

Differences in Strength, Patient-Reported Outcomes, and Return-to-Play Rates Between Athletes With Primary Versus Revision ACL Reconstruction at 9 Months After Surgery

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Background: Patient-reported outcomes and return-to-play (RTP) rates are inferior after revision anterior cruciate ligament reconstruction (ACLR) compared with primary ACLR. Physical properties such as maximal, explosive, and reactive strength influence reinjury and RTP rates after ACLR. No study has compared these outcomes between revision and primary ACLR.

Purpose: To compare maximal, explosive, and reactive strength of the ACLR limb, as well as patient-reported outcomes and RTP rates between primary and revision ACLR at 9 months after surgery.

Study Design: Cohort study; Level of evidence, 2.

Methods: A comparative study was performed at 9 months after surgery for 344 male athletes who had undergone ACLR (298 primary, 46 revision). Maximal strength of the ACLR limb was measured by means of isokinetic dynamometry. Explosive strength was measured by use of single-leg countermovement jump height, and reactive strength was measured by single-leg drop jump. Patient-reported outcomes and responses to RTP questionnaires were recorded for both groups.

Results: The primary ACLR group had higher scores than the revision ACLR group for single-leg countermovement jump height ($P = .02$) and single-leg drop jump reactive strength index ($P = .01$) on the ACLR limb. No significant difference was observed between groups on maximal strength of the quadriceps or hamstring, and no significant difference in limb symmetry index was observed between groups on any strength or jump test. The primary ACLR group demonstrated higher scores on the Marx Activity Rating Scale ($P = .03$) and the Anterior Cruciate Ligament–Return to Sport after Injury scale ($P < .001$). Athletes in the primary ACLR group were more likely to have returned to sport ($P < .001$).

Conclusion: At 9 months after surgery, athletes who had undergone revision ACLR achieved maximal strength similar to that of athletes who had undergone primary ACLR. However, athletes who had revision ACLR demonstrated lower scores on explosive and reactive strength tests. Athletes who underwent revision ACLR had lower RTP rates at 9 months after surgery, potentially due to explosive and reactive strength deficits and lower perceived readiness for RTP.

Keywords: knee ligaments; ACL; physical therapy/rehabilitation; general sports trauma

Anterior cruciate ligament (ACL) injury is a common knee injury, with an incidence of 68.6 per 100,000 person-years.³² ACL injuries are commonly seen during landing and cutting movements in field and court sports.^{20,30} The incidence of ACL rupture has been reported to be as high as 0.32 tears per 1000 exposures in athletes who play sports such as soccer, rugby, and basketball.³¹ ACL reconstruction (ACLR) is often performed to restore structural stability to

the knee and facilitate return to sport. Approximately 75% of ACL ruptures will have ACLR, with this figure even higher in young athletes targeting return to sport.³²

Despite the volume of ACLR carried out annually, outcomes after ACLR can be mixed. Ardern et al³ found that only 55% of athletes managed successful return to competitive sport after primary ACLR (P-ACLR). Reinjury is also a significant concern after ACLR, with reinjury rates shown to be as high as 23% in younger athletes.^{34,36} In athletes who are reinjured and wish to return to sport, a revision ACLR (R-ACLR) is commonly performed. Athletes who undergo R-ACLR have poorer patient-reported outcomes

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at 1 and 5 years after surgery^{1,22} and are significantly less likely to return to their previous level of participation in sport compared with P-ACLR.²² Previous research comparing the 2 groups has focused on scoring of patient-reported outcome measures but has not explored whether the 2 groups perform differently on sport-specific functional tests.²² Deficits in these physical properties may account for the poorer outcomes and the poorer return-to-play (RTP) rates.

