

Persistent neuromuscular deficits and injury risk after return to play: A 24-month prospective follow-up in elite handball players following ACL reconstruction

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ABSTRACT

Return to play (RTP) after anterior cruciate ligament (ACL) reconstruction is often considered the final milestone of rehabilitation; however, the extent to which athletes achieve full neuromuscular recovery at this stage remains unclear. Persistent deficits in strength and neuromuscular control may increase the risk of reinjury, particularly in physically demanding sports such as handball. The purpose of this study was to investigate neuromuscular performance, functional knee status, and injury incidence during the first 24 months following RTP in elite handball players after ACL reconstruction, and to explore potential associations between neuromuscular deficits and subsequent injuries. Seventeen elite Greek handball players (8 males and 9 females) who had returned to full competitive activity after ACL reconstruction were prospectively monitored for two years. Neuromuscular performance was assessed every six months using isokinetic dynamometry at angular velocities of 60°, 180°, and 300°/sec, while knee function was evaluated using the International Knee Documentation Committee (IKDC) subjective questionnaire. Strength deficits, hamstring-to-quadriceps (H/Q) ratios, and peak torque-to-body weight ratios were analysed, and both ACL reinjuries and other lower-limb injuries were systematically recorded. Descriptive statistics, chi-square analyses, and repeated-measures ANOVA were applied. ACL reinjury occurred in 35.3% of the participants, with most cases observed within the first six months after RTP. In addition, 28 other lower-limb injuries were recorded, predominantly affecting the previously injured limb. Isokinetic assessments revealed persistent quadriceps and hamstring strength deficits and asymmetries in H/Q ratios throughout the monitoring period, while only 23.3% of IKDC scores reached normative reference values. These findings indicate that athletes may return to high-level competition despite incomplete neuromuscular recovery, potentially increasing reinjury risk. Systematic post-RTP monitoring and objective performance-based criteria may therefore be critical for improving long-term athlete health and safe participation in elite sport.

Keywords: Sport medicine, Anterior cruciate ligament reconstruction, Return to play, Handball, Neuromuscular deficits, Reinjury, Isokinetic testing.

Cite this article as:

Skandalis, V., Hatzimanouil, D., Stavropoulou, G., Bakirtzoglou, P., Semaltianou, E., & Lola, A. (2026). Persistent neuromuscular deficits and injury risk after return to play: A 24-month prospective follow-up in elite handball players following ACL reconstruction. *Journal of Human Sport and Exercise*, 21(3), 936-954. <https://doi.org/10.55860/v83eyp11>

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Submitted for publication March 05, 2026.

Accepted for publication April 08, 2026.

Published May 07, 2026.

[Journal of Human Sport and Exercise](https://doi.org/10.55860/v83eyp11). ISSN 1988-5202.

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doi: <https://doi.org/10.55860/v83eyp11>

INTRODUCTION

Anterior cruciate ligament (ACL) rupture is one of the most common and severe knee injuries in sport, often leading to prolonged absence from competition, decreased quality of life, and an increased risk of long-term complications (Carlson, 2020). It occurs frequently in athletic populations and may significantly affect an athlete's ability to return to the pre-injury level of performance (Paterno et al., 2014). In addition to the direct consequences on physical function, ACL injuries may also influence athletic success, as previous findings indicate an interaction between injury occurrence, performance, and competitive outcomes (Maestroni et al., 2019). Alarming, the global incidence of ACL injuries has nearly doubled over the past two decades despite ongoing efforts to reduce injury risk (Arundale, Silvers-Granelli & Myklebust, 2022).

ACL rupture typically occurs when the mechanical load applied to the ligament exceeds its structural capacity, resulting in compromised knee stability (Maniar et al., 2022). The ligament plays a crucial role in maintaining both translational and rotational stability of the knee joint (Fones et al., 2020), while excessive anterior shear forces have been identified as important contributors to ACL overloading and injury mechanisms (Maniar et al., 2022). Consequently, restoring functional stability and neuromuscular control after ACL reconstruction is essential for athletes seeking to return to competitive activity.

Rehabilitation following ACL reconstruction represents a critical component of the recovery process. The primary objective of rehabilitation is to enable athletes to safely return to competitive sport as quickly as possible, ideally at their previous level of performance and with minimal risk of reinjury (Kotsifaki et al., 2022). Although most athletes aspire to return fully to their pre-injury level (Gokeler et al., 2017), evidence indicates that many athletes experience persistent impairments even after completing rehabilitation and returning to sport. Strength deficits, neuromuscular asymmetries, and proprioceptive impairments have been reported to persist several years after surgery (Carlson, 2020). Moreover, the rate of reinjury following ACL reconstruction remains concerning, with studies reporting reinjury rates ranging from approximately 30% to 39% (Wilk et al., 2023).

Several studies have demonstrated that returning to high-risk sports after ACL reconstruction is associated with a substantial risk of sustaining a second ACL injury (Barber-Westin & Noyes, 2020; Winkler et al., 2025). Younger athletes appear to be particularly vulnerable, with evidence suggesting an elevated risk of reinjury within the first two years after returning to sport (Nageli & Hewett, 2017). Furthermore, previous research has shown that approximately one-third of athletes who return to sport after ACL reconstruction may sustain a second ACL injury, either in the ipsilateral or contralateral limb (Paterno et al., 2017). Despite advances in rehabilitation strategies, the proportion of athletes who successfully return to their previous level of competition within the first year remains relatively limited (Kotsifaki et al., 2023; Paterno et al., 2017).

Modern rehabilitation approaches increasingly emphasize criterion-based return-to-play (RTP) decisions rather than time-based protocols (van Melick et al., 2016). Nevertheless, there remains considerable variation in rehabilitation practices and no clear consensus regarding the optimal criteria for returning to competitive activity after ACL reconstruction (Andrande et al., 2020; Greenberg et al., 2018; Korakakis et al., 2021; Kotsifaki et al., 2022; Risberg et al., 2024). Evidence suggests that premature return to sport without objective functional assessment may increase the risk of reinjury and negatively influence long-term athletic performance (Grindem et al., 2016; Kotsifaki et al., 2023; Kyritsis et al., 2016). Furthermore, only a small proportion of athletes participating in pivoting sports meet the recommended functional criteria for safe return to play (van Melick et al., 2020).

Handball is a highly dynamic and physically demanding sport characterized by explosive jumps, rapid changes of direction, repeated high-intensity movements, and frequent physical contact between players (Bojic, Valdevit & Velickovic, 2019). These demands contribute to a high incidence of injuries, particularly in the lower extremities. ACL injuries in handball often occur without contact and are frequently associated with sudden directional changes or single-leg landings (Monaco et al., 2019; Myklebust, 2014). Epidemiological data indicate that knee injuries account for a substantial proportion of lower limb injuries in handball, with reported rates ranging from 11% to 23% in male players and from 11% to 31.7% in female players (Andrade et al., 2018; Luig & Henke, 2010). Moreover, female handball players appear to have a higher risk of ACL injury compared to males, with incidence rates estimated at 0.86 and 0.24 injuries per 1000 hours of exposure, respectively (Terzidis et al., 2023).

Although previous studies have examined RTP assessments and reinjury rates at various time points following ACL reconstruction (Arden et al., 2010; Heijne, 2010; Paterno et al., 2017; Carlson, 2020; Paterno et al., 2021; Kew et al., 2022; Terzidis et al., 2023), limited research has focused on systematic long-term monitoring of elite handball players who have already returned to high-level competition. In particular, prospective studies investigating neuromuscular performance, functional status, and injury incidence during the first two years following return to play remain scarce. Considering the high physical demands and injury risk associated with handball, such longitudinal monitoring may provide valuable insights into the long-term recovery process and potential risk factors for reinjury.

Therefore, the purposes of the present study were: (1) to assess the return-to-play condition of male and female high-level handball players following ACL reconstruction and evaluate their rehabilitation procedures; (2) to systematically reassess these athletes every six months over two years after RTP to record ACL reinjuries and other lower-limb injuries; and (3) to explore potential associations between neuromuscular performance variables, strength deficits, and the occurrence of subsequent injuries during this follow-up period.

