Journal of Clinical Orthopaedics and Trauma 34 (2022) 102025

Contents lists available at ScienceDirect

Journal of Clinical Orthopaedics and Trauma

journal homepage: www.elsevier.com/locate/jcot

Low percentage of patients passed the 'Back in Action' test battery 9 months after bone-patellar tendon-bone anterior cruciate ligament reconstruction

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ARTICLE INFO

Article history:
Received 5 May 2022
Received in revised form
28 August 2022
Accepted 7 September 2022
Available online 11 September 2022

Keywords:
Anterior cruciate ligament
Bone-patellar tendon-bone
Functional performance
Patient reported outcome
Test battery

ABSTRACT

Background: Anterior cruciate ligament (ACL) reconstruction is recommended in patients who intend to return to high-level sports. However, there is only a 55–80% return to pre-injury level of sports after ACL reconstruction, with a re-injury rate up to 20%. The aim of this study was to determine the percentage of patients passing the Back in Action (BIA) test 9 months after primary bone-patellar-tendon-bone (BPTB) ACL reconstruction, and evaluate the association between passing the BIA test and patient reported outcome measurements (PROMs).

Methods: Patients underwent the BIA test 9 months after BPTB ACL reconstruction. In total 103 patients were included. Passing the BIA test (PASSED-group) was defined as a normal or higher score at all subtests with limb symmetry index (LSI) ≥90% for the dominant leg and LSI >80% for the non-dominant leg. Patients who did not meet these criteria were defined as the FAILED-group. PROMs included the International Knee Documentation Committee, Knee injury Osteoarthritis Outcome Score and Anterior Cruciate Ligament-Return to Sport after Injury.

Results: Eighteen patients (17.5%) passed the BIA test 9 months after BPTB ACL reconstruction. PROMs were not statistically significant different between the PASSED- and FAILED-group.

Conclusion: Low percentage of patients passed the BIA test 9 months after BPTB ACL reconstruction. Although current PROMs cut-off values were met, the BIA test results show persistent functional deficits. Therefore, the BIA test could be of additional value in the decision-making process regarding return to sport (RTS). This study highlights the need for additional rehabilitation as RTS in a condition of incomplete recovery may increase the risk of re-injury.

Level of evidence: II.

1. Introduction

Anterior cruciate ligament (ACL) injuries are common in pivoting sports and lead to instability, decreased activity and dissatisfaction.[1,2] An ACL reconstruction is recommended in patients who intend to return to high-level sports.[3,4] However, previous studies demonstrated that only 55–80% of patients return to the pre-injury level of sports.[5,6] Furthermore, a re-injury rate up to 20% is observed in young and active patients.[6,7] Therefore, standardized criteria to evaluate readiness for a safe return to sport (RTS) are imperative.

A delayed RTS from 6 to 9 months after ACL reconstruction has shown to decrease the risk of ACL re-injury.[8,9] In addition, patient reported outcome measurements (PROMs) have shown to predict RTS after ACL reconstruction.[10,11] Also, functional performance tests such as hop and muscle strength tests are commonly used to evaluate readiness for safe RTS.[8,12–17] The outcomes of hop and

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https://doi.org/10.1016/j.jcot.2022.102025
0976-5662/

muscle strength tests are generally reported as limb symmetry index (LSI). Thereby, RTS is allowed with a LSI of ≥90%.[8,18] However to date no standardized criteria are available to predict a safe RTS.[12,19]

Recently, a standardized test battery for decision-making regarding RTS was introduced.[20] This test battery (Back in Action CoRehab srl, Trento, Italy) consists of seven subtests and allows for comparison of results with age and gender matched healthy control subjects.[20] The test battery could have additional value to PROMs, functional testing, and strength measurements in deciding whether a patient is allowed to RTS. Previous studies report Back in Action (BIA) test battery outcomes after ACL reconstruction using mainly hamstring-tendon or quadriceps-tendon autograft.[21–23] However, BIA outcomes are unknown after ACL reconstruction using the bone-patellar tendon-bone (BPTB) autograft.

This study aimed to determine the percentage of patients passing the BIA test battery 9 months after BPTB ACL reconstruction, and evaluate the association between passing the BIA test battery and PROMs. We hypothesized that a low percentage of patients pass the BIA test battery 9 months after BPTB ACL reconstruction. Furthermore, we hypothesized that patients passing the BIA test battery have higher PROMs as compared to patients failing the BIA test battery.

