test leg in slight hip abduction. The dynamometer was placed over the lateral aspect of the distal thigh while the participant performed hip abduction against resistance. To ensure accurate measurement of isolated isometric muscle strength

and prevent compensatory movements, a stabilization belt was used to secure the participant's body and the tested limb during all measurements. Each measurement was performed three times on both the dominant (kicking limb) and non-dominant sides, with a brief rest between trials, and the recorded values were expressed in kilograms (kg). The mean of the three trials was used for analysis.[15,16]

Vertical Jump Performance Evaluation

The jumping performance of each participant was assessed using the VertiMetric device (Lafayette Instrument Company, Lafayette, IN, USA). The squat jump, characterized by a maximal vertical jump initiated from a static half-squat position without any preparatory countermovement, was selected to evaluate pure concentric muscle contraction. Prior to testing, participants were familiarized with the procedure through several practice trials. For each assessment, the device was applied to the right foot. Participants performed the test barefoot, standing upright with body weight evenly distributed on both feet, and were instructed to jump vertically from a half-squat position to achieve maximum height. Jump height was recorded in centimeters (cm), and power output was measured in watts. Three trials were conducted for each participant, with 30-second rest intervals between attempts, and the mean value was used for analysis. The VertiMetric device has demonstrated high relative reliability, with reported intraclass correlation coefficients ranging from 0.85 to 0.91.[17,18]

Statistical Analysis

The statistical analysis of data obtained from the professional football players included in the study was performed using IBM Statistical Package for Social Sciences version 27.0 (IBM Inc., Armonk, NY, USA). Frequency analysis was conducted to evaluate the distribution of participants' sociodemographic characteristics, sports-related information, and health status. The normality of the data used to compare foot reaction time, proprioception, isometric muscle strength, and vertical jump performance between the operated and non-operated sides was assessed using the Shapiro-Wilk test, which indicated that the data were not normally distributed. Therefore, the Wilcoxon signed-rank test was used for these comparisons. In addition, the effect size (r) was calculated to determine the magnitude of differences between the operated and non-operated sides. The level of statistical significance was set at $p<0.05$.

RESULTS

The mean age, anthropometric characteristics, and year of reconstruction of the 15 professional football players included in the study are presented in Table 1. The 15 professional football players had a mean age of 29.07 years, a mean height of 1.77 meters, and a mean weight of 81.73 kg. Their mean body mass index was 26.12 kg/m², and the mean time since reconstruction was 6 years.

Of the 15 professional football players included in the study, 73.3% (11 players) were right-side dominant, while 26.7% (4 players) were left-side dominant. Among those who underwent reconstruction, 73.3% (11 players) had surgery on the right side and 26.7% (4 players) on the left side. Regarding injury frequency, 66.7% (10 players), 20.0% (3 players), and 13.3% (2 players) experienced one, two, and three injuries, respectively. During reconstruction, a hamstring graft was used in 46.7% of players (7 players), and a patellar graft was used in 53.3% of players (8 players). All participants (n=15; 100%) received physiotherapy and rehabilitation. The duration of rehabilitation was 1-2 months for 26.7% (4 players), 3 months for 26.7% (4 players), 4 months for 33.3% (5 players), and 5 months or more for 13.3% (2 players). The time to return to team training was 1-3 months for 20.0% (3 players), 4-6 months for 53.3% (8 players), and 7 months or more for 26.7% (4 players). The time to first match participation was 1-3 months for 13.3% (2 players), 4-6 months for 33.3% (5 players), and ≥7 months for 53.4% (8 players). By playing position, 53.3% (8 players) were defenders, 26.7% (4 players) were wingers, 13.3% (2 players) were midfielders, and 6.7% (1 player) was a forward.

Table 2 presents a comparison of foot reaction times and knee proprioception measurements between the operated and healthy sides of professional football players. No statistically significant differences were observed between the operated and healthy sides for foot reaction time and for knee proprioception measured at different angles ($p>0.05$; Table 2).

Table 3 presents comparisons of isometric muscle strength between the operated and healthy sides of the professional football players. No statistically significant differences were found between the two sides for isometric strength of the quadriceps, hamstrings, gluteus maximus, and gluteus medius ($p>0.05$; Table 3).