MATERIAL AND METHODS

Participants

The sample of the present study initially consisted of 20 Greek high-level handball players (male and female) competing in teams of the Greek Handball Premier League for Men and the Greek A1 National Division for Women. All participants had previously sustained an anterior cruciate ligament (ACL) rupture that required surgical reconstruction and had completed their rehabilitation program before returning to full competitive activity. Participants were recruited and assessed over a period of three years. During the study, three athletes were excluded from the sample because they terminated their playing careers for reasons unrelated to reinjury. Therefore, the final sample consisted of 17 elite handball players who completed the entire assessment process.

Measures

Demographic and injury questionnaire

Upon their return to competitive activity, all participants completed a questionnaire including demographic characteristics and detailed information about their initial injury and rehabilitation process. The questionnaire collected information regarding the type of graft used in the reconstruction, the presence of concomitant injuries, the duration and structure of the rehabilitation program, and the professionals responsible for conducting the rehabilitation process.

International Knee Documentation Committee (IKDC) questionnaire

Participants also completed the Subjective Knee Evaluation Form of the International Knee Documentation Committee (IKDC 2000). The Greek translated and cross-culturally validated version of the questionnaire was used, as adapted by Koumantakis et al. (2016). The IKDC questionnaire is widely used to evaluate subjective knee function and symptoms following knee injuries and surgical procedures. Participants were asked to provide a subjective evaluation of their knee condition upon their return to competitive activity and during each follow-up assessment.

Isokinetic strength assessment

Neuromuscular performance was evaluated using isokinetic testing at three angular velocities: 60°, 180°, and 300°/sec. Assessments were conducted using a Humac Norm 770 CSMi isokinetic dynamometer (Stoughton, MA, USA) at the Human Biological Performance Assessment Laboratory of the School of Physical Education and Sport Science at the Aristotle University of Thessaloniki. The isokinetic assessment was used to evaluate lower-limb muscle strength, detect possible asymmetries between limbs, and determine whether hamstring-to-quadriceps (H/Q) ratios and peak torque-to-body weight (PT/BW) ratios fell within normative values reported in the literature.

Procedures

All participants were assessed immediately after returning to full competitive activity following ACL reconstruction. During the initial assessment, they completed the demographic and injury questionnaire as well as the IKDC questionnaire, and they underwent the isokinetic strength testing protocol. The same assessment procedure was repeated every six months for a total follow-up period of two years. During each follow-up evaluation, participants completed the IKDC questionnaire and reported whether they had received any special treatment or injury-specific training programs within their teams during the previous six-month period. Additionally, all ACL reinjuries and other serious lower limb injuries were systematically recorded throughout the monitoring period. For an injury to be recorded, the player had to abstain from training and competition for at least one week. In cases of ACL reinjury, the incident was documented, and the participant was excluded from further testing. The testing protocol was approved by the Research Ethics Committee of the Faculty of Physical Education and Sport Sciences at the Aristotle University of Thessaloniki (Approval No. 115/27-6-2022). All participants were fully informed about the testing procedures and provided written informed consent before participation.

Analysis

Descriptive statistical analyses were conducted for the questionnaire data and the IKDC scores. In addition, descriptive statistics were calculated for all isokinetic assessment variables, including quadriceps and hamstring strength deficits, hamstring-to-quadriceps (H/Q) ratios, and peak torque-to-body weight ratios at angular velocities of 60°, 180°, and 300°/sec for both injured and non-injured limbs. Means, standard deviations, and ranges were calculated to characterize athletes' neuromuscular performance at return to play (RTP). Inferential statistical analyses were also performed. Chi-square tests were applied to examine associations between categorical variables, such as reinjury occurrence and strength deficit classifications. Finally, repeated measures ANOVA was used to examine within-subject differences across the different testing angular velocities (60°, 180°, 300°/sec) and between injured and non-injured limbs, allowing the evaluation of limb symmetry and velocity-dependent changes in muscle performance.

RESULTS

The analysis of demographic and sport-related characteristics indicated that 47.1% of the participants were male ($n = 8$), whereas 52.9% were female ($n = 9$). With respect to preferred playing side, 70.6% ($n = 12$) reported a right-side preference and 29.4% ($n = 5$) reported a left-side preference. Examination of playing positions revealed that back players represented the largest proportion of the sample (47.1%, $n = 8$), followed by wings (23.5%, $n = 4$), goalkeepers (17.6%, $n = 3$), and pivots (11.8%, $n = 2$).

Analysis of injury-related characteristics showed that over half of the participants sustained an isolated anterior cruciate ligament (ACL) injury (52.9%, $n = 9$), while 35.3% ($n = 6$) had combined ACL and meniscus injuries, and 11.8% ($n = 2$) presented with ACL injuries in combination with other concomitant injuries. Regarding injury recurrence, 82.4% ($n = 14$) reported experiencing an ACL injury for the first time, 11.8% ($n = 2$) reported a second ipsilateral injury, and 5.9% ($n = 1$) reported a second contralateral injury. Concerning the professionals involved in rehabilitation, 5.9% ($n = 1$) were managed by a doctor outside the team, 11.8% ($n = 2$) by a physiotherapist outside the team, 17.6% ($n = 3$) by the team's conditioning coach, 17.6% ($n = 3$) by a conditioning coach outside the team, 5.9% ($n = 1$) by a special rehabilitation coach, and 41.2% ($n = 7$) by a multidisciplinary team of specialists. These findings provide a descriptive profile of the injuries. More specifically, types of injuries, recurrence patterns, and rehabilitation support received by the participants.

The data on graft type show that among the 17 participants, 58.8% underwent reconstruction using a bone-patellofemoral-bone graft, while 41.2% received a hamstring (semitendinosus) graft. Moreover, only a 29.4% ($n = 5$) reported that they received pre-operative training, while a 70.6% ($n = 12$) reported no pre-operative training.

The rehabilitation evaluation data show that out of 17 participants, 5.9% underwent minimal structured rehabilitation, another 5.9% had three months of minimal structured rehab, and 5.9% received three months of structured rehab. A higher proportion, 11.8%, engaged in structured rehab for over three months, while 17.6% completed six months of structured rehab. The most common category was nine months of totally structured rehab at 35.3%, followed by 5.9% who reported over nine months of totally structured rehab, and 11.8% who completed over nine months of fully supervised rehab. Moreover, the participants reported their rehabilitation program characteristics and training components. This information is presented in Table 1.

Table 1. Distribution of rehabilitation program characteristics and training components among participants.

	Frequency	Percentage	Valid percentage	Cumulative percentage
Minimal structured rehab	1	5.9	5.9	5.9
3 months of minimal structured rehab	1	5.9	5.9	11.8
3 months structured rehab	1	5.9	5.9	17.6
Over 3 months of structured rehab	2	11.8	11.8	29.4
6 months structured rehab	3	17.6	17.6	47.1
9 months of totally structured rehab	6	35.3	35.3	82.4
Over 9 months, totally structured rehab	1	5.9	5.9	88.2
Over 9 months of fully supervised rehab	2	11.8	11.8	100.0
Total	17	100.0	100.0	
Physiotherapy				
Not at all	3	17.6	17.6	17.6
Average	1	5.9	5.9	23.5
Much	7	41.2	41.2	64.7
Very much	6	35.3	35.3	100.0
Total	17	100.0	100.0	