Physical properties such as maximum strength, explosive strength, and reactive strength have also been shown to influence reinjury outcomes after ACLR,^{11,21} and it is recommended that objective physical testing be carried out before athletes are cleared for RTP.^{4,26} Isokinetic dynamometry is commonly used to assess quadriceps (QT) and hamstring (HS) strength and to assess strength imbalances between limbs after ACLR.¹⁴ *Explosive strength* (speed strength) refers to the ability to rapidly change from eccentric to concentric muscle action on jumping tasks (duration >250 ms).³⁷ The countermovement jump has been shown to be a valid and reliable measure of lower limb explosive strength in male athletes.²⁴ *Reactive strength* refers to the ability to rapidly change from eccentric to concentric muscle action on plyometric tasks of shorter duration (100–250 ms).³⁷ The drop jump has been shown to be a valid and reliable measure of reactive strength.²⁴ Asymmetries and deficits on the drop jump have been shown to predict dysfunction 2 years after ACLR.¹⁷ A 2018 study by King et al¹⁸ demonstrated the relevance of assessing reactive strength using a single-leg drop jump (SLDJ) to identify deficits after ACLR. Reactive strength capabilities are typically expressed as a reactive strength index (RSI), which involves dividing jump height by ground contact time on a plyometric task.³⁷ RSI has been shown to give a reliable measurement of an athlete's explosive capabilities in plyometric activities.⁹ Despite the importance of physical recovery after ACLR, deficits in maximum strength, explosive strength, and reactive strength have been observed in the operated limb after ACLR when athletes RTP.^{12,18} The current literature does not provide insight as to whether these qualities are worse after R-ACLR, and given that these are trainable qualities, this knowledge could be used to enhance rehabilitation after R-ACLR to result in greater RTP rates and improvements in performance.

Psychological factors and subjective knee function as measured by patient-reported outcomes have also been shown to influence outcomes after ACLR.^{2,27} Instruments such as the International Knee Documentation Committee (IKDC) subjective knee form,^{15,16} the Anterior Cruciate Ligament–Return to Sport after Injury (ACL-RSI) scale,^{2,35} the Cincinnati Knee Score,⁵ and the Marx Activity Rating

Scale²⁵ have been shown to be valid and reliable measures of subjective knee function, perceived readiness to return to sport, and activity levels after ACLR. It has been reported that patient-reported outcomes and RTP rates are lower after R-ACLR.^{1,22} However, to our knowledge, no previous studies have compared physical outcomes relating to maximum strength, explosive strength, and reactive strength between R-ACLR and P-ACLR, which may play some role in the difference in subjective and perceived function between the groups.

The aim of this study was to compare maximum muscular strength and jump performance (explosive and reactive strength) of the ACL-reconstructed limb (ACLR limb) as well as evaluate limb symmetry, patient-reported outcomes, and RTP rates in P-ACLR versus R-ACLR male, field-sport athletes at 9 months after surgery. The 9-month follow-up assessment was selected for this study because this was when participants were most commonly cleared for RTP by their surgeon. It was hypothesized that the R-ACLR group would demonstrate inferior performance of the ACLR limb on objective maximum strength, explosive strength, and reactive strength tests. It was also hypothesized that the R-ACLR group would demonstrate inferior outcomes on patient-reported outcome measures, RTP rates, and level of RTP at 9 months from surgery.

METHODS

Study Design

Participants for this study were recruited from a caseload of 2 specialist orthopaedic surgeons (R.M., M.J.) from January 2014 to December 2016. Individuals who were scheduled to undergo ACLR were invited to participate in the study and were included after informed consent was provided. Ethical approval was granted through the institution's ethics board.

To maintain a homogeneous sample, we defined the study inclusion criteria as male athletes between the ages of 18 and 35 years who played multidirectional field sports, had undergone P-ACLR or R-ACLR, intended to return to the same or higher level of sport than before injury, and returned for their 9-month follow-up assessment after discharge from their surgeon. Exclusion criteria included patients who experienced a contralateral second injury, those who underwent multiligament reconstructive surgery, those who did not intend to return to a similar level of sport compared with before their injury, and those who did not complete their 9-month follow-up assessment. In total, 344 male field-sport athletes who had undergone ACLR

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Ethical approval for this study was obtained from the Sports Surgery Clinic Research Ethics Committee (ref No. 25-AFM-010).

