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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

OBJECTIVE: To investigate the association between sustaining a second anterior cruciate ligament (ACL) injury and (1) time to return to sport, (2) symmetrical muscle function, and (3) symmetrical quadriceps strength at the time of return to sport in young athletes after primary ACL reconstruction.

DESIGN: Prospective cohort study.

METHODS: Patient demographics and results from 5 tests of muscle function (2 strength tests and 3 hop tests) were extracted from a rehabilitation registry. A questionnaire was sent to athletes (15-30 years old) who were involved in knee-strenuous sport before the injury and had undergone primary ACL reconstruction to determine time of return to knee-strenuous sport (preinjury Tegner Activity Scale score of 6 or greater). We used the Cox proportional hazard regression model to analyze time to event.

RESULTS: One hundred fifty-nine (32% of the initial sample) athletes (mean ± SD age, 21.5 ± 4.4 years; 64% female) were included. Athletes with a higher preinjury Tegner Activity Scale score had a higher rate of second ACL injury (hazard ratio = 2.1; 95% confidence interval: 1.2, 3.6; $P<.01$). Athletes who returned to knee-strenuous sport before 9 months after reconstruction had a higher rate of second ACL injury (hazard ratio = 6.7; 95% confidence interval: 2.6, 16.7; $P<.001$). There was no association between symmetrical muscle function or quadriceps strength and second ACL injury.

CONCLUSION: Returning to knee-strenuous sport before 9 months after ACL reconstruction was associated with an approximately 7-fold increased rate of sustaining a second ACL injury. Achieving symmetrical muscle function or quadriceps strength was not associated with new ACL injury in young athletes. *J Orthop Sports Phys Ther 2020;50(2):83-90. doi:10.2519/jospt.2020.9071*

KEY WORDS: *adolescent, rehabilitation, subsequent ACL injury*

Approximately 1 in 4 patients who are 25 years of age or younger and return to high-risk sport (eg, soccer and team handball) after primary anterior cruciate ligament (ACL) reconstruction sustain a second ACL injury.[28] Given that younger patients return to sport after ACL reconstruction in greater numbers than older patients, their greater exposure may explain the elevated reinjury risk.[3,4,17,27]

There are conflicting findings regarding the relationship between passing specific return-to-sport tests and the risk of second ACL injury.[10,15,19] Among youth athletes with a mean age of 17 years, there were no differences in strength and hop performance at the time of return-to-sport clearance between those who successfully resumed their preinjury sports participation and those who sustained a second ACL injury.[15] Professional athletes who did not meet 6 discharge criteria before returning to sport had 4 times the risk of graft rupture compared to their peers who met the discharge criteria.[19] In addition, patients with more symmetrical quadriceps strength and who returned to sport at least 9 months after surgery had an 84% reduction in the rate of knee injuries.[10]

Key considerations when interpreting previous research on the relationship between passing return-to-sport discharge criteria and second ACL injury include the heterogeneous populations (eg, profession-

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al athletes,[19] youth athletes,[15] recreational athletes[10]) and heterogeneous outcomes (eg, graft ruptures[19] or all knee-related reinjuries[10]) evaluated in previous studies. There remain unanswered questions about the protective effects of delaying return to sport and achieving symmetrical muscle function for young athletes involved in knee-strenuous sport, especially because of the low proportion of young athletes who achieve symmetrical muscle function prior to returning to sport.[4,25]

The aim of this study was to investigate the association between sustaining a second ACL injury and (1) time to return to sport, (2) symmetrical muscle function, and (3) symmetrical quadriceps strength at the time of return to sport in young athletes after primary ACL reconstruction. In addition, the association between demographics and sustaining a second ACL injury was assessed.

METHODS

This prospective observational study was based on data from an ACL rehabilitation outcome registry, "Project ACL."[4,12] All patients received written information about the study, and informed consent was obtained. The data were coded, and none of the included athletes could be identified during analyses. Ethical approval was obtained from the Regional Ethical Review Board in Gothenburg (registration numbers 265-13, T023-17). All data were extracted from the Project ACL database on November 8, 2018.

Patients

We included patients with primary ACL reconstruction (surgery between March 2013 and December 2017) who were aged between 15 and 30 years at time of surgery and active in knee-strenuous sport before ACL injury (preinjury Tegner Activity Scale[24] score of 6 or greater). We excluded patients who had more than 1 subsequent ACL injury registered in the Project ACL database, who had any complication during the muscle function tests that was considered to have influenced the results (eg, muscle strain or knee pain), or who did not respond to the study-specific questionnaire (**TABLE 1**).