Stretching-ROM				
Minimal	3	17.6	17.6	17.6
Average	6	35.3	35.3	52.9
Much	4	23.5	23.5	76.5
Very much	4	23.5	23.5	100.0
Total	17	100.0	100.0	
Physical condition				
Not at all	1	5.9	5.9	5.9
Minimal	1	5.9	5.9	11.8
Average	7	41.2	41.2	52.9
Much	4	23.5	23.5	76.5
Very much	4	23.5	23.5	100.0
Total	17	100.0	100.0	
Strength training				
Minimal	1	5.9	5.9	5.9
Average	1	5.9	5.9	11.8
Much	5	29.4	29.4	41.2
Very much	10	58.8	58.8	100.0
Total	17	100.0	100.0	
Plyometric training				
Minimal	2	11.8	11.8	11.8
Average	4	23.5	23.5	35.3
Much	5	29.4	29.4	64.7
Very much	6	35.3	35.3	100.0
Total	17	100.0	100.0	
Proprio training				
Minimal	2	11.8	11.8	11.8
Average	5	29.4	29.4	41.2
Much	5	29.4	29.4	70.6
Very much	5	29.4	29.4	100.0
Total	17	100.0	100.0	
Balance training				
Average	2	11.8	11.8	11.8
Much	7	41.2	41.2	52.9
Very much	8	47.1	47.1	100.0
Total	17	100.0	100.0	
Handball training				
Minimal	1	5.9	5.9	5.9
Average	11	64.7	64.7	70.6
Much	4	23.5	23.5	94.1
Very much	1	5.9	5.9	100.0
Total	17	100.0	100.0	

Regarding ACL reinjury from the time of RTP up to six months after RTP, 11.8% (n = 2) experienced ipsilateral ACL reinjury, 11.8% (n = 2) had contralateral ACL reinjury in total, 22.4% (n = 4) reported an ACL reinjury, whereas 70.9% reported no reinjury; one participant's data (5.9%) was missing due to another injury. At 12 months after RTP, none of the remaining participants reported any new ACL reinjury. At 18 months, 11.8% (n = 2) reported ipsilateral ACL reinjury and 58.8% reported no ACL reinjury; five participants (29.4%) had no data due to previous reported ACL reinjury or other serious lower limb injury that prohibited them to participate to the programmed assessments. By 24 months after RTP, reinjury data were only available for ten participants, all of whom reported no ACL reinjury. In contrast, data for seven participants (41.2%) were missing due to ACL reinjuries or other leg injuries that prevented them from participating in the programmed

assessments. Overall, the data show that ACL reinjury rates reached a level of 35,29% (n = 6, 3 male and 3 female players), in a total period of two years after returning to full playing activity.

Regarding other lower limb injuries that forced the players to abstain from training and games for at least seven days, concerning either the ipsilateral or the contralateral leg, from the time of RTP up to 24 months, the results are shown in Table 2.

Table 2. Type of injuries, their frequency, and distribution among assessment periods.

Type of injury	RTP-6m	6m-12m	12m-18m	18m-24m	Injuries total frequency	Injuries percentage
Hams strain/fracture	1	1			2	7.14
Knee pain	3	5	3	2	13	46.42
Gastrocnemius strain/fracture	1				1	3.57
Adductors strain/fracture	1	1			2	7.14
Sprains	1				1	3.57
Lateral collateral ligament		1			1	3.57
Quads strain/fracture				1	1	3.57
Meniscus injury			3	3	6	21.42
Back surgery			1		1	3.57
Total	7	8	7	6	28	100
Ipsilateral	5	6	6	6	23	82.14
Contralateral	1	1			2	7.14
Both legs / Not related	1	1	1		3	10.71

In the question if they performed any special or injury-specific training within their teams, the majority of the participants replied negatively (n = 15), and only two participants replied positively. This finding persisted throughout the whole period of the 24 months.

Regarding the isokinetic assessment performed at 60⁰-180⁰-300⁰ / sec, although deficits still exist up to 24 months after RTP, we can see from the results that there is a small but clear reduction of the values that are out of the normative values, as we reach the 18 and 24 months after RTP, especially at the 24 months assessments. This information can be seen in Table 3.

Table 3. Normative and non-normative values for Isokinetic assessments at 60⁰-180⁰-300⁰ /sec throughout 6, 12, 18, 24 months.

ISOK06 for 6 months	Quads deficit	Hams deficit	HQratio injured	HQratio Non injured	PTBW Ratio injured	PTBWratio Non injured
Into normative values	7	6	6	9	7	8
Out of normative values	5*	6*	6*	3*	5*	4*
ISOK180 for 6 months						
Into normative values	7	4	6	11	10	12
Out of normative values	5*	8*	6*	1*	2*	19*
ISOK300 for 6 months						
Into normative values	9	3	8	10	11	12
Out of normative values	3*	9*	4*	2*	1*	19*
ISOK06 for 12 months						
Into normative values	9	7	7	10	7	9
Out of normative values	3*	5*	5*	2*	5*	3*
ISOK180 for 12 months						
Into normative values	9	7	9	10	10	12
Out of normative values	3*	5*	3*	2*	1*	19*

ISOK300 for 12 months						
Into normative values	8	5	6	11	12	11
Out of normative values	4*	7*	6*	1*	19*	1*
ISOK06 for 18 months						
Into normative values	5	5	7	8	5	7
Out of normative values	5*	5*	3*	2*	5*	3*
ISOK180 for 18 months						
Into normative values	5	4	5	8	7	10
Out of normative values	5*	6*	5*	2*	3*	
ISOK300 for 18 months						
Into normative values	6	4	5	7	8	9
Out of normative values	4*	6*	5*	3*	2*	1*
ISOK06 for 24 months						
Into normative values	4	3	5	6	5	7
Out of normative values	4*	5*	3*	2*	3*	1*
ISOK180 for 24 months						
Into normative values	3	6	5	7	6	8
Out of normative values	5*	2*	3*	1*	2*	
ISOK300 for 24 months						
Into normative values	5	4	4	6	7	8
Out of normative values	3*	4*	4*	2*	1*	

Note. * Out of normative values. Quads deficit = Quadriceps isokinetic assessment deficit between limbs, Hams deficit = Hamstrings isokinetic assessment deficit between limb, HQ ratio INJURED = Hamstrings and Quadriceps isokinetic assessment values ratio on injured limb, HQ ratio non-INJURED = Hamstrings and Quadriceps isokinetic assessment values ratio on non-injured limb, PTBW ratio INJURED = Peak torque values and body weight ratio on injured limb, PTBW ratio non-INJURED = Peak torque values and body weight ratio on non-injured limb.

According to the IKDC questionnaire evaluations, results show that the participants do not value their injured leg within the normative values that exist according to age and gender (Logerstedt et al. 2014). More specifically, in the majority of cases, it appears that the reported values are out of the normative data. This information exists in Table 4.

Table 4. IKDC values at RTP and 6, 12, 18, 24, months after RTP for all participants.

Participants	RTP	6 months	12 months	18 months	24 months
1	63.21	66.6	Other injury**	67.81	75.86
2	86.2**	78*	83.9	79.31*	Other injury
3	74.71	72.4*	79.3	71.26*	77.01
4	72.4	75.8	74.7*	77.01	75.86*
5	62.02	ACL reinjury**			
6	67.81	80.45	79.3*	74.71*	75.86
7	58.6	72.41	68.9*	55.17*	62.6
8	74.71	86.2	82.75*	ACL reinjury	
9	55.17	ACL reinjury**			
10	57.47	ACL reinjury**			
11	88.76**	89.65**	87.35*	88.2**	86.35*
12	85.6	ACL reinjury			
13	77	85.5**	85.5**	Other injury	
14	82.7**	54*	82.7**	82.8**	81.6*
15	77	72.41*	87.35**	ACL reinjury	
16	83.9	Other injury**	85.05**	86.7**	87.2**
17	82.7	85.6**	73.56*	75.6	72.58*

Note. *All data that showed a worse result than the previous assessment. **all data that are within normative values according to gender and age.