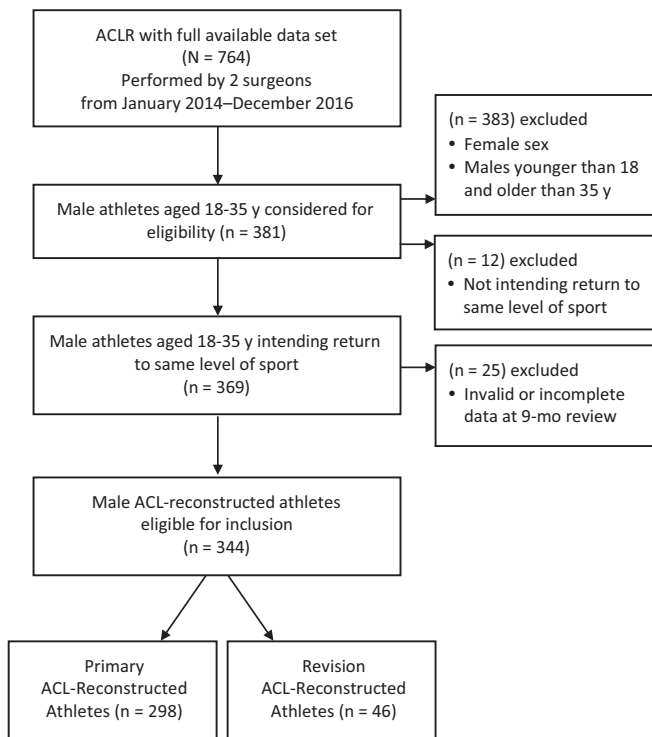


Figure 1. Distribution of groups. ACL, anterior cruciate ligament; ACLR, ACL reconstruction.

were included in the analysis (298 P-ACLR and 46 R-ACLR) (Figure 1). Descriptive data for the cohort are reported in Table 1.

After recruitment into the study, all participants completed a preoperative questionnaire providing details on their mechanism of injury, sports played, and the level of sport to which they planned to return. Arthroscopic ACLR was performed in all cases in a standardized fashion with grafts placed within the remnant footprints. All R-ACLR procedures were performed as a 1-stage procedure. Graft choice varied between bone–patellar tendon–bone (BPTB) and HS (gracilis/semitendinosus double bundle) in the P-ACLR group (252 BPTB, 46 HS) and BPTB, HS, and QT in the R-ACLR group (22 BPTB, 17 HS, 7 QT). An extra-articular tenodesis using the iliotibial band was performed where deemed appropriate by the operating surgeon, in a total of 11 cases (2 P-ACLR and 9 R-ACLR) (Table 1).

Owing to geographical limitations and sample size, athletes were rehabilitated by their own physiotherapist locally. They were advised to see their physiotherapist approximately every 2 to 3 weeks over the duration of their rehabilitation, and a rehabilitation protocol was provided to all participating physiotherapists. Participants presented to the facility for follow-up functional testing at 3, 6, and 9 months after surgery, at which time progress was assessed subjectively through patient-reported outcomes and objectively through maximum strength, explosive strength, and reactive strength tests. Patient-reported outcome measures and information on RTP status were also collected at this assessment.

TABLE 1
Descriptive Data for the Cohort^a

Variable	Primary ACLR (n = 298)	Revision ACLR (n = 46)
Age, y	24.16 ± 4.6	24.9 ± 3.93
Height, cm	179.7 ± 6.11	180.1 ± 6.2
Weight, kg	82.8 ± 10.2	83.0 ± 7.4
Graft type		
Bone–patellar tendon–bone	252 (84.5)	22 (47.8)
Quadriceps tendon	0	7 (15.2)
Hamstring tendon	46 (15.5)	17 (37)
Extra-articular tenodesis	2 (0.7)	9 (19.6)
Days from surgery to 9-month assessment	280 ± 18	282 ± 16
Primary sport		
Gaelic football	140 (47)	26 (56.5)
Hurling	52 (17.4)	5 (10.9)
Soccer	61 (20.5)	11 (23.9)
Rugby	45 (15.1)	4 (8.7)
Target activity level at return to play		
Same level	223 (74.8)	36 (78.2)
Higher level	75 (25.2)	10 (21.8)

^aValues are expressed as mean ± SD or n (%). ACLR, anterior cruciate ligament reconstruction.