2. Methods

2.1. Participants

This study was approved by the medical ethical committee of Zuyderland Medical Center (METZ20180053). All patients provided informed consent before enrollment. Patients who underwent ACL reconstruction between May 2018 and March 2020 were selected. Inclusion criteria were primary ACL reconstruction using BPTB autograft and age >14 years old. Exclusion criteria were pre-injury Tegner activity score less than 4, previous knee surgery, no intention to RTS and incomplete BIA test data. A total of 103 patients (78 male and 25 female) were included (Fig. 1). All ACL reconstructions were performed by one experienced orthopedic surgeon. Patients underwent an ACL reconstruction using a BPTB autograft, which was fixed with titanium screws (Zimmer Biomet, Indiana, USA). An accessory anteromedial portal was made to improve anatomical positioning of the graft. The postoperative rehabilitation was guided by local physical therapists and followed a standardized rehabilitation protocol conform the Dutch Society for Physical Therapy (KNGF).[24]

2.2. Patient assessment

Patients underwent the BIA test battery at 9 months after primary BPTB ACL reconstruction. Patient demographics (e.g. pre-injury Tegner activity score), the presence of concomitant injury and PROMs were collected before BIA testing. Patient assessment was performed by three main researchers. Concomitant injury was defined as grade 2–3 collateral ligament injury (based on Fetto and Marshall classification), partial meniscectomy, meniscal repair or grade 3–4 cartilage injury (based on International Cartilage Repair Score).[25–27] PROMs included the International Knee Documentation Committee (IKDC; 1–100, best score is 100), the Knee injury Osteoarthritis Outcome Score (KOOS; 1–100, best score is 100) and the Anterior Cruciate Ligament-Return to Sport after Injury (ACL-RSI; 1–100, best score is 100).[28–30] Present criteria used for a clearance to RTS are an IKDC cutoff score of ≥15th percentile from normative data of uninjured athletes (score of ≥85) and an ACL-RSI cutoff score >56 [10-12, 31]. In addition, the duration of supervised rehabilitation (<9-months or ≥9-months) was documented.

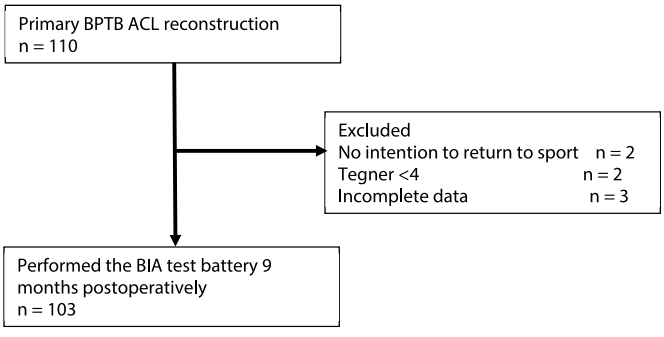


Fig. 1. Flow chart of the patients included in the study.
ACL, anterior cruciate ligament; BIA, Back In Action; BPTB, bone-patellar tendon-bone.

All patients completed a 10-min warm-up by cycling on sub-maximal speed. The BIA test battery consists of seven subtests and were performed with 30s inter-set rest: 1. two-legs stability (TL-ST), 2. one-leg stability (OL-ST), 3. two-legs counter movement jump (TL-CMJ), 4. one-leg counter movement jump (OL-CMJ), 5. two-legs plyometric jump (TL-PJ), 6. one-leg speedy jump (OL-SY) and 7. two-legs quick feet (TL-QF) test.[20] Table 1 shows an overview of this test battery. For each subtest the patients performed one test trial and then performed 2 or 3 approved trials, conform the protocol presented by Hildebrandt et al.[20] The best score of the trials was used for analysis. The numeral scores of the seven tests were then expressed as "very good", "good", "normal", "weak" or "very weak" according to age- and gender-matched data obtained from healthy subjects. In addition, LSI was calculated to register differences between the dominant and non-dominant leg. Leg dominancy was based upon which leg the patient would use to push a ball as strongly as possible. Passing the BIA test battery (PASSED-group) was defined as a "very good", "good", or "normal" score at all sub-tests with LSI ≥90% for the dominant leg and LSI >80% for the non-dominant leg. Patients who did not meet all these criteria were defined as the FAILED-group. For instance, when one of the subtests was scored as "weak" or "very weak" the patient automatically failed for the BIA test battery.