A chi-square test of independence was conducted to examine the association between the type of injury and isokinetic assessments. Specifically, it tried to investigate whether the isokinetic quadriceps peak torque-to-

body weight ratio at 60°/sec (injured limb) at RTP fell within normative values. The analysis revealed a statistically significant association, $\chi^2(3, N = 8) = 8, p = .046$. The crosstabulation examined the relationship between the type of injury and whether the PTBW ratio at 180° / sec at RTP falls within normative values. Out of the eight cases analysed, most injuries (7 out of 8) were within normative values, while only one case (ham strain/fracture) was out of normative values. The Chi-Square test indicated a statistically significant association between injury type and normative status ($\chi^2 = 8, df = 3, p = .046$). The use of frequency illustrated the relationship between the type of injury and whether the ISOK300PTBW ratio at return to play (RTP) falls within normative values. Out of the eight cases analysed, seven were within normative ranges, while only one case (injury type “ham strain/fracture”) was outside normative values. The Pearson Chi-Square test indicated a statistically significant association ($\chi^2 = 8, df = 3, p = .046$), suggesting that the type of injury may be related to the likelihood of the score being within normal limits.

Also, the relationship between the type of injury and whether the PTBW ratio at 60° at RTP for the injured leg falls within normative values was examined. Out of the six total cases, five were within normative values, while only one case (injury type “ham strain/fracture”) was outside normative values. The Chi-Square analysis showed borderline statistical significance ($\chi^2 = 6, df = 2, p = .050$), suggesting a possible association between the type of injury and performance.

The crosstab analysis examined the relationship between the type of injury and whether the quadriceps deficit at 180°/sec (ISOK180Quaddef) at RTP is within normative values. Among the six total cases, three were within normative values (all reported meniscus injuries), while the other three cases (“quads strain/fracture” and “knee pain”) were outside normative values. The Chi-Square test showed borderline statistical significance ($\chi^2 = 6, df = 2, p = .050$), indicating a possible association between injury type and quadriceps deficit status. The crosstab analysis investigated the relationship between the type of injury and whether the quadriceps deficit at 300°/sec (ISOK300Quaddef) at return to play (RTP) falls within normative values. Of the six total cases, three (all related to “meniscus” injuries) were within normative limits, while the remaining three cases (“quads strain/fracture” and “knee pain”) were outside normative limits. The Chi-Square test showed borderline statistical significance ($\chi^2 = 6, df = 2, p = .050$).

The crosstab analysed the relationship between the type of injury and whether the hamstring-to-quadriceps ratio at 300°/sec (ISOK300HQ ratio) for the injured limb (INJ) at RTP falls within normative values. Out of the six total cases, five were within normative limits (3 from the “meniscus” group and 2 from the “knee pain” group), while only one case (“quads strain/fracture”) was outside normative values. The Chi-Square test showed borderline statistical significance ($\chi^2 = 6.000, df = 2, p = .050$), suggesting a potential association between injury type and whether the HQ ratio is normative.

The Repeated Measures ANOVA test was used to investigate how the same athletes perform under 12 and 18 months. Specifically, it evaluated whether isokinetic measures such as quadriceps deficit, hamstring deficit, and hamstring-to-quadriceps ratios at 300°/sec change between repeated assessments and whether these changes differ depending on the type of variable measured. Initially, the results explore how performance measures at 300°/sec (quadriceps deficit, hamstring deficit, and hamstring-to-quadriceps ratios for both injured and non-injured limbs) vary across repeated testing. The within-subjects effects show that the main repeated-measure factor itself is not significant ($p = .90$), indicating no overall time effect across all variables. However, interactions reveal that the hamstring deficit (ISOK300Hamsdef_RTP) demonstrates a statistically significant change over time ($F = 5.705, p = .05$), suggesting improvements or differences in hamstring performance between measurements. The interaction for hamstring-to-quadriceps ratio on the injured limb (ISOK300HQratioINJ_RTP) approaches significance ($p = .055$), indicating a possible trend.

Quadriceps deficit ($p = .13$) and the HQ ratio for the non-injured limb ($p = .10$) did not reach significance. The between-subjects effects mirror these results, confirming that only the hamstring deficit shows a clear effect, while other measures indicate trends but are not statistically significant. This information is presented in Table 5.

Table 5. Within-subject effects for Repeated Measures Anova between Re-Injury in 12 and 18 months and isokinetic assessment.

Cases	Sum of Squares	df	Mean Square	F	p
RM Factor 1	0.004	1	0.004	0.019	.896
RM Factor 1 * ISOK300Quaddef_RTP	0.725	1	0.725	3.011	.126
RM Factor 1 * ISOK300Hamsdef_RTP	1.373	1	1.373	5.705	.048
RM Factor 1 * ISOK300HQratioINJ_RTP	1.273	1	1.273	5.289	.055
RM Factor 1 * ISOK300HQratioNINJ_RTP	0.896	1	0.896	3.722	.095
Residuals	1.685	7	0.241		

Note. Type III Sum of Squares. ISOK300Quaddef_RTP = Quadriceps deficit between limbs during isokinetic assessment at 300 °/sec angular velocity during Return to play assessment, SOK300Hamsdef_RTP = Hamstrings deficit between limbs during isokinetic assessment at 300 °/sec angular velocity during Return to play assessment, ISOK300HQratioINJ_RTP = Hamstrings and Quadriceps isokinetic assessment values ratio on injured limb during isokinetic assessment at 300 °/sec angular velocity during Return to play assessment, RM Factor 1 * ISOK300HQratioNINJ_RTP = Repeated Measures factor: Hamstrings and Quadriceps isokinetic assessment values ratio on non-injured limb during isokinetic assessment at 300 °/sec angular velocity during Return to play assessment.

The repeated measures ANOVA examining changes in isokinetic performance over 6, 12, 18, and 24 months shows no overall significant main effect of time ($F = 1.836$, $p = .18$), indicating that when all measures are combined, performance does not significantly change across these intervals. However, when interactions between time and specific performance variables are considered, quadriceps deficit at 300°/sec (ISOK300Quaddef_RTP) approaches statistical significance ($F = 3.260$, $p = .05$), suggesting notable improvements or fluctuations in quadriceps recovery after RTP, over time. Similar trends are observed for hamstring deficit ($F = 2.732$, $p = .08$) and hamstring-to-quadriceps ratio on the injured limb ($F = 2.765$, $p = .08$), implying possible changes in muscle symmetry and functional patterns across the follow-up period. The non-injured limb HQ ratio shows less pronounced change ($p = .12$). Between-subject effects are uniformly non-significant (all $p > .86$), indicating that differences in recovery after RTP are largely driven by within-subject changes rather than variability between individuals. This information is represented in Table 6.

Table 6. Within-subject effects for Repeated Measures Anova between Re-Injury in 6, 12, 18, and 24 months and isokinetic assessments.

Cases	Sum of Squares	df	Mean Square	F	p
RM Factor 1	8.078	3	2.693	1.836	.184
RM Factor 1 * ISOK300Quaddef_RTP	14.342	3	4.781	3.260	.051
RM Factor 1 * ISOK300Hamsdef_RTP	12.019	3	4.006	2.732	.081
RM Factor 1 * ISOK300HQratioINJ_RTP	12.161	3	4.054	2.765	.078
RM Factor 1 * ISOK300HQratioNINJ_RTP	10.227	3	3.409	2.325	.116
Residuals	21.994	15	1.466		

Note. Type III Sum of Squares. ISOK300Hamsdef_RTP = Hamstrings deficit between limbs during isokinetic assessment at 300 °/sec angular velocity during Return to play assessment, ISOK300HQratioINJ_RTP = Hamstrings and Quadriceps isokinetic assessment values ratio on injured limb during isokinetic assessment at 300 °/sec angular velocity during Return to play assessment injured limb, ISOK300HQratioNINJ_RTP = Hamstrings and Quadriceps isokinetic assessment values ratio on injured limb during isokinetic assessment at 300 °/sec angular velocity during Return to play assessment non-injured limb.