Testing Procedure

Athletes performed a standardized 5-minute dynamic warm-up before testing. The non-ACL reconstructed (non-ACLR) limb was always tested first. Isokinetic dynamometry was conducted by use of the Humac Norm Isokinetic Extremity System (Computer Sports Medicine) to measure QT and HS strength. Following the guidelines published in a recent systematic review,³³ we used a protocol of 5 repetitions of concentric knee extension and flexion at an angular velocity of 60 deg/s, at a set range of motion of 0° to 100° using gravity correction. Athletes were given a practice set to familiarize themselves with the machine and the procedure before completing 2 test sets. Of these 2 sets, the set with the lowest interrepetition coefficient of variance was selected as an athlete’s maximum strength score to ensure optimum accuracy. Strength measures of the QT and HS were recorded in terms of peak torque (N·m) as a percentage of the participant’s bodyweight in kilograms [(Peak Torque ÷ Bodyweight) × 100] per O’Malley et al.²⁹ Limb symmetry index (LSI) was then calculated for both QT and HS strength by dividing the ACLR limb score by that of the non-ACLR limb and multiplying the outcome by 100.

Lower limb explosive strength was evaluated by analyzing jump height on the single-leg countermovement jump (SLCMJ). Reactive strength was evaluated through analysis of the SLDJ. Testing was conducted in a 3-dimensional (3D) motion capture laboratory using an 8-camera 3D motion analysis system (Bonita B10; Vicon), synchronized with two 40 × 60-cm force platforms (BP400600; AMTI). Vicon Nexus software (Version 1.8.2; Vicon) simultaneously collected and analyzed the force data at 1000 Hz. Kinetic and kinematic

TABLE 2
Descriptive Data for Outcome Variables^a

Outcome Variable	Group	Mean ± SD	P Value	Effect Size	95% CI
Isokinetic dynamometry					
ACLR limb quadriceps peak torque % bodyweight	Primary	224.00 ± 46.64	.52	-0.10	-18.97 to 9.58
	Revision	228.70 ± 39.97			
ACLR limb hamstring peak torque % bodyweight	Primary	153.28 ± 29.25	.19	0.21	-3.02 to 15.14
	Revision	147.22 ± 28.39			
Quadriceps strength LSI	Primary	83.91 ± 14.11	.23	-0.11	-7.0 to 2.0
	Revision	86.91 ± 11.62			
Hamstring strength LSI	Primary	96.97 ± 13.74	.54	0.06	-3.0 to 6.0
	Revision	95.24 ± 16.52			
ACLR limb single-leg drop jump RSI	Primary	0.35 ± 0.13	.01	0.23	0.01 to 0.09
	Revision	0.30 ± 0.11			
ACLR limb single-leg drop jump RSI (LSI)	Primary	77.19 ± 19.36	.31	0.09	-3.0 to 9.0
	Revision	73.00 ± 21.09			
ACLR limb single-leg countermovement jump height, cm	Primary	12.14 ± 3.24	.02	0.39	0.252 to 0.274
	Revision	10.88 ± 3.27			
Single-leg countermovement jump height (LSI)	Primary	85.40 ± 15.31	.78	0.03	-4.0 to 6.0
	Revision	84.76 ± 20.35			
Patient-reported outcomes					
ACL-RSI scale	Primary	75.49 ± 15.89	<.001	0.51	12.5 to 25.0
	Revision	55.88 ± 22.93			
IKDC subjective knee form	Primary	82.85 ± 9.69	.15	0.13	-1.0 to 5.2
	Revision	79.65 ± 12.27			
Marx Activity Rating Scale	Primary	11.49 ± 3.05	.03	0.2	3.2 to 2.0
	Revision	10.50 ± 3.29			
Cincinnati Knee Score	Primary	90.37 ± 8.68	.16	0.13	-0.7 to 4.3
	Revision	88.68 ± 8.67			
Return to play					
Return to preinjury level of sport ^b	Primary	164/298 (55)	<.001		
	Revision	12/46 (26)			

^aBolded *P* values indicate statistically significant differences between the primary and revision ACLR groups ($P < .05$). ACL, anterior cruciate ligament; ACLR, ACL reconstruction; ACL-RSI, Anterior Cruciate Ligament–Return to Sport after Injury scale; IKDC, International Knee Documentation Committee; LSI, limb symmetry index; RSI, reactive strength index. Peak torque % bodyweight was calculated as follows: $[Peak Torque (N\cdot m) \div Bodyweight (kg)] \times 100$. LSI was calculated as follows: $(Operated Limb \div Nonoperated Limb) \times 100$.