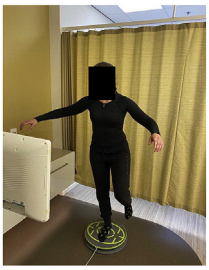
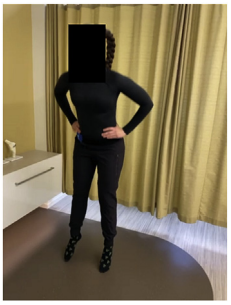
2.3. Statistical analysis

Statistical analysis was performed using SPSS Statistics (IBM Corp. SPSS Statistics for Windows, Version 25.0). Continuous variables were tested for normality using the Shapiro-Wilk test. Categorical variables were presented as frequencies (%). Continuous variables were presented as mean ± standard deviation (SD) or median ± interquartile range (IQR). Categorical variables were tested using Chi-square test or, in case of expected cell count <20% the Fisher's Exact Test was used. Normally distributed data were tested with parametric t-tests. In case of violation of the assumption for parametric tests (i.e. normality and homogeneity of variances), Mann-Whitney *U* test was used instead of independent samples *t*-test. Statistical significance was set at $p < 0.05$.

3. Results

Table 2 shows the patient demographics. No statistically significant differences were observed between the PASSED- and FAILED-group in gender, age, type of sport, concomitant injury, or duration of supervised revalidation. All patients completed the BIA test battery, and no injury was observed during the tests. Table 3 shows the BIA test results of the included patients. In total 17.5% (n = 18) passed the BIA test battery at a median of 9 months (range, 8–10) after BPTB ACL reconstruction. In total 4.7% (n = 4) in the

Table 1
Overview of the BIA test battery.

Test	Picture	Exercise	Outcome
TL-ST		Stand with both legs on a balance board and maintain stability for 20s. Instant visual feedback was available with the aim to maintain a marker in the centre of a circular target.	Neuromuscular and postural control
OL-ST		Stand with one leg on a balance board and maintain stability for 20s. Instant visual feedback was available with the aim to maintain a marker in the centre of a circular target.	Neuromuscular and postural control
TL-CMJ		An accelerometer was placed above the greater trochanter of the hip. From an upright position, first bend the knees and then jump upward as high as possible with the arms placed on the hips.	Strength
OL-CMJ		Similar as the TL-CMJ but performed with one leg.	Strength
TL-PJ		Perform four consecutive two-leg jumps aiming maximum height and velocity.	Strength and agility

(*continued on next page*)

Table 1 (*continued*)

Test	Picture	Exercise	Outcome
OL-SY		A series of one-leg jumps: forward-backward-forward jumps through the course of red and one sideway jumps through the course of blue. Twisting of the hip was not allowed. The test was stopped when the raised leg touched the ground or was in contact with the hurdles.	Agility and speed
TL-QF		Step in and out with one foot after the other until 15 repetitions were completed. One repetition was finished when the starting leg returned to its initial position.	Agility and speed

TL-ST, two let stability; OL-ST, one leg stability; TL-CMJ, two leg counter movement jump; OL-CMJ, one-leg counter movement jump; TL-PJ, two leg plyometric jump; OL-SY, one leg speedy test; TL-QF, two leg quick feet test.

FAILED-group followed a supervised revalidation program less than 9 months due to "good clinical progress" or "work-related" issues. The pre-injury Tegner activity score was significantly higher ($p = 0.019$) in the PASSED-group as compared to the FAILED-group: 7(1) versus 7(0) for the PASSED and FAILED-group, respectively. In Table 4 the PROMs are presented at 9 months postoperatively. The PROMs were not statistically significant different between the PASSED- and FAILED-group.

4. Discussion

This is the first study which estimated the percentage of patients that passed the Back in Action (BIA) test battery after anterior cruciate ligament (ACL) reconstruction using bone-patellar tendon-bone (BPTB) autografts. The most important finding of the present study was that 17.5% of the patients passed the BIA test battery 9 months after ACL reconstruction. The low percentage of patients passing the BIA test battery 9 months after ACL reconstruction is concerning as the BIA test battery allows for comparison with age and gender matched healthy subjects.

Functional performance tests such as hop and muscle strength tests are commonly used to evaluate readiness for return to sport (RTS).[15,31–33] The outcomes of hop tests and strength measurements are generally reported as limb symmetry index (LSI). Thereby, RTS is allowed with a LSI of $\geq$90%.[16,18] A drawback of using the LSI is that it might overestimate functional performance as studies demonstrated decreased strength and function in the uninvolved leg.[34,35] Additionally, a recent systematic review demonstrated that current hop tests lack association with ACL re-injury.[32] In this study we used the BIA test battery to evaluate readiness for RTS, which allows for comparison of results with age and gender matched healthy control subjects. The BIA test battery could be of additional value since it is compared to normative data and not being solely depending on LSI scores.