DISCUSSION

The present study aimed to examine neuromuscular performance, functional status, and injury incidence during two years following return to play (RTP) after anterior cruciate ligament (ACL) reconstruction in elite handball players. The main findings indicate that: (a) ACL reinjury rates were relatively high within the two-year follow-up period, (b) several other lower-limb injuries occurred during the same period, predominantly in the previously injured limb, and (c) neuromuscular deficits in quadriceps and hamstrings strength persisted even up to 24 months after RTP. Collectively, these findings suggest that athletes may return to competitive activity despite incomplete neuromuscular recovery.

Regarding the demographic characteristics of the sample, the distribution between male and female athletes was relatively balanced. This finding is somewhat inconsistent with previous research suggesting that female athletes are generally more susceptible to ACL injuries (Ireland, 2002; Myklebust, Skjoelberg & Bahr, 2013; Setuain et al., 2019; Raya-Gonzales et al., 2020; Terzidis et al., 2023). However, the present sample consisted of elite players competing in the highest national leagues, which may partly explain this difference. In terms of playing position, back players represented the largest proportion of injured athletes, which is consistent with previous studies reporting higher injury incidence in these positions due to the greater physical demands and frequent high-intensity actions involved in gameplay (Myklebust, 2014; Hatzimanouil et al., 2020; Skandalis et al., 2020; Terzidis et al., 2023).

The analysis of injury characteristics revealed that more than half of the participants sustained isolated ACL injuries, while the remaining cases involved concomitant injuries, most commonly meniscal lesions. Such injury patterns have been widely reported in the literature and may occur either at the time of the initial trauma or as a result of progressive damage before surgical intervention (Fanelli & Edson, 1995; Sankar et al., 2006; Brambila et al., 2015; Lee et al., 2018; Ang, Doris, & Lui, 2022; Pruneski et al., 2024). Although the majority of athletes in the present sample experienced their first ACL injury, a smaller proportion reported previous ACL injuries, which is consistent with the elevated reinjury risk observed in athletes returning to high-risk sports (Barber-Westin & Noyes, 2020; Winkler et al., 2025).

Another important finding concerns the rehabilitation process followed by the athletes. According to the questionnaire responses, a considerable proportion of participants did not complete a fully structured rehabilitation program or returned to competition earlier than the recommended timeframe. Previous studies have emphasized the importance of both the duration and structure of rehabilitation programs in achieving optimal functional recovery (Grindem et al., 2016; Webster & Feller, 2020; Kotsifaki et al., 2022). In the present study, more than half of the athletes reported incomplete rehabilitation programs, either in terms of duration or supervision. Although some evidence suggests that supervised and unsupervised rehabilitation may produce similar outcomes (Kotsifaki et al., 2022), early return to sport before adequate neuromuscular recovery may increase the likelihood of reinjury.

The reinjury rate observed in the present study reached 35.3% within the two-year follow-up period, with the majority of reinjuries occurring within the first six months after RTP. These findings are consistent with previous research reporting reinjury rates ranging between 30% and 39% (Wilk et al., 2023). Similar patterns have been reported in other studies indicating that the risk of a second ACL injury is particularly elevated during the first year following return to sport (Paterno et al., 2012; Nageli & Hewett, 2017). The relatively high reinjury rate observed in the present study may therefore reflect incomplete neuromuscular recovery at the time of RTP or insufficient monitoring during the early post-RTP period.

In addition to ACL reinjuries, a substantial number of other lower-limb injuries were recorded during the follow-up period. Most of these injuries affected the previously injured limb, suggesting that residual deficits may alter movement patterns and increase mechanical stress on the musculoskeletal system. Previous research has shown that prior injuries may influence neuromuscular control and lead to compensatory movement strategies, potentially increasing the risk of subsequent injuries (Hodges & Tucker, 2011; Bien & Dubuque, 2015; Petway et al., 2025). In the present study, knee pain and meniscal injuries were among the most frequently reported conditions, supporting the hypothesis that incomplete recovery may have long-term functional consequences.

The isokinetic assessments revealed that deficits in quadriceps and hamstring strength persisted throughout the entire 24-month monitoring period. Similar findings have been reported in previous studies demonstrating long-lasting neuromuscular impairments following ACL reconstruction (Palmieri-Smith, Thomas & Wojtys, 2008; Schmitt, Paterno & Hewett, 2012; Tayfur et al., 2021; Maestroni et al., 2021; Gokeler et al., 2022). Persistent strength asymmetries may negatively affect knee joint biomechanics and contribute to altered movement patterns during high-intensity sport-specific actions (Ithurburn et al., 2018; Kew et al., 2022). Interestingly, deficits were observed not only in the injured limb but also in the contralateral limb, suggesting possible bilateral neuromuscular adaptations following ACL injury.

The results of the IKDC questionnaire further support the presence of functional limitations among the participants. Only a small proportion of the athletes reported knee function values within the normative ranges for their age and sex. Although gradual improvements were observed over time, several athletes continued to report suboptimal knee function even 18 to 24 months after returning to competitive activity. This finding highlights the discrepancy that may exist between medical clearance for RTP and the athlete's perceived functional readiness.

The statistical analyses also indicated potential associations between neuromuscular deficits and the occurrence of subsequent injuries. Although some of these relationships did not reach strong statistical significance, likely due to the relatively small sample size, the observed trends suggest that strength deficits in quadriceps and hamstrings may contribute to the development of additional injuries. Similar associations have been described in previous research demonstrating that deficits in neuromuscular function may increase the risk of both ACL graft failure and secondary musculoskeletal injuries (Kuenze et al., 2015; Messer et al., 2021).

The repeated-measures analyses did not reveal strong overall time effects in neuromuscular performance across the follow-up period. However, some variables, particularly hamstring deficits, demonstrated significant or near-significant changes across time points. These findings may reflect gradual adaptations during long-term athletic participation after RTP. Nevertheless, the relatively small sample size and the specificity of the population examined may have limited the statistical power of the analyses.

Despite these limitations, the present study provides valuable insight into the long-term recovery process of elite handball players following ACL reconstruction. One of the main strengths of the study is the homogeneity of the sample, as all participants were high-level handball players who sustained the same type of injury. At the same time, several limitations should be acknowledged. First, the sample size was relatively small due to the specificity of the injury examined. Second, the study focused exclusively on handball players, which may limit the generalizability of the findings to athletes from other sports. Finally, the limited number of longitudinal studies examining post-RTP monitoring in handball highlights the need for further research in this area.

Overall, the findings of the present study emphasize the importance of systematic follow-up assessments after RTP. Regular neuromuscular evaluations may help identify persistent deficits and provide opportunities for targeted interventions aimed at reducing reinjury risk. In addition, improved monitoring and individualized rehabilitation strategies may support safer long-term participation in high-level sport following ACL reconstruction.

CONCLUSIONS

The findings of the present study indicate that elite handball players may return to competitive activity following anterior cruciate ligament (ACL) reconstruction despite incomplete neuromuscular recovery. Persistent deficits in quadriceps and hamstring strength, as well as asymmetries in neuromuscular performance, were observed throughout the 24-month follow-up period after return to play. In addition, relatively high rates of ACL reinjury and other lower-limb injuries were recorded, particularly during the early months following return to competition. Although statistical analyses revealed mostly trends rather than strong significance, likely due to the limited sample size, the results suggest that neuromuscular deficits may be associated with an increased risk of subsequent injuries.

These findings highlight the importance of objective performance-based criteria and systematic neuromuscular monitoring during the post-return-to-play period. Therefore, regular follow-up assessments, ideally conducted at six-month intervals during the first two years after return to play, may be essential for identifying persistent deficits and reducing reinjury risk in elite handball players. Future research, including larger samples and athletes from different sports, is needed to further clarify the long-term recovery process following ACL reconstruction and to improve return-to-play decision-making strategies.

From a practical perspective, the findings highlight the importance of continuous neuromuscular monitoring and individualized post-return-to-play training programs in order to reduce reinjury risk and optimize long-term athletic performance in handball players following ACL reconstruction.