^bValues are expressed as n/N (%).

data were collected, but only the kinetic data were reported in this study. Jump height on the countermovement jump was calculated through use of the momentum impulse relationship.²³ Athletes executed 3 practice repetitions before performing 3 recorded maximal efforts on each leg, starting with the non-ACLR limb. Athletes kept their hands on their hips in all cases for consistency. The best jump height from the recorded valid trials was used in the analysis. A similar testing protocol was used for evaluation of reactive strength on the SLDJ, which was carried out from a 20-cm box.¹⁸ Athletes were instructed to “spend as little time as possible on the ground” and “jump as high as possible.” Jump height and ground contact time were recorded. RSI for the drop jump was calculated by dividing jump height by ground contact time.³⁷ The LSI was calculated for both the SLCMJ and SLDJ to report any interlimb differences in explosive and reactive strength.

Statistical Analysis

A Shapiro-Wilk test was used to test for normal distribution of the data. The P-ACLR and R-ACLR groups were

compared on each variable. An independent-samples Student *t* test was used to analyze parametric variables, whereas a Mann-Whitney *U* test was used to analyze non-parametric variables. A chi-square test was used to analyze distribution of the RTP rates between the 2 groups. All statistical analysis was conducted through JASP statistical analysis (Version 0.8.6). Where appropriate, effect sizes were reported; an effect size threshold of $d \geq 0.2$ was categorized as small, $d \geq 0.5$ was categorized as medium, and $d \geq 0.8$ was categorized as large.⁶

RESULTS

No significant difference was seen on the ACLR limb between groups in QT or HS peak torque relative to bodyweight (Table 2), and no significant difference was found between groups in relation to QT or HS LSI. A significant difference between the R-ACLR and P-ACLR groups was noted in SLDJ performance on the ACLR limb, although the effect size was small, with the R-ACLR group demonstrating a lower RSI on the ACLR limb ($P = .01$). A small

effect size difference was also seen between the 2 groups in relation to SLCMJ height on the ACLR limb, with the R-ACLR group producing lower jump heights than the P-ACLR group ($P = .02$). No significant difference was observed between groups in relation to LSI of SLCMJ and SLDJ height or RSI of SLDJ.

In relation to patient-reported outcomes, a significant difference was noted, with medium effect size, between the 2 groups on the ACL-RSI questionnaire ($P < .001$), with the R-ACLR group demonstrating lower scores than the P-ACLR group. As well, a significant difference was found between groups, with small effect size, in the Marx Activity Rating Scale ($P = .03$), with the R-ACLR group reporting lower scores. No significant difference between the 2 groups was noted on the Cincinnati Knee Score or the IKDC at 9 months after surgery. A significant difference was found between groups relating to return to sports (Table 2), with the R-ACLR group reporting lower RTP rates ($P < .001$). In the P-ACLR group, 55% of athletes had returned to play by 9 months after surgery, whereas only 26% of the R-ACLR athletes reported doing so.

DISCUSSION

This study demonstrated that athletes who underwent R-ACLR performed significantly worse than those who underwent P-ACLR on jump tests measuring explosive strength and reactive strength of their ACLR limb, despite there being no difference between the 2 groups in relation to QT or HS strength of the ACLR limb. Patient-reported outcomes were also significantly different between the 2 groups for the Marx Activity Rating Scale (small effect size) and the ACL-RSI (medium effect size), with lower scores in the R-ACLR group for both despite no between-group difference on the IKDC and Cincinnati questionnaires. This combination of reduced explosive and reactive strength alongside lower perceived readiness to RTP may contribute to the lower RTP rates and activity levels in the R-ACLR group at 9 months after surgery, and additional targeting of these qualities during rehabilitation may improve outcomes.