Table 4 presents the comparison of vertical-jump performance between the operated and healthy sides of the professional football players. No statistically significant differences were found between the two sides for vertical jump height and power ($p>0.05$; Table 4).

DISCUSSION

Based on the outcome measures obtained in this study, we believe that these findings will help guide the development of more effective RTS rehabilitation programs for football players who have undergone unilateral reconstruction. The results are also expected to provide insights into which parameters are most affected following ACLR and how these parameters change over time.

When the results of our study were examined, no statistically significant differences were found in vertical-jump height or power between the operated and non-operated limbs. All participating athletes underwent sport-specific rehabilitation during the postoperative period, and evaluations were conducted long after surgery; these factors may have

Table 1. The participants' age, anthropometric characteristics, and year of reconstruction

	n	$\bar{X} \pm SD$	Median (min-max)
Age (years)	15	29.07±5.40	29.00 (21.00-38.00)
Height (m)	15	1.77±0.05	1.77 (1.68-1.85)
Weight (kg)	15	81.73±11.28	80.00 (65.00-98.00)
BMI (kg/m²)	15	26.12±3.06	25.88 (21.97-30.72)
Year of reconstruction	15	6.00±2.04	6.00 (3.00-9.00)

BMI: Body mass index, SD: Standard deviation, min-max: Minimum-maximum.

Table 2. Comparison of foot reaction time and knee proprioception measurements between the operated and healthy sides

	n	$\bar{X} \pm SD$	Median (min-max)	r	p
Operated side foot reaction time (cm)	15	15.48±6.18	16.00 (7.45-27.00)	0.132	0.609
Healthy side foot reaction time (cm)	15	14.49±6.85	11.10 (6.00-26.00)		
Operated side 40° knee proprioception deviation (°)	15	10.87±4.09	11.00 (3.50-16.50)	0.117	0.649
Healthy side 40° knee proprioception deviation (°)	15	11.20±3.17	11.00 (7.00-18.50)		
Operated side 20° knee proprioception deviation (°)	15	4.40±2.14	4.00 (1.50-10.50)	0.089	0.729
Healthy side 20° knee proprioception deviation (°)	15	4.63±3.50	4.00 (0.50-11.50)		
Operated side 5° knee proprioception deviation (°)	15	13.43±3.92	12.50 (8.50-20.00)	0.162	0.531
Healthy side 5° knee proprioception deviation (°)	15	12.30±3.27	12.00 (6.00-18.00)		

r: Effect size, SD: Standard deviation, min-max: Minimum-maximum.

Table 3. Comparison of isometric muscle strength measurements between the operated and healthy sides

	n	$\bar{X} \pm SD$	Median (min-max)	r	p
Operated side quadriceps muscle strength (kg)	15	33.95±6.97	34.30 (22.40-43.45)	0.018	0.975
Healthy side quadriceps muscle strength (kg)	15	34.01±6.92	37.20 (19.90-46.70)		
Operated side hamstring muscle strength (kg)	15	19.93±5.63	21.40 (7.85-29.15)	0.477	0.061
Healthy side hamstring muscle strength (kg)	15	22.78±4.13	22.40 (14.75-28.40)		
Operated side gluteus maximus muscle strength (kg)	15	27.39±8.46	25.85 (15.65-42.05)	0.308	0.233
Healthy side gluteus maximus muscle strength (kg)	15	29.95±6.34	32.20 (20.95-41.60)		
Operated side gluteus medius muscle strength (kg)	15	33.44±5.95	34.45 (18.00-40.90)	0.294	0.256
Healthy side gluteus medius muscle strength (kg)	15	35.21±3.70	33.85 (30.35-40.35)		

r: Effect size, SD: Standard deviation, min-max: Minimum-maximum.

contributed to these findings. Another important aspect of this study is that, over time, the asymmetry and deficits between the operated and non-operated limbs appear to have resolved.