AUTHOR CONTRIBUTIONS

All authors meet the criteria for authorship in accordance with established ethical guidelines. V. S. conceived and designed the study, coordinated data collection, performed the statistical analysis, and drafted the manuscript. D. H. contributed to the study design, supervision of the research process, and critical revision of the manuscript. G. S. contributed to data collection and interpretation of the results. P. B. assisted in the data analysis and interpretation of the findings. E. S. contributed to the literature review and manuscript editing. A. L. contributed to the methodological design of the study and critically revised the manuscript for important intellectual content. All authors have critically reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

FUNDING

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CONFLICT OF INTEREST

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 manuscript.

AI USE DISCLOSURE

In accordance with current publishing ethics and transparency recommendations, artificial intelligence (AI) tools were used solely to assist with translation and language editing, with the aim of improving clarity and readability. No AI tools were used in the generation of scientific content, including the study design, data collection, analysis, interpretation of results, or the formulation of conclusions. The authors retain full responsibility for the content of the manuscript and confirm its originality, integrity, and accuracy.

REFERENCES

- Anderson, A. F., Irrgang, J. J., Kocher, M. S., Mann, B. J., Harrast, J. J., & International Knee Documentation Committee. (2006). The International Knee Documentation Committee subjective knee evaluation form: normative data. *The American journal of sports medicine*, 34(1), 128-135. <https://doi.org/10.1177/0363546505280214>
- Andrade, R., Pereira, R., Bastos, R., Saavedra, C., Pereira, H., Laver, L., ... & Espregueira-Mendes, J. (2018). Management of Cartilage Injuries in Handball. *Handball Sports Medicine: Basic Science, Injury Management and Return to Sport*, 325-340. https://doi.org/10.1007/978-3-662-55892-8_23
- Andrade, R., Pereira, R., van Cingel, R., Staal, J. B., & Espregueira-Mendes, J. (2020). How should clinicians rehabilitate patients after ACL reconstruction? A systematic review of clinical practice guidelines (CPGs) with a focus on quality appraisal (AGREE II). *British journal of sports medicine*, 54(9), 512-519. <https://doi.org/10.1136/bjsports-2018-100310>
- Ang, A. C. H., Wong, D., & Lui, P. P. Y. (2022). Increased risk of concomitant meniscal injuries in adolescents with elevated body mass index after anterior cruciate ligament tear: a systematic review. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, 38(12), 3209-3221. <https://doi.org/10.1016/j.arthro.2022.05.004>
- Ardern, C. L., Webster, K. E., Taylor, N. F., & Feller, J. A. (2011). Return to the preinjury level of competitive sport after anterior cruciate ligament reconstruction surgery: two-thirds of patients have not returned by 12 months after surgery. *The American journal of sports medicine*, 39(3), 538-543. <https://doi.org/10.1177/0363546510384798>
- Arundale, A. J., Silvers-Granelli, H. J., & Myklebust, G. (2022). ACL injury prevention: Where have we come from and where are we going? *Journal of Orthopaedic Research®*, 40(1), 43-54. <https://doi.org/10.1002/jor.25058>
- Baltaci, G., Harput, G., Haksever, B., Ulusoy, B., & Ozer, H. (2013). Comparison between Nintendo Wii Fit and conventional rehabilitation on functional performance outcomes after hamstring anterior cruciate ligament reconstruction: prospective, randomized, controlled, double-blind clinical trial. *Knee surgery, sports traumatology, arthroscopy*, 21(4), 880-887. <https://doi.org/10.1007/s00167-012-2034-2>
- Barber-Westin, S., & Noyes, F. R. (2020). One in 5 athletes sustain reinjury upon return to high-risk sports after ACL reconstruction: a systematic review in 1239 athletes younger than 20 years. *Sports Health*, 12(6), 587-597. <https://doi.org/10.1177/1941738120912846>
- Bien, D. P., & Dubuque, T. J. (2015). Considerations for late-stage ACL rehabilitation and return to sport to limit re-injury risk and maximize athletic performance. *International journal of sports physical therapy*, 10(2), 256.
- Bojić, I., Valdevit, Z., & Veličković, M. (2020). The causes and prevention of injuries in handball. *Teme*, 423-438. <https://doi.org/10.22190/TEME191015004B>
- Brambilla, L., Pulici, L., Carimati, G., Quaglia, A., Prospero, E., Bait, C., ... & Volpi, P. (2015). Prevalence of associated lesions in anterior cruciate ligament reconstruction: correlation with surgical timing and

- with patient age, sex, and body mass index. *The American Journal of Sports Medicine*, 43(12), 2966-2973. <https://doi.org/10.1177/0363546515608483>
- Buckthorpe, M. (2019). Optimising the late-stage rehabilitation and return-to-sport training and testing process after ACL reconstruction. *Sports Medicine*, 49(7), 1043-1058. <https://doi.org/10.1007/s40279-019-01102-z>
- Carlson, K. (2020). Assessment of post-rehabilitation ACL reconstructed knees. *International Journal of Kinesiology & Sports Science*, 8(2), 33. <https://doi.org/10.7575/aiac.ijkss.v.8n.2p.33>
- Claes, S., Verdonk, P., Forsyth, R., & Bellemans, J. (2011). The "ligamentization" process in anterior cruciate ligament reconstruction: what happens to the human graft? A systematic review of the literature. *The American journal of sports medicine*, 39(11), 2476-2483. <https://doi.org/10.1177/0363546511402662>
- Eitzen, I., Moksnes, H., Snyder-Mackler, L., & Risberg, M. A. (2010). A progressive 5-week exercise therapy program leads to significant improvement in knee function early after anterior cruciate ligament injury. *Journal of orthopaedic & sports physical therapy*, 40(11), 705-721. <https://doi.org/10.2519/jospt.2010.3345>
- Fanelli, G. C., & Edson, C. J. (1995). Posterior cruciate ligament injuries in trauma patients: part II. Arthroscopy: The Journal of Arthroscopic & Related Surgery, 11(5), 526-529. [https://doi.org/10.1016/0749-8063\(95\)90127-2](https://doi.org/10.1016/0749-8063(95)90127-2)
- Fones, L., Kostyun, R. O., Cohen, A. D., & Pace, J. L. (2020). Patient-reported outcomes, return-to-sport status, and reinjury rates after anterior cruciate ligament reconstruction in adolescent athletes: minimum 2-year follow-up. *Orthopaedic journal of sports medicine*, 8(11), 2325967120964471. <https://doi.org/10.1177/2325967120964471>
- Gokeler, A., Dingenen, B., & Hewett, T. E. (2022). Rehabilitation and return to sport testing after anterior cruciate ligament reconstruction: where are we in 2022? *Arthroscopy, Sports Medicine, and Rehabilitation*, 4(1), e77-e82. <https://doi.org/10.1016/j.asmr.2021.10.025>
- Gokeler, A., Dingenen, B., Mouton, C., & Seil, R. (2017). Clinical course and recommendations for patients after anterior cruciate ligament injury and subsequent reconstruction: a narrative review. *EFORT open reviews*, 2(10), 410-420. <https://doi.org/10.1302/2058-5241.2.170011>
- Greenberg, E. M., Greenberg, E. T., Albaugh, J., Storey, E., & Ganley, T. J. (2018). Rehabilitation practice patterns following anterior cruciate ligament reconstruction: a survey of physical therapists. *Journal of orthopaedic & sports physical therapy*, 48(10), 801-811. <https://doi.org/10.2519/jospt.2018.8264>
- Grindem, H., Granan, L. P., Risberg, M. A., Engebretsen, L., Snyder-Mackler, L., & Eitzen, I. (2015). How does a combined preoperative and postoperative rehabilitation programme influence the outcome of ACL reconstruction 2 years after surgery? A comparison between patients in the Delaware-Oslo ACL Cohort and the Norwegian National Knee Ligament Registry. *British journal of sports medicine*, 49(6), 385-389. <https://doi.org/10.1136/bjsports-2014-093891>
- Grindem, H., Snyder-Mackler, L., Moksnes, H., Engebretsen, L., & Risberg, M. A. (2016). Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: the Delaware-Oslo ACL cohort study. *British journal of sports medicine*, 50(13), 804-808. <https://doi.org/10.1136/bjsports-2016-096031>
- Hatzimanouil, D., Saavedra, J. M., Lola, A., Skandalis, V., & Gkagkanas, K. (2024). Analysis of movement and actions of wingers as second-line players in organized attack in handball. *Journal of Human Kinetics*, 92, 181. <https://doi.org/10.5114/jhk/175281>
- Heijne, A., Äng, B. O., & Werner, S. (2009). Predictive factors for 12-month outcome after anterior cruciate ligament reconstruction. *Scandinavian journal of medicine & science in sports*, 19(6), 842-849. <https://doi.org/10.1111/j.1600-0838.2008.00852.x>
- Hodges, P. W., & Tucker, K. (2011). Moving differently in pain: a new theory to explain the adaptation to pain. *Pain*, 152(3), S90-S98. <https://doi.org/10.1016/j.pain.2010.10.020>