Dauty et al⁷ also demonstrated that strength deficits in the ACLR limb after R-ACLR were similar to those observed after P-ACLR. However, our findings differ from those of Gifstad et al,¹⁰ who reported lower isokinetic QT and HS strength on the ACLR limb in R-ACLR compared with P-ACLR. No studies have previously compared explosive and reactive strength between R-ACLR and P-ACLR groups. Prior research has shown that single-leg explosive strength and reactive strength qualities are related to running speed and change of direction performance⁸ and form a key component of ACL injury prevention programs.^{13,28} The current study demonstrated lower scores for single-leg explosive strength (SLCMJ height) and single-leg reactive strength (SLDJ) on the ACLR limb after R-ACLR despite there being no difference in LSI between groups. Neither group achieved >90% LSI on SLCMJ, SLDJ, or QT maximal strength tests, indicating that neither group achieved RTP criteria identified in previous research. As well, no

significant difference was seen in LSI between the 2 groups on any of the tests, despite the R-ACLR group demonstrating significantly smaller absolute scores on jumping tasks. This raises a possibility that R-ACLR athletes may experience a chronic deconditioning effect in not only their ACLR limb but also their non-ACLR limb. In summary, although R-ACLR participants regained similar levels of QT and HS strength at 9 months after surgery, they had yet to regain similar explosive and reactive strength qualities relative to their P-ACLR counterparts. This suggests that R-ACLR athletes place a greater emphasis on development of these qualities throughout their end-stage rehabilitation.

This study also reported differences between groups in relation to the ACL-RSI questionnaire, with the R-ACLR group scoring lower than the P-ACLR on this scale. The ACL-RSI is a patient-reported outcome measure that focuses on analyzing the athlete's perceived readiness to return to sport. The lower score seen in the R-ACLR group highlights the potential additional psychological impact that a second ACL injury can have on an athlete's perceived readiness to RTP at the same stage after surgery as P-ACLR. Given the high physical, psychological, and financial cost of ACLR, these differences are understandable. Previous studies have demonstrated that psychological readiness to return to sport (as measured by the ACL-RSI) is the variable most associated with returning to preinjury level of participation in sport.² Ardern et al² reported that the 3 most common reasons athletes do not RTP after ACLR are lack of trust in the knee, fear of reinjury, and poor knee function. Our findings are in agreement with a 2017 study by Lefevre et al,²² who also related poorer outcomes on the ACL-RSI along with poorer RTP rates in their R-ACLR group compared with their P-ACLR group (49.1% vs 63.6% RTP) at 1 year after surgery. We observed a significantly lower RTP rate at 9 months after surgery in the R-ACLR group compared with the P-ACLR group, in keeping with the lower scores reported on the ACL-RSI scale and the Marx Activity Rating Scale. This occurred despite no difference between groups on self-reported knee function in the IKDC and Cincinnati questionnaires. In our cohort, 55% of the P-ACLR group had succeeded in returning to their sport at 9 months compared with 26% of the R-ACLR group. Both the reduced perceived readiness to RTP and deficits in explosive and reactive strength may have contributed to this lower RTP rate and activity levels at 9 months after R-ACLR.

These findings suggest that clinicians treating R-ACLR athletes who intend to return to sport may need to inform athletes that their recovery may take longer than after their primary reconstruction. There is also the possibility that clinicians, surgeons, and athletes are more cautious about returning to sport after the second injury, and this could account for the delayed RTP times in this group. Clinicians should direct end-stage rehabilitation toward targeted strategies to improve jump performance through specific jump and plyometric training to address deficits in explosive and reactive strength in this cohort. These R-ACLR athletes may also need more exposure to sport-specific and match-specific practice before they RTP to address their fears about reinjury.

Limitations

Cohort size differed between the P-ACLR and R-ACLR groups. This was due to the lower incidence of R-ACLR surgery, and future studies should look to obtain larger numbers of R-ACLR athletes. Objective knee laxity was not measured using a device such as the KT-1000 arthrometer. There is a possibility that knee laxity could be more evident in the R-ACLR group, thereby affecting performance on dynamic tasks. Although the relatively homogeneous participant group (male field-sport athletes between the ages of 18 and 35 years) is undoubtedly a strength of this study, we cannot transpose our results to different participant groups such as female or adolescent athletes. In addition, the study examined only the performance qualities of maximum, explosive, and reactive strength, without examining the movement patterns with which these tests were executed. Previous research has suggested that biomechanical deficits can be evident in the absence of jump performance deficits, and biomechanical analysis may demonstrate physical differences between the 2 groups not highlighted by the performance measures used.¹⁹ Future research should examine biomechanical differences between groups and the influence of interventions specifically targeting explosive and reactive strength after R-ACLR on RTP, activity levels, and self-perceived readiness for RTP.