In our study only 17.5% of the patients passed the BIA test battery 9 months after ACL reconstruction using BPTB autografts. Previous studies show passing percentages between 2.5% and 52.7% after ACL reconstruction using other autografts.[21–23] Herbst et al. showed a passing percentage of 17.4% for the BIA test battery after ACL reconstruction.[21] In their study mainly hamstring autografts (68.1%) were used, compared to bone-patellar tendon-bone grafts (14.5%). They tested sixty-nine patients approximately 8 months after following a standard early rehabilitation protocol. Authors stated that the LSI was the most limiting factor for passing the BIA test battery due to ongoing functional deficits of the operated leg. Ebert et al. reported a passing rate of only 2.5% 12 months after hamstring ACL reconstruction.[22] In their protocol, patients did not follow a standardized rehabilitation program. Authors pointed out that passing rates for the OL-CMJ could be relatively low due to restricted arm movement compared to standard hop tests were arm use may increase jump performance.[22] A recently published study demonstrated that 52.7% of the patients, with an average Tegner activity score of 7, passed the BIA test battery 6 months after quadriceps or hamstring ACL reconstruction.[23] However, in their study the LSI was not used as a passing criterium for the BIA test. This could explain the higher passing rate compared to our and other studies using the BIA test battery.[23] Comparable patient demographics between these studies, such as age, gender, BMI or pre-injury Tegner activity scores could not explain the big variety in passing rates.

This study shows higher pre-injury Tegner activity scores in the PASSED-group compared to the FAILED-group, which might indicate that patients with higher pre-injury Tegner activity scores are more likely to pass the BIA test battery. However, the median pre-injury Tegner scores in both groups is 7, showing no clinically relevant difference. Although previous studies show a good intra-observer reliability for the Tegner activity score, inter-observer reliability has not been investigated yet.[36] In this study data collection was performed by 3 independent researchers, which may lead to the current pre-injury Tegner activity results.

Findings indicate that 9 months of rehabilitation is not enough to recover completely. Therefore, the question remains whether RTS is safe. Several possible reasons could explain the low percentage of patients passing the BIA test battery 9 months after BPTB

Table 2
Demographics of the patients included in the study.

	PASSED n = 18	FAILED n = 85
Gender, male*	12 (66.7)	66 (77.6)
Age, years at index surgery**	18.5 ± 15	21.0 ± 7.0
Body mass index**	21.8 ± 3.2	23.7 ± 4.3
Preinjury Tegner Activity Score**	7 ± 1	7 ± 0
Sport*		
Soccer	11 (61.1)	61 (71.8)
Handball	2 (11.1)	10 (11.8)
Other	5 (27.8)	14 (16.5)
Trauma mechanism, non-contact*	15 (83.3)	67 (78.8)
Dominant side operated*	9 (50.0)	46 (54.1)
Concomitant injury, total*	11 (61.1)	55 (64.7)
Collateral ligament injury, yes	1 (5.6)	9 (10.6)
- MCL-injury	1 (5.6)	8 (9.4)
- LCL-injury	0 (0.0)	1 (1.2)
Meniscal injury, yes	9 (50.0)	49 (57.6)
- Medial	5 (27.8)	21 (24.7)
- Lateral	3 (16.7)	19 (22.4)
- Combined	1 (5.6)	9 (10.6)
Cartilage injury, yes	3 (16.7)	1 (15.3)
Duration of supervised rehabilitation, >9 months*	18 (100)	81 (95.3)

Results are presented as *numbers (and percentages) or **median ± interquartile range. Body mass index, kg/m^2. MCL, medial collateral ligament. LCL, lateral collateral ligament.

ACL reconstruction. Firstly, postural stability did not recover completely at 9 months postoperatively as was shown as relatively high failure rates in the two-legs stability and the one-leg stability tests. Previous studies demonstrated that postural stability decreases after ACL reconstruction because of surgery on knee proprioception.[37–39] Furthermore, postural stability has been shown to predict RTS and ACL re-injury because of its role in dynamic knee valgus during the landing phase.[40–42] This emphasizes the need to increase the quality of standardized rehabilitation protocols embedding attention to stability and neuromuscular control in the early postoperative rehabilitation phase before starting with jumping exercises. Secondly, strength deficits after ACL reconstruction using BPTB autografts could be another reason for the low passing percentage. Strength deficits are common after ACL surgery, with greater quadriceps strength deficits after BPTB as compared to hamstring ACL reconstruction.[33,43–45] Patients in our study showed different results in the jumping subtests as compared to the BIA test battery results after ACL reconstruction using hamstring or quadriceps grafts.[22,23] Relatively high failure rates were observed in the plyometric jump and two-legs counter movement jump indicating strength deficits when jumping. This is of importance as strength deficits have been associated with RTS.[18,31,46] Lastly, almost 50% of patients fail the one-leg speedy test. This subtest of the BIA test battery is a high demanding hop test requiring knee joint stability in multiple planes and directions.[20] Low passing percentages of the stability tests therefore may explain the high failure rates of the one-leg speedy test of the present study. These findings suggest persistent functional deficits in higher demanding functional performance tests 9 months postoperatively since the results are compared to healthy age and gender matched subjects.