- Ireland, M. L. (2002). The female ACL: why is it more prone to injury? *Orthopedic Clinics*, 33(4), 637-651. [https://doi.org/10.1016/S0030-5898\(02\)00028-7](https://doi.org/10.1016/S0030-5898(02)00028-7)
- Ithurburn, M. P., Altenburger, A. R., Thomas, S., Hewett, T. E., Paterno, M. V., & Schmitt, L. C. (2018). Young athletes after ACL reconstruction with quadriceps strength asymmetry at the time of return-to-sport demonstrate decreased knee function 1 year later. *Knee Surgery, Sports Traumatology, Arthroscopy*, 26(2), 426-433. <https://doi.org/10.1007/s00167-017-4678-4>
- Kew, M. E., Bodkin, S., Diduch, D. R., Brockmeier, S. F., Lesevic, M., Hart, J. M., & Werner, B. C. (2022). Reinjury rates in adolescent patients 2 years following ACL reconstruction. *Journal of Pediatric Orthopaedics*, 42(2), 90-95. <https://doi.org/10.1097/BPO.0000000000002031>
- Korakakis, V., Kotsifaki, A., Korakaki, A., Karanasios, S., & Whiteley, R. (2021). Current perspectives and clinical practice of physiotherapists on assessment, rehabilitation, and return to sport criteria after anterior cruciate ligament injury and reconstruction. An online survey of 538 physiotherapists. *Physical Therapy in Sport*, 52, 103-114. <https://doi.org/10.1016/j.ptsp.2021.08.012>
- Kotsifaki, R., Korakakis, V., King, E., Barbosa, O., Maree, D., Pantouveris, M., ... & Whiteley, R. (2023). Aspetar clinical practice guideline on rehabilitation after anterior cruciate ligament reconstruction. *British journal of sports medicine*, 57(9), 500-514. <https://doi.org/10.1136/bjsports-2022-106158>
- Koumantakis, G. A., Tsoligkas, K., Papoutsidakis, A., Ververidis, A., & Drosos, G. I. (2016). Cross-cultural adaptation and validation of the international knee documentation committee subjective knee form in Greek. *Journal of Orthopaedics and Traumatology*, 17, 123-129. <https://doi.org/10.1007/s10195-015-0362-y>
- Kuenze, C. M., Hertel, J., Weltman, A., Diduch, D., Saliba, S. A., & Hart, J. M. (2015). Persistent neuromuscular and corticomotor quadriceps asymmetry after anterior cruciate ligament reconstruction. *Journal of athletic training*, 50(3), 303-312. <https://doi.org/10.4085/1062-6050-49.5.06>
- Kvist, J. (2004). Rehabilitation following anterior cruciate ligament injury: current recommendations for sports participation. *Sports Medicine*, 34(4), 269-280. <https://doi.org/10.2165/00007256-200434040-00006>
- Kyritsis, P., Bahr, R., Landreau, P., Miladi, R., & Witvrouw, E. (2016). Likelihood of ACL graft rupture: not meeting six clinical discharge criteria before return to sport is associated with a four times greater risk of rupture. *British journal of sports medicine*, 50(15), 946-951. <https://doi.org/10.1136/bjsports-2015-095908>
- Laver, L., Landreau, P., Seil, R., & Popovic, N. (Eds.). (2018). *Handball sports medicine*. Springer Berlin Heidelberg. <https://doi.org/10.1007/978-3-662-55892-8>
- Lee, R. J., Margalit, A., Nduaguba, A., Gunderson, M. A., & Ganley, T. J. (2018). Risk factors for concomitant collateral ligament injuries in children and adolescents with anterior cruciate ligament tears. *Orthopaedic Journal of Sports Medicine*, 6(11), 2325967118810389. <https://doi.org/10.1177/2325967118810389>
- Logerstedt, D., Di Stasi, S., Grindem, H., Lynch, A., Eitzen, I., Engebretsen, L., ... & Snyder-Mackler, L. (2014). Self-reported knee function can identify athletes who fail return-to-activity criteria up to 1 year after anterior cruciate ligament reconstruction: a Delaware-Oslo ACL cohort study. *Journal of Orthopaedic & Sports Physical Therapy*, 44(12), 914-923. <https://doi.org/10.2519/jospt.2014.4852>
- Luig, P., & Henke, T. (2010). *Safety in Sports*. European Network for Sports Injury Prevention.
- Maestroni, L., Read, P., Turner, A., Korakakis, V., & Papadopoulos, K. (2021). Strength, rate of force development, power and reactive strength in adult male athletic populations post anterior cruciate ligament reconstruction-A systematic review and meta-analysis. *Physical Therapy in Sport*, 47, 91-104. <https://doi.org/10.1016/j.ptsp.2020.11.024>
- Maniar, N., Cole, M. H., Bryant, A. L., & Opar, D. A. (2022). Muscle force contributions to anterior cruciate ligament loading. *Sports Medicine*, 52(8), 1737-1750. <https://doi.org/10.1007/s40279-022-01674-3>