CONCLUSION

This study demonstrated deficits in explosive and reactive strength in the ACLR limb of patients in the R-ACLR group compared with the P-ACLR group at 9 months after surgery. Participants who had undergone R-ACLR had lower RTP rates, lower self-perceived readiness to RTP (ACL-RSI scores), and lower activity levels (Marx Activity Rating Scale scores), despite there being no between-group difference in QT and HS strength. This study suggests that R-ACLR athletes target additional explosive and reactive strength exercises during rehabilitation as well as strategies to improve perceived readiness to RTP, which may improve activity levels and RTP rates, compared with P-ACLR groups. These findings may influence the management strategies of the clinician aiming to return an athlete to multidirectional field sport after R-ACLR.

REFERENCES

- Anand BS, Feller JA, Richmond AK, Webster KE. Return-to-sport outcomes after revision anterior cruciate ligament reconstruction surgery. *Am J Sports Med.* 2016;44(3):580-584.
- Ardern CL, Österberg A, Tagesson S, Gauffin H, Webster KE, Kvist J. The impact of psychological readiness to return to sport and recreational activities after anterior cruciate ligament reconstruction. *Br J Sports Med.* 2014;48(22):1613-1619.
- 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(21):1543-1552.
- Barber-Westin SD, Noyes FR. Objective criteria for return to athletics after anterior cruciate ligament reconstruction and subsequent reinjury rates: a systematic review. *Phys Sportsmed.* 2011;39(3):100-110.
- Barber-Westin SD, Noyes FR, McCloskey JW. Rigorous statistical reliability, validity, and responsiveness testing of the Cincinnati knee rating system in 350 subjects with uninjured, injured, or anterior cruciate ligament-reconstructed knees. *Am J Sports Med.* 1999;27(4):402-416.
- Cohen J. *Statistical Analysis for the Behavioural Sciences.* New York: Academic Press Inc. 1988.
- Dauty M, Menu P, Fouasson-Chailloux A, Dubois C. Muscular isokinetic strength recovery after knee anterior cruciate ligament reconstruction revision: preliminary study. *Ann Phys Rehabil Med.* 2014;57(1):55-65.
- Delaney JA, Scott TJ, Ballard DA, et al. Contributing factors to change-of-direction ability in professional rugby league players. *J Strength Cond Res.* 2015;29(10):2688-2696.
- Flanagan EP, Ebben WP, Jensen RL. Reliability of the reactive strength index and time to stabilization during depth jumps. *J Strength Cond Res.* 2008;22(5):1677-1682.
- Gifstad T, Drogset JO, Viset A, Grøntvedt T, Hortemo GS. Inferior results after revision ACL reconstructions: a comparison with primary ACL reconstructions. *Knee Surg Sports Traumatol Arthrosc.* 2013;21(9):2011-2018.
- 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(13):804-808.
- Gustavsson A, Neeter C, Thomeé P, et al. A test battery for evaluating hop performance in patients with an ACL injury and patients who have undergone ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2006;14(8):778-788.
- Hewett TE, Ford KR, Myer GD. Anterior cruciate ligament injuries in female athletes: part 2, a meta-analysis of neuromuscular interventions aimed at injury prevention. *Am J Sports Med.* 2006;34(3):490-498.
- Impellizzeri FM, Bizzini M, Rampinini E, Cereda F, Maffiuletti NA. Reliability of isokinetic strength imbalance ratios measured using the Cybex NORM dynamometer. *Clin Physiol Funct Imaging.* 2008;28(2):113-119.
- Irrgang JJ, Anderson AF, Boland AL, et al. Development and validation of the International Knee Documentation Committee subjective knee form. *Am J Sports Med.* 2001;29(5):600-613.
- Irrgang JJ, Anderson AF, Boland AL, et al. Responsiveness of the International Knee Documentation Committee subjective knee form. *Am J Sports Med.* 2006;34(10):1567-1573.
- Ithurburn MP, Paterno MV, Ford KR, Hewett TE, Schmitt LC. Young athletes after anterior cruciate ligament reconstruction with single-leg landing asymmetries at the time of return to sport demonstrate decreased knee function 2 years later. *Am J Sports Med.* 2017;45(11):2604-2613.
- King E, Richter C, Franklyn-Miller A, et al. Whole body biomechanical differences between limbs exist 9 months after ACL reconstruction across jump/landing tasks. *Scand J Med Sci Sports.* 2018;28(12):2567-2578.
- King E, Richter C, Franklyn-Miller A, Wadey R, Moran R, Strike S. Back to normal symmetry? Biomechanical variables remain more asymmetrical than normal during jump and change-of-direction testing 9 months after anterior cruciate ligament reconstruction. *Am J Sports Med.* 2019;47(5):1175-1185.
- Krosshaug T, Nakamae A, Boden BP, et al. Mechanisms of anterior cruciate ligament injury in basketball: video analysis of 39 cases. *Am J Sports Med.* 2007;35(3):359-367.
- 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(15):946-951.
- Lefevre N, Klouche S, Mirouse G, Herman S, Gerometta A, Bohu Y. Return to sport after primary and revision anterior cruciate ligament