The BIA test battery is a standardized computer-assisted test battery, easy to use and easy to interpret.[20–22] It supports current functional performance tests to evaluate readiness for RTS. Usually, it is used in the final stage of the rehabilitation following ACL reconstruction. Noteworthy, it might also be beneficial to implement sub-tests of the BIA test battery at an earlier stage in rehabilitation. Deviations or deficits might be detected earlier so that physiotherapists can change or optimize their rehabilitation protocol. Further studies are needed to investigate whether implementing the BIA test battery at an earlier stage in the rehabilitation results in higher percentages of patients passing the BIA test battery.

In addition to functional performance tests, patient reported outcome measurements (PROMs) are used to evaluate readiness for RTS.[10–12,31,33,47] Present criteria used for a clearance to RTS are an International Knee Documentation Committee (IKDC) cutoff score of ≥15th percentile from normative data of uninjured athletes (score of ≥85) and an Anterior Cruciate Ligament-Return to Sport after Injury (ACL-RSI) cutoff score >56 [10-12, 31]. In the present study, the mean IKDC and mean ACL-RSI were higher than the cutoff scores in both groups. This indicates for a clearance to RTS in patients that did pass the BIA test battery, but also patients that did not pass the BIA test battery. This is of interest because high PROMs might indicate that patients believe they are ready to resume their sports, but when not passing the BIA test battery still have functional deficits 9 months after ACL reconstruction using BPTB autograft. Therefore, the BIA test battery may be of additional value

Table 3
Back in Action test results.

Test	Very good	Good	Normal	Weak	Very weak
TL-ST	10 (9.7)	11 (10.7)	38 (36.9)	11 (10.7)	33 (32.0)
OL-ST H	9 (8.7)	7 (6.8)	35 (34.0)	19 (18.4)	33 (32.0)
OL-ST I	7 (6.8)	6 (5.8)	37 (35.9)	22 (21.4)	31 (30.1)
TL-CMJ height	27 (26.2)	10 (9.7)	38 (36.9)	8 (7.8)	20 (19.4)
TL-CMJ power	31 (30.1)	17 (16.5)	48 (46.6)	3 (2.9)	4 (3.9)
OL-CMJ height H	63 (61.2)	10 (9.7)	21 (20.4)	5 (4.9)	4 (3.9)
OL-CMJ power H	82 (79.6)	11 (10.7)	10 (9.7)	0 (0.0)	0 (0.0)
OL-CMJ height I	36 (35.0)	8 (7.8)	32 (31.1)	10 (9.7)	17 (16.5)
OL-CMJ power I	61 (59.2)	19 (18.4)	22 (21.4)	1 (1.0)	0 (0.0)
TL-PJ	2 (1.9)	4 (3.9)	47 (45.6)	16 (15.5)	34 (33.0)
OL-SY H	2 (1.9)	6 (5.8)	48 (46.6)	20 (19.4)	27 (26.2)
OL-SY I	4 (3.9)	4 (3.9)	46 (44.7)	13 (12.6)	36 (35.0)
TL-QF	14 (13.6)	14 (13.6)	53 (51.5)	10 (9.7)	12 (11.7)

In one-leg tests, H and I represents the healthy and injured leg, respectively. Results are presented as numbers (n) and percentages (%).

Table 4
Patient reported outcome measurements of the patients included in the study.

	PASSED n = 18	FAILED n = 85	p-value
KOOS	91.1 ± 11.6	91.1 ± 7.8	0.812
IKDC	87.4 ± 12.6	85.1 ± 15.2	0.588
ACL-RSI	69.2 ± 28.4	70.0 ± 23.3	0.618

Results are presented as median ± interquartile range.

to the PROMS to predict safe RTS after ACL reconstruction. On the other hand, it is not clear yet whether resuming sport activities after failing the BIA test battery will result in higher re-rupture rates.