Assessing lower-extremity function and sports performance after ACLR, and establishing objective criteria for RTS are important for reducing the risk of re-injury.[19,20] Among the performance measures frequently employed during postoperative rehabilitation are reaction time, proprioception, muscle strength, and jump test parameters. These measures play a critical role in evaluating neuromuscular control, functional performance, and readiness to RTS.[21,22]

Proprioception refers to the sense of joint position in space. A significant deficit in proprioceptive sensation occurs following ACL injury. A systematic review reported that proprioceptive deficits in the operated limb may persist even after ACLR, negatively influencing neuromuscular control and functional performance, particularly the single-leg hop performance.[21] Following ACL injury, altered or reduced afferent proprioceptive input may induce cortical reorganization, leading to decreased mechanoreceptor input from the contralateral uninjured limb. Consequently, sensory processing may be altered, indicating that proprioceptive impairment is not confined to the operated limb.[23] This bilateral manifestation is considered a

Table 4. Comparison of vertical jump performance between the operated and healthy sides

	n	$\bar{X} \pm SD$	Median (min-max)	r	p
Operated side vertical jump height (cm)	15	29.55±7.45	28.00 (21.90-52.00)	0.203	0.436
Healthy side vertical jump height (cm)	15	30.91±7.18	28.70 (24.30-52.00)		
Operated side vertical jump power (Watt)	15	3677.20±787.79	3542.50 (2904-5807)	0.209	0.429
Healthy side vertical jump power (Watt)	15	3981.40±998.58	3445.50 (2942-5785)		

r: Effect size, SD: Standard deviation, min-max: Minimum-maximum.

result of sensorimotor adaptation, underscoring the importance of comprehensive evaluation of both extremities following ACLR.[24] The reduction in proprioceptive input, cortical reorganization resulting from altered mechanoreceptor afference, and decreased muscular strength collectively contribute to impaired reaction time following ACLR. Postoperative cortical reorganization and alterations in motor planning and reaction processes may lead to delayed or modified motor responses, thereby influencing dynamic stability.[25] Additional factors contributing to alterations in reaction time include delays in the hamstring protective reflex due to spinal and cortical adaptations fatigue, and cognitive load. These neurophysiological and functional changes have been shown to prolong reaction time of the operated knee, particularly under dual-task conditions.[24] Previous studies have reported that reaction time is significantly prolonged in the operated limb, while the contralateral limb may also exhibit mild impairments due to central adaptations. In particular, delayed hamstring activation in the operated limb has been identified as a potential risk factor for impaired control of anterior tibial translation.[24,26] It has also been emphasized that particularly within the first 6-12 months after surgery, persistent deficits in hamstring strength and activation play a key role in sustaining reaction-time differences between the operated and non-operated limbs.[21] In this context, the absence of a significant difference in reaction time between the two extremities in our study may be attributed to the fact that the participating athletes had completed their physiotherapy programs and received perturbation- and balance-based exercise training.

Muscle strength loss represents a critical determinant of athletic performance and successful RTS following ACLR. Marked reductions in both quadriceps and hamstring strength are commonly observed, with arthrogenic quadriceps muscle inhibition being particularly prominent during the early postoperative phase. Despite rehabilitation, the operated limb often remains approximately 10-20% weaker than the contralateral limb, even at 9-12 months postoperatively.[27] Moreover, the hamstring-to-quadriceps ratio frequently decreases, indicating persistent muscle imbalance.[28,29] In the contralateral limb, compensatory increases in muscle mass and/or strength may occur; however, strength deficits are typically more pronounced in the operated limb. Reductions in muscle strength, proprioceptive deficits, and balance impairments have been reported to be interrelated, and this interplay negatively affects athletic performance.[29]

The decline in quadriceps muscle strength contributes to the development of motor control deficits by reducing eccentric knee control and increasing valgus stress. This impairment results in poor landing mechanics during jump tasks and consequently elevates the risk of re-injury.[30,31] During the RTS phase following ACLR, insufficient recovery of quadriceps strength in the operated limb-commonly defined as achieving less than 85% of the strength of the contralateral limb-has been identified as a significant predictor of secondary ACL injury. Evidence indicates that such deficits are associated with approximately a fourfold increase in the risk of re-injury, underscoring the critical importance of restoring near-symmetrical strength prior to resuming athletic participation.[32] In this context, the absence of a significant difference in muscle strength between the operated and contralateral limbs may be interpreted as successful restoration of inter-limb strength symmetry. This outcome reflects the effectiveness of the rehabilitation process in optimizing muscular strength, which is considered a key determinant of a safe and successful RTS following ACLR.