Independent Variables

Time to Return to Sport We sent an online questionnaire (**TABLE 1**) to athletes in the Project ACL database who had performed muscle function tests at the 8-, 12-, and 18-month follow-ups. Our questionnaire included the question, "Have you, since your primary ACL reconstruction, reached any of these levels of physical activity?" (yes/no) (**TABLE 1**). If the athlete answered "yes," then he or she was asked, "Please specify when [month/year] you returned to at least level 6" (on the Tegner Activity Scale). We calculated the variable "time (months) of return to knee-strenuous sport" based on the questionnaire responses. We pilot tested the questionnaire with 10 patients with ACL injury (not included in the study) to improve face validity, and made no changes to the questionnaire.

The online questionnaire was sent to 494 athletes who had fulfilled the inclusion criteria. The athletes who did not respond to the questionnaire received up to 2 reminders by text message within a week of first contact, followed by up to 2 reminders by e-mail. Finally, nonresponders were contacted by telephone. A total of 344 athletes responded.

Achieving Symmetrical Muscle Function Data from strength and hop tests from the follow-up closest to return to sport were extracted from the Project ACL database (**TABLE 2**).

All athletes completed a test battery of 2 strength tests (either isokinetic or isometric knee extension and knee flexion, reflecting quadriceps and hamstring strength) and 3 single-leg hop tests. Before completing the test battery, athletes had to fulfill the following criteria: minimal knee pain, minimal knee effusion, performed single-leg exercise without

TABLE 1 Project-Specific Questionnaire Regarding Return to Sport

1. Have you, since your primary anterior cruciate ligament reconstruction, reached any of these levels of physical activity? (yes/no)
   If yes:
   1a. Please specify when you returned to at least level 6 (month/year)

Tegner Activity Scale Levels 6 to 10 and Corresponding Sports
Level 6: baseball, hurdling, orienteering, snowboarding
Level 7: badminton, high jump, tennis, downhill skiing, volleyball
Level 8: basketball, handball, floorball, long jump
Level 9: football, ice hockey, mogul skiing
Level 10: football: national or international level, American football, wrestling, figure skating

TABLE 2 Follow-ups and Number of Athletes Included in the Analysis, With Respect to Time to RTS

Time to RTS, mo	Month Data Were Extracted	Included Athletes (n = 159), n (%)
7-11	8	101 (63.5)
12-17	12	40 (25.2)
18-23	18	13 (8.2)
24-35	24	4 (2.5)
≥36	36	1 (0.6)

Abbreviation: RTS, return to sport.

perceiving new or increased symptoms, and trained single-leg maximal hop tests with their responsible physical therapist outside the testing environment for Project ACL data collection. At the time of follow-up, the test leader assessed the patient's health status to ensure that he or she was well prepared to perform the tests.

The test procedure, including a warm-up procedure, familiarization, and maximum repetitions in both strength and hop tests, has been described in detail in previous studies (**TABLE 3**).[4,13] The results from the strength and hop tests were expressed as the limb symmetry index (LSI), defined as the ratio between the injured side and the uninjured side and expressed as a percentage. Symmetrical muscle function was defined as achieving an LSI of 90% or greater in all 5 tests of muscle function.

The LSI for the strength tests was calculated from isometric tests of quadriceps strength and hamstring strength using the F200 DMS-EVE (David Health Solutions Ltd, Helsinki, Finland) and from isokinetic concentric strength tests of the quadriceps and hamstrings using the Biodex System 4 (Biodex Medical Systems, Shirley, NY). In our study, the isometric tests contributed to 9% of the total muscle strength LSI data. Isometric and isokinetic strength tests are highly reliable (intraclass correlation coefficient = 0.91-0.99).[1,7,21,23]

After the strength testing, the participants performed 3 single-leg hop tests in the following order: vertical hop, hop for distance, and side hop.[4,13] High test-retest reliability for the 3 different tests in the battery of hop tests has been reported (intraclass correlation coefficient = 0.93-0.97).[11]

Patient Characteristics

We extracted age at primary ACL reconstruction, sex, anthropometric data, and preinjury Tegner Activity Scale score from the Project ACL database.

Outcome

The primary outcome was sustaining a subsequent ACL injury (yes/no). The injuries were confirmed by the treating physical therapist or orthopaedic surgeon. There were no specific criteria to verify the ACL injury. No maximum time of follow-up was determined. Data regarding subsequent ACL injury were extracted from the Project ACL database, comprising the number of ACL injuries, date of the subsequent ACL injury, and side of injury.

Statistical Analysis

Statistical analysis was performed using the SAS statistical analysis system (SAS/STAT Version 14.2; SAS Institute Inc, Cary, NC). Descriptive statistics for patient demographics and outcomes were reported with count and proportion for categorical variables. Continuous variables were reported with mean, SD, median, and range.