This study has several limitations. Firstly, although a standardized supervised ACL rehabilitation protocol was available for physical therapists, the role of different approaches on the present results could not be ruled out.[24] Secondly, the present study mainly included patients participating in recreational sport activities prior to ACL injury. Higher passing percentages might be observed in professional athlete groups. Thirdly, the BIA test battery uses the LSI to compare one-leg stability, counter movement jump and speedy test scores of the healthy and injured leg. However, LSI frequently overestimates functional performance as studies demonstrated decreased strength and function in the uninvolved leg.[34,35] Fourthly, the quality of movement is not evaluated when using the BIA test battery. This is of importance, as dynamic knee valgus, knee flexion angle and trunk control plays a role in rehabilitation and prevention of ACL (re-)injury.[48–50] Therefore, the authors recommend using qualitative criteria, such as video-assessed knee flexion angles and dynamic knee valgus during jump tests, in addition to the quantitative evaluation of the BIA test battery in the decision-making of safe RTS.

5. Conclusions

A low percentage of patients passed the BIA test battery 9 months after BPTB ACL reconstruction. High PROMs might indicate that patients believe they are ready to resume their sports, but when not passing the BIA test battery still have functional deficits 9 months after ACL reconstruction using BPTB autograft. Therefore, the BIA test battery may be of additional value to the PROMS to predict safe RTS after ACL reconstruction. This study highlights the need for additional rehabilitation as return to sport in a condition of incomplete recovery may increase the risk of re-injury.

Funding

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

CRediT author statements

AE Ronden: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Writing-Original Draft and Editing.

BB Koc: Conceptualization, Methodology, Writing-Original Draft and Editing.

L van Rooij: Investigation, Project administration.

MGM Schotanus: Formal analysis, Writing-Review and Editing.

EJP Jansen: Conceptualization, Writing-Review and Editing, Supervision.

Declaration of competing interest

The authors have declared no conflict of interest.

Acknowledgements

None.

FundingReferences

1. Sanders TL, Maradit Kremers H, Bryan AJ, et al. Incidence of anterior cruciate ligament tears and reconstruction: a 21-year population-based study. *Am J Sports Med*. 2016;44:1502–1507.
2. Ardern CL, Osterberg A, Sonesson S, Gauffin H, Webster KE, Kvist J. Satisfaction with knee function after primary anterior cruciate ligament reconstruction is associated with self-efficacy, quality of life, and returning to the preinjury physical activity. *Arthroscopy*. 2016;32:1631–1638 e1633.
3. Grassi A, Carulli C, Innocenti M, et al. New trends in anterior cruciate ligament reconstruction: a systematic review of national surveys of the last 5 years. *Joints*. 2018;6:177–187.
4. Grevnerts HT, Sonesson S, Gauffin H, Ardern CL, Stålman A, Kvist J. Decision making for treatment after ACL injury from an orthopaedic surgeon and patient perspective: results from the NACOX study. *Orthop J Sports Med*. 2021;9, 23259671211005090.
5. Ardern CL, Taylor NF, Feller JA, Webster KE. Fifty-five per cent return to competitive sport following anterior cruciate ligament reconstruction surgery: an updated systematic review and meta-analysis including aspects of physical functioning and contextual factors. *Br J Sports Med*. 2014;48:1543–1552.