Vertical jump performance is an important indicator of lower-extremity muscle strength and coordination. In explosive sports such as football, vertical jump height is an indirect predictor of athletic performance upon RTS after ACLR, reflecting quadriceps and hamstring strength.[31,33] After ACLR, several factors have been identified as negatively affecting vertical jump performance, including arthrogenic muscle inhibition-particularly of the quadriceps-which leads to reduced maximal force production;[34] deficits in proprioceptive and neuromuscular control; asymmetrical load distribution between the limbs; altered mechanical properties of the muscle harvested for grafting; and kinesiophobia.[31,35] A study conducted in 2023 demonstrated that concentric impulse was significantly impaired in the operated limb during all vertical-jump assessments. Moreover, greater peak landing force asymmetry was observed during countermovement jump and double-leg drop-jump tasks, and vertical jump height was consequently reduced in the operated limb.[36] Similarly, Giacomazzo et al.[37] reported that at seven months postoperatively, vertical reactive strength remained impaired, and both the operated and non-operated limbs of individuals who had undergone ACLR demonstrated reduced jump performance compared with healthy controls, indicating a generalized reduction in overall performance and power. Another study showed that asymmetries during double-leg drop landing persisted for 6 to 18 months postoperatively and were particularly evident in sports involving frequent vertical tasks.[38] Furthermore, individuals in the ACLR group exhibit greater

biomechanical asymmetry across a range of jump tests. Performance asymmetry was most pronounced during the single-leg drop jump test, whereas no significant difference in performance was observed in the hop test. Overall, performance decreased in both the operated and non-operated limbs.[39] In an athletic population, a study evaluating vertical jump metrics after ACLR found that vertical jump height in the operated limb was, on average, 1-4 cm lower than in the contralateral limb. However, the authors noted that kinetic metrics other than jump height may be more sensitive for detecting performance deficits.[40]

Study Limitations

The present study has several limitations. The sample size was small (n=15), limiting statistical power and the generalizability of the findings. The cross-sectional design prevents causal inference or assessment of recovery trajectories over time. Participants varied in graft type, rehabilitation duration, and time since surgery (range 3-9 years), which may have introduced heterogeneity. Finally, selection bias is possible because only athletes who returned to professional play were included. Future studies with larger sample sizes, longitudinal and controlled designs, and more comprehensive biomechanical assessments are warranted to confirm and extend these findings.

CONCLUSION

Our findings show that, in professional football players, there are no significant longterm differences between operated and contralateral limbs in reaction time, proprioception, isometric strength of the hip and lower extremity, or squatjump performance, suggesting that sportspecific rehabilitation can largely restore functional symmetry. Small residual deficits in hamstring and gluteal strength and jump power-though not statistically significant-support continued targeted strengthening and routine limb-symmetry monitoring during return-to-sport follow-up.

MAIN POINTS

- In professional footballers approximately 6 years after unilateral anterior cruciate ligament reconstruction, no significant inter-limb differences were detected in reaction time, proprioception, isometric strength, or squat-jump performance.
- Nonetheless, interpretation should incorporate limb symmetry index and effect sizes with 95% confidence intervals, as small residual asymmetries may remain clinically relevant for hamstrings and gluteal strength and jump metrics.
- Larger, stratified cohorts and standardized sport-specific testing are needed to confirm these findings and refine return to sport decision thresholds.

ETHICS

Ethics Committee Approval: Ethical approval for the study was obtained from the Cyprus International University Scientific Research and Publication Ethics Committee (approval number: TBF.00.0-020-8152, date: 23.06.2021).

Informed Consent: Written informed consent was obtained from all participants.

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Footnotes

Authorship Contributions

Surgical and Medical Practices: R.Ö., Concept: R.Ö., B.İ.D., M.M., Design: R.Ö., B.İ.D., M.M., Data Collection and/or Processing: M.M., Analysis and/or Interpretation: R.Ö., B.İ.D., Literature Search: B.İ.D., M.M., Writing: R.Ö., B.İ.D., M.M.

DISCLOSURES

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