- reconstruction: a prospective comparative study of 552 patients from the FAST cohort. *Am J Sports Med.* 2017;45(1):34-41.
23. Linthorne NP. Analysis of standing vertical jumps using a force platform. *Am J Phys.* 2001;69(11):1198-1204.
 24. Markovic G, Dizdar D, Jukic I, Cardinale M. Reliability and factorial validity of squat and countermovement jump tests. *J Strength Cond Res.* 2004;18(3):551-555.
 25. Marx RG, Stump TJ, Jones EC, Wickiewicz TL, Warren RF. Development and evaluation of an activity rating scale for disorders of the knee. *Am J Sports Med.* 2001;29(2):213-218.
 26. Müller U, Krüger-Franke M, Schmidt M, Rosemeyer B. Predictive parameters for return to pre-injury level of sport 6 months following anterior cruciate ligament reconstruction surgery. *Knee Surg Sports Traumatol Arthrosc.* 2015;23(12):3623-3631.
 27. Myklebust G, Engebretsen L, Brækken IH, Skjølberg A, Olsen OE, Bahr R. Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clin J Sport Med.* 2003;13(2):71-78.
 28. Olsen OE, Myklebust G, Engebretsen L, Bahr R. Injury mechanisms for anterior cruciate ligament injuries in team handball: a systematic video analysis. *Am J Sports Med.* 2004;32(4):1002-1012.
 29. O'Malley E, Richter C, King E, et al. Countermovement jump and isokinetic dynamometry as measures of rehabilitation status after anterior cruciate ligament reconstruction. *J Athl Train.* 2018;53(7):687-695.
 30. Prodromos CC, Han Y, Rogowski J, Joyce B, Shi K. A meta-analysis of the incidence of anterior cruciate ligament tears as a function of gender, sport, and a knee injury-reduction regimen. *Arthroscopy.* 2007;23(12):1320-1325.
 31. 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(6):1502-1507.
 32. Undheim MB, Cosgrave C, King E, et al. Isokinetic muscle strength and readiness to return to sport following anterior cruciate ligament reconstruction: is there an association? A systematic review and a protocol recommendation. *Br J Sports Med.* 2015;49(20):1305-1310.
 33. Van Melick N, Van Cingel REH, 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(24):1506-1515.
 34. Webster KE, Feller JA. Exploring the high reinjury rate in younger patients undergoing anterior cruciate ligament reconstruction. *Am J Sports Med.* 2016;44(11):2827-2832.
 35. Webster KE, Feller JA, Lambros C. Development and preliminary validation of a scale to measure the psychological impact of returning to sport following anterior cruciate ligament reconstruction surgery. *Phys Ther Sport.* 2008;9(1):9-15.
 36. Wiggins AJ, Grandhi RK, Schneider DK, Stanfield D, Webster KE, Myer GD. Risk of secondary injury in younger athletes after anterior cruciate ligament reconstruction. *Am J Sports Med.* 2016;44(7):1861-1876.
 37. Young WB. Laboratory strength assessment of athletes. *New Stud Athl.* 1995;10(1):89-96.