6. King E, Richter C, Jackson M, et al. Factors influencing return to play and second anterior cruciate ligament injury rates in level 1 athletes after primary anterior cruciate ligament reconstruction: 2-year follow-up on 1432 reconstructions at a single center. *Am J Sports Med*. 2020;48:812–824.
7. Lai CCH, Feller JA, Webster KE. Fifteen-Year audit of anterior cruciate ligament reconstructions in the Australian football league from 1999 to 2013: return to play and subsequent ACL injury. *Am J Sports Med*. 2018;46:3353–3360.
8. Grindem H, Snyder-Mackler L, Moksnes H, Engebretsen L, Risberg MA. Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: the Delaware-Oslo ACL cohort study. *Br J Sports Med*. 2016;50:804–808.
9. Bodkin SG, Hertel J, Diduch DR, et al. Predicting anterior cruciate ligament reinjury from return-to-activity assessments at 6 Months postsurgery: a prospective cohort study. *J Athl Train*. 2022;57:325–333.
10. Ardern CL, Taylor NF, Feller JA, Whitehead TS, Webster KE. Psychological responses matter in returning to preinjury level of sport after anterior cruciate ligament reconstruction surgery. *Am J Sports Med*. 2013;41:1549–1558.
11. Logerstedt D, Di Stasi S, Grindem H, et al. 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. *J Orthop Sports Phys Ther*. 2014;44:914–923.
12. Dingenen B, Gokeler A. Optimization of the return-to-sport paradigm after anterior cruciate ligament reconstruction: a critical step Back to move forward. *Sports Med*. 2017;47:1487–1500.
13. Lai CCH, Ardern CL, Feller JA, Webster KE. Eighty-three per cent of elite athletes return to preinjury sport after anterior cruciate ligament reconstruction: a systematic review with meta-analysis of return to sport rates, graft rupture rates and performance outcomes. *Br J Sports Med*. 2018;52:128–138.
14. Kitaguchi T, Tanaka Y, Takeshita S, et al. Importance of functional performance and psychological readiness for return to preinjury level of sports 1 year after ACL reconstruction in competitive athletes. *Knee Surg Sports Traumatol Arthrosc*. 2020;28:2203–2212.
15. Gokeler A, Welling W, Zaffagnini S, Seil R, Padua D. Development of a test battery to enhance safe return to sports after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2017;25:192–199.
16. Sousa PL, Krych AJ, Cates RA, Levy BA, Stuart MJ, Dahm DL. Return to sport: does excellent 6-month strength and function following ACL reconstruction predict midterm outcomes? *Knee Surg Sports Traumatol Arthrosc*. 2017;25:1356–1363.
17. Beischer S, Gustavsson L, Senorski EH, et al. Young athletes who return to sport before 9 Months after anterior cruciate ligament reconstruction have a rate of new injury 7 times that of those who delay return. *J Orthop Sports Phys Ther*. 2020;50:83–90.
18. Kyritsis P, Bahr R, Landreau P, Miladi R, Witvrouw E. 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. *Br J Sports Med*. 2016;50:946–951.
19. Roe C, Jacobs C, Hoch J, Johnson DL, Noehren B. Test batteries after primary anterior cruciate ligament reconstruction: a systematic review. *Sport Health*. 2022;14:205–215.
20. Hildebrandt C, Muller L, Zisch B, Huber R, Fink C, Raschner C. Functional assessments for decision-making regarding return to sports following ACL reconstruction. Part I: development of a new test battery. *Knee Surg Sports Traumatol Arthrosc*. 2015;23:1273–1281.
21. Herbst E, Hoser C, Hildebrandt C, et al. Functional assessments for decision-making regarding return to sports following ACL reconstruction. Part II: clinical application of a new test battery. *Knee Surg Sports Traumatol Arthrosc*. 2015;23:1283–1291.
22. Ebert JR, Edwards P, Currie J, et al. Comparison of the 'Back in action' test battery to standard hop tests and isokinetic knee dynamometry in patients