- van Melick, N., Hoogeboom, T. J., Pronk, Y., Rutten, B., van Tienen, T. G., Nijhuis-van der Sanden, M. W., & van Cingel, R. E. (2020). Less than half of ACL-reconstructed athletes are cleared for return to play based on practice guideline criteria: Results from a prospective cohort study. *International Journal of Sports Physical Therapy*, 15(6), 1006. <https://doi.org/10.26603/ijsp20201006>
- Van Melick, N., Van Cingel, R. E., Brooijmans, F., Neeter, C., van Tienen, T., Hullegie, W., & Nijhuis-van der Sanden, M. W. (2016). Evidence-based clinical practice update: practice guidelines for anterior cruciate ligament rehabilitation based on a systematic review and multidisciplinary consensus. *British journal of sports medicine*, 50(24), 1506-1515. <https://doi.org/10.1136/bjsports-2015-095898>
- van Melick, N., van der Weegen, W., & van der Horst, N. (2022). Quadriceps and hamstrings strength reference values for athletes with and without anterior cruciate ligament reconstruction who play popular pivoting sports, including soccer, basketball, and handball: a scoping review. *journal of orthopaedic & sports physical therapy*, 52(3), 142-155. <https://doi.org/10.2519/jospt.2022.10693>
- Messer, D. J., Williams, M. D., Bourne, M. N., Opar, D. A., Timmins, R. G., & Shield, A. J. (2022). Anterior cruciate ligament reconstruction increases the risk of hamstring strain injury across football codes in Australia. *Sports Medicine*, 52(4), 923-932. <https://doi.org/10.1007/s40279-021-01567-x>
- Mónaco, M., Rincón, J. A. G., Ronsano, B. J. M., Whiteley, R., Sanz-Lopez, F., & Rodas, G. (2019). Injury incidence and injury patterns by category, player position, and maturation in elite male handball elite players. *Biology of sport*, 36(1), 67-74. <https://doi.org/10.5114/biolSport.2018.78908>
- Myklebust, G. (2014). Between basketball and rugby: The risk of injury in handball. *Aspetar sports medicine journal*, 138-141.
- Myklebust, G., Skjøberg, A., & Bahr, R. (2013). ACL injury incidence in female handball 10 years after the Norwegian ACL prevention study: important lessons learned. *British journal of sports medicine*, 47(8), 476-479. <https://doi.org/10.1136/bjsports-2012-091862>
- Nagai, T., Schilaty, N. D., Laskowski, E. R., & Hewett, T. E. (2020). Hop tests can result in higher limb symmetry index values than isokinetic strength and leg press tests in patients following ACL reconstruction. *Knee Surgery, Sports Traumatology, Arthroscopy*, 28(3), 816-822. <https://doi.org/10.1007/s00167-019-05513-3>
- Nagelli, C. V., & Hewett, T. E. (2017). Should return to sport be delayed until 2 years after anterior cruciate ligament reconstruction? Biological and functional considerations. *Sports medicine*, 47(2), 221-232. <https://doi.org/10.1007/s40279-016-0584-z>
- Øiestad, B. E., Juhl, C. B., Culvenor, A. G., Berg, B., & Thorlund, J. B. (2022). Knee extensor muscle weakness is a risk factor for the development of knee osteoarthritis: an updated systematic review and meta-analysis including 46 819 men and women. *British journal of sports medicine*, 56(6), 349-355. <https://doi.org/10.1136/bjsports-2021-104861>
- Olsen, O. E., Myklebust, G., Engebretsen, L., & Bahr, R. (2006). Injury pattern in youth team handball: a comparison of two prospective registration methods. *Scandinavian journal of medicine & science in sports*, 16(6), 426-432. <https://doi.org/10.1111/j.1600-0838.2005.00484.x>
- Paterno, M. V., Huang, B., Thomas, S., Hewett, T. E., & Schmitt, L. C. (2017). Clinical factors that predict a second ACL injury after ACL reconstruction and return to sport: preliminary development of a clinical decision algorithm. *Orthopaedic journal of sports medicine*, 5(12), 2325967117745279. <https://doi.org/10.1177/2325967117745279>
- Palmieri-Smith, R. M., Thomas, A. C., & Wojtys, E. M. (2008). Maximizing quadriceps strength after ACL reconstruction. *Clinics in sports medicine*, 27(3), 405-424. <https://doi.org/10.1016/j.csm.2008.02.001>
- Paterno, M. V., Rauh, M. J., Schmitt, L. C., Ford, K. R., & Hewett, T. E. (2012). Incidence of contralateral and ipsilateral anterior cruciate ligament (ACL) injury after primary ACL reconstruction and return to sport. *Clinical Journal of Sport Medicine*, 22(2), 116-121. <https://doi.org/10.1097/JSM.0b013e318246ef9e>

- Paterno, M. V., Rauh, M. J., Thomas, S., Hewett, T. E., & Schmitt, L. C. (2022). Return-to-sport criteria after anterior cruciate ligament reconstruction fail to identify the risk of second anterior cruciate ligament injury. *Journal of athletic training*, 57(9-10), 937-945. <https://doi.org/10.4085/1062-6050-0608.21>
- Petway, A. J., Burch, R. F., Saucier, D. N., Gillen, Z. M., Rimer, E., Epsley, S., & Forbes, R. (2025). Examining prior injury relative to anterior cruciate ligament tears in National Basketball Association players. *Research in Sports Medicine*, 1-14. <https://doi.org/10.1080/15438627.2025.2532524>
- Pruneski, J. A., Heyworth, B. E., Kocher, M. S., Tavabi, N., Milewski, M. D., Kramer, D. E., ... & Kiapour, A. M. (2024). Prevalence and predictors of concomitant meniscal and ligamentous injuries associated with ACL surgery: an analysis of 20 years of ACL reconstruction at a tertiary care children's hospital. *The American Journal of Sports Medicine*, 52(1), 77-86. <https://doi.org/10.1177/03635465231205556>
- Raya-González, J., Clemente, F. M., Beato, M., & Castillo, D. (2020). Injury profile of male and female senior and youth handball players: A systematic review. *International journal of environmental research and public health*, 17(11), 3925. <https://doi.org/10.3390/ijerph17113925>
- Risberg, M. A., Lewek, M., & Snyder-Mackler, L. (2004). A systematic review of evidence for anterior cruciate ligament rehabilitation: how much and what type? *Physical Therapy in Sport*, 5(3), 125-145. <https://doi.org/10.1016/j.ptsp.2004.02.003>
- Sankar, W. N., Wells, L., Sennett, B. J., Wiesel, B. B., & Ganley, T. J. (2006). Combined anterior cruciate ligament and medial collateral ligament injuries in adolescents. *Journal of Pediatric Orthopaedics*, 26(6), 733-736. <https://doi.org/10.1097/01.bpo.0000242433.81187.89>
- Sepúlveda, F., Sánchez, L., Amy, E., & Micheo, W. (2017). Anterior cruciate ligament injury: return to play, function and long-term considerations. *Current sports medicine reports*, 16(3), 172-178. <https://doi.org/10.1249/JSR.0000000000000356>
- Schmitt, L. C., Paterno, M. V., & Hewett, T. E. (2012). The impact of quadriceps femoris strength asymmetry on functional performance at return to sport following anterior cruciate ligament reconstruction. *Journal of orthopaedic & sports physical therapy*, 42(9), 750-759. <https://doi.org/10.2519/jospt.2012.4194>
- Skandalis, V., Hatzimanouil, D., Giatsis, G., Stavropoulos, N., Semaltianou, E., & Sykaras, E. (2020). Knee joint bilateral symmetry evaluation in high-level handball players prior to their return to playing. *Journal of Physical Education & Sport*, 20.
- Tayfur, B., Charupongsa, C., Morrissey, D., & Miller, S. C. (2021). Neuromuscular function of the knee joint following knee injuries: does it ever get back to normal? A systematic review with meta-analyses. *Sports medicine*, 51(2), 321-338. <https://doi.org/10.1007/s40279-020-01386-6>
- Terzidis I, Papasoulis E, Karampampa C, Hatzimanouil D, Evaggelia D, et al. (2023) Return to Play and Long-Term Participation Following ACL Reconstruction in Elite Handball Players. *J Orthop Res Ther* 8: 1324. <https://doi.org/10.29011/2575-8241.001324>
- Webster, K. E., & Feller, J. A. (2020). Who passes return-to-sport tests, and which tests are most strongly associated with return to play after anterior cruciate ligament reconstruction? *Orthopaedic journal of sports medicine*, 8(12), 2325967120969425. <https://doi.org/10.1177/2325967120969425>
- Wilk, K. E., Thomas, Z. M., Arrigo, C. A., & Davies, G. J. (2023). The need to change return to play testing in athletes following ACL injury: A theoretical model. *International Journal of Sports Physical Therapy*, 18(1), 272. <https://doi.org/10.26603/001c.67988>
- Winkler, P. W., Thorolfsson, B., Piussi, R., Snaebjörnsson, T., Senorski, R. H., Karlsson, J., ... & Senorski, E. H. (2025). Sport-specific concomitant injuries, return-to-sport rates and second anterior cruciate ligament (ACL) injuries in adolescents with ACL reconstruction. *British Journal of Sports Medicine*, 59(13), 931-940. <https://doi.org/10.1136/bjsports-2024-108694>

- Wylie, J. D., Marchand, L. S., & Burks, R. T. (2017). Etiologic factors that lead to failure after primary anterior cruciate ligament surgery. *Clinics in sports medicine*, 36(1), 155-172.
<https://doi.org/10.1016/j.csm.2016.08.007>
- Xaverova, Z., Dirnberger, J., Lehnert, M., Belka, J., Wagner, H., & Orechovska, K. (2015). Isokinetic strength profile of elite female handball players. *Journal of Human Kinetics*, 49, 257.
<https://doi.org/10.1515/hukin-2015-0128>



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