following anterior cruciate ligament reconstruction. *Int J Sports Phys Ther*. 2018;13:389–400.
23. Csapo R, Pointner H, Hoser C, Gfoller P, Raschner C, Fink C. Physical fitness after anterior cruciate ligament reconstruction: influence of graft, age, and sex. *Sports (Basel)*. 2020;8.
24. van Melick N, van Cingel RE, Brooijmans F, et al. Evidence-based clinical practice update: practice guidelines for anterior cruciate ligament rehabilitation based on a systematic review and multidisciplinary consensus. *Br J Sports Med*. 2016;50:1506–1515.
25. van den Borne MP, Raijmakers NJ, Vanlauwe J, et al. International cartilage repair society (ICRS) and oswestry macroscopic cartilage evaluation scores validated for use in autologous chondrocyte implantation (ACI) and microfracture. *Osteoarthritis Cartilage*. 2007;15:1397–1402.
26. Fetto JF, Marshall JL. Medial collateral ligament injuries of the knee: a rationale for treatment. *Clin Orthop Relat Res*. 1978:206–218.
27. Akada T, Yamaura I, Gupta A, Sakai H, Takahashi K, Tsuchiya A. Partial meniscectomy adversely affects return-to-sport outcome after anatomical double-bundle anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2019;27:912–920.
28. Salavati M, Akhbari B, Mohammadi F, Mazaheri M, Khorrami M. Knee injury and Osteoarthritis Outcome Score (KOOS); reliability and validity in competitive athletes after anterior cruciate ligament reconstruction. *Osteoarthritis Cartilage*. 2011;19:406–410.
29. Slagers AJ, Reininga IH, van den Akker-Scheek I. The Dutch language anterior cruciate ligament return to sport after injury scale (ACL-RSI) - validity and reliability. *J Sports Sci*. 2017;35:393–401.
30. Higgins LD, Taylor MK, Park D, et al. Reliability and validity of the international knee documentation committee (IKDC) subjective knee form. *Joint Bone Spine*. 2007;74:594–599.
31. Welling W, Benjaminse A, Lemmink K, Gokeler A. Passing return to sports tests after ACL reconstruction is associated with greater likelihood for return to sport but fail to identify second injury risk. *Knee*. 2020;27:949–957.
32. Losciale JM, Bullock G, Cromwell C, Ledbetter L, Pietrosimone L, Sell TC. Hop testing lacks strong association with key outcome variables after primary anterior cruciate ligament reconstruction: a systematic review. *Am J Sports Med*. 2020;48:511–522.
33. Welling W, Benjaminse A, Seil R, Lemmink K, Zaffagnini S, Gokeler A. Low rates of patients meeting return to sport criteria 9 months after anterior cruciate ligament reconstruction: a prospective longitudinal study. *Knee Surg Sports Traumatol Arthrosc*. 2018;26:3636–3644.
34. Wellsandt E, Failla MJ, Snyder-Mackler L. Limb symmetry indexes can overestimate knee function after anterior cruciate ligament injury. *J Orthop Sports Phys Ther*. 2017;47:334–338.
35. Hiemstra LA, Webber S, MacDonald PB, Kriellaars DJ. Contralateral limb strength deficits after anterior cruciate ligament reconstruction using a hamstring tendon graft. *Clin Biomech*. 2007;22:543–550.
36. Briggs KK, Lysholm J, Tegner Y, Rodkey WG, Kocher MS, Steadman JR. The reliability, validity, and responsiveness of the Lysholm score and Tegner activity scale for anterior cruciate ligament injuries of the knee: 25 years later. *Am J Sports Med*. 2009;37:890–897.
37. Aghdam HA, Kavyani M, Bosak M, Karimi MT, Motififard M. Evaluation of the stability of the subjects with anterior cruciate injuries reconstruction. *J Knee Surg*. 2021;34:1527–1530.
38. Staples JR, Schafer KA, Smith MV, et al. Decreased postural control in patients undergoing anterior cruciate ligament reconstruction compared to healthy controls. *J Sport Rehabil*. 2019:1–6.
39. Culvenor AG, Alexander BC, Clark RA, et al. Dynamic single-leg postural control is impaired bilaterally following anterior cruciate ligament reconstruction: implications for reinjury risk. *J Orthop Sports Phys Ther*. 2016;46:357–364.
40. Paterno MV, Schmitt LC, Ford KR, et al. Biomechanical measures during landing and postural stability predict second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport. *Am J Sports Med*. 2010;38:1968–1978.
41. Albano TR, Rodrigues CAS, Melo AKP, de Paula PO, Almeida GPL. Clinical decision algorithm associated with return to sport after anterior cruciate ligament reconstruction. *J Athl Train*. 2020;55:691–698.
42. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med*. 2005;33:492–501.
43. Harput G, Tunay VB, Ithurburn MP. Quadriceps and hamstring strength symmetry after anterior cruciate ligament reconstruction: a prospective study. *J Sport Rehabil*. 2020:1–8.
44. Smith AH, Capin JJ, Zarzycki R, Snyder-Mackler L. Athletes with bone-patellar tendon-bone autograft for anterior cruciate ligament reconstruction were slower to meet rehabilitation milestones and return-to-sport criteria than athletes with hamstring tendon autograft or soft tissue allograft : secondary analysis from the ACL-SPORTS trial. *J Orthop Sports Phys Ther*. 2020;50:259–266.
45. Cristiani R, Mikkelsen C, Forssblad M, Engstrom B, Stalman A. Only one patient out of five achieves symmetrical knee function 6 months after primary anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2019;27:3461–3470.
46. Edwards PK, Ebert JR, Joss B, et al. Patient characteristics and predictors of return to sport at 12 Months after anterior cruciate ligament reconstruction: the importance of patient Age and postoperative rehabilitation. *Orthop J Sports Med*. 2018;6, 2325967118797575.
47. Faleide AGH, Magnussen LH, Strand T, et al. The role of psychological readiness in return to sport assessment after anterior cruciate ligament reconstruction. *Am J Sports Med*. 2021;49:1236–1243.
48. Capin JJ, Khandha A, Zarzycki R, Manal K, Buchanan TS, Snyder-Mackler L. Gait mechanics and second ACL rupture: implications for delaying return-to-sport. *J Orthop Res*. 2017;35:1894–1901.
49. Markstrom JL, Tengman E, Hager CK. ACL-reconstructed and ACL-deficient individuals show differentiated trunk, hip, and knee kinematics during vertical hops more than 20 years post-injury. *Knee Surg Sports Traumatol Arthrosc*. 2018;26:358–367.
50. Larwa J, Stoy C, Chafetz RS, Boniello M, Franklin C. Stiff landings, core stability, and dynamic knee valgus: a systematic review on documented anterior cruciate ligament ruptures in male and female athletes. *Int J Environ Res Publ Health*. 2021;18.