For comparisons between athletes with complete data and those lost to follow-up, we used the Fisher exact test (lowest 1-sided *P* value multiplied by 2) for dichotomous variables, the Mantel-Haenszel chi-square exact test for ordered categorical variables, and the Mann-Whitney *U* test for continuous variables.

We used a Cox proportional hazard regression model for the analyses of time to second ACL injury, with time to return to sport, symmetrical muscle function, symmetrical quadriceps strength, and demographics as independent variables. Time to return to sport was dichotomized into less than 9 months and 9 months or greater.[10] Time 0 was defined as the first month of participation in sports equal to knee-strenuous sport (ie, a Tegner Activity Scale score of 6 or greater). Symmetrical muscle function was defined as achieving an LSI of 90% or greater in all 5 tests of muscle function. Symmetrical quadriceps strength was defined as achieving an LSI of 90% or greater in quadriceps strength. Hazard ratios (HRs) were calculated for descriptive purposes.

Data were checked for nonproportionality using the supremum test for proportional hazards assumption, and by introducing a time-dependent covariate (the interaction between the

TABLE 3 Tests of Muscle Function[a]

	Knee Angle, deg	Practice Trials, n (% 1-RM)	Maximum Repetitions, n	Rest Between Repetitions, s
Knee extension			3-5	40
Isometric[b]	60	3 (70, 80, 90)		
Isokinetic[c]	0-90	1-2 (90)		
Knee flexion			3-5	40
Isometric[d]	30	3 (70, 80, 90)		
Isokinetic[c]	0-90	1-2 (90)		
Single-leg vertical hop[e]	...	2	3	20-30
Single-leg hop for distance	...	2	3	20-30
Single-leg side hop[f]	...	10	1	180

Abbreviation: RM, repetition maximum.

[a]*Modified under a Creative Commons CC-BY-NC license (https://creativecommons.org/licenses/by-nc/4.0/) with permission from Beischer S, Hamrin Senorski E, Thomeé C, Samuelsson K, Thomeé R. Knee strength, hop performance and self-efficacy at 4 months are associated with symmetrical knee muscle function in young athletes 1 year after an anterior cruciate ligament reconstruction. BMJ Open Sport Exerc Med. 2019;5:e000504. https://doi.org/10.1136/bmjsem-2018-000504*

[b]*Measured with the F200 DMS-EVE (David Health Solutions Ltd, Helsinki, Finland).*

[c]*Measured with the Biodex System 4 (Biodex Medical Systems, Shirley, NY) at 90°/s.*

[d]*Measured with the F300 DMS-EVE (David Health Solutions Ltd).*

[e]*Measured with MUSCLELAB (Ergotest Innovation AS, Porsgrunn, Norway).*

[f]*As many hops as possible in 30 seconds over 2 lines 40 cm apart.*

independent variable of time to return to sport and the time variable of time from return to sport). To compare models, generalized R^2 was calculated for the univariable analysis. We planned a multiple survival analysis with stepwise Cox proportional hazard regression. However, a model based on fewer than 20 events would have been overfitted with unreliable results[5] and was not performed.

Sensitivity analyses were performed to check for influential outliers by excluding 10% of the variables with the most influence on significant factors. In addition, we analyzed the association between time to return to sport and subsequent ACL injury for all eligible athletes, regardless of whether they had performed the muscle function tests. Significance tests were conducted at the 5% level.

RESULTS

One hundred fifty-nine (32%) athletes completed the muscle function tests. The main reason for exclusion from further analyses was that the athlete had not performed tests of muscle function close to the time of return to sport (n = 105) (**FIGURE 1**).

There were no differences in sex, age, preinjury level of physical activity, and anthropometrics between athletes with complete data (n = 159) and athletes with missing data from the muscle function tests or the study-specific questionnaire (n = 335). The athletes with complete data had a shorter time from injury to ACL reconstruction compared with the excluded individuals, by an average of 2 months (P = .007).

The athletes (n = 159) had an average age of 21.5 ± 4.4 years at their primary ACL reconstruction, and 64% were female. The median time to return to sport for all included athletes was 11.0 months (range, 7.5-37.9 months). One hundred one athletes (64%) returned to knee-strenuous sport between 7 and 11 months after ACL reconstruction (**TABLE 2**). The median follow-up time was 15.5 months (range, 0.4-46.5 months) after return to sport, and the time between return to sport and athletes answering the study-specific questionnaire ranged from 2 days to 5 years, with an average of 1.3 years. Athletes performed the tests of muscle function 65 ± 47 days before return to sport. The average LSI for each of the 5 muscle function tests varied between 89% and 99%. Twenty-four percent (n = 39) of the athletes achieved symmetrical muscle function across the battery of tests before returning to knee-strenuous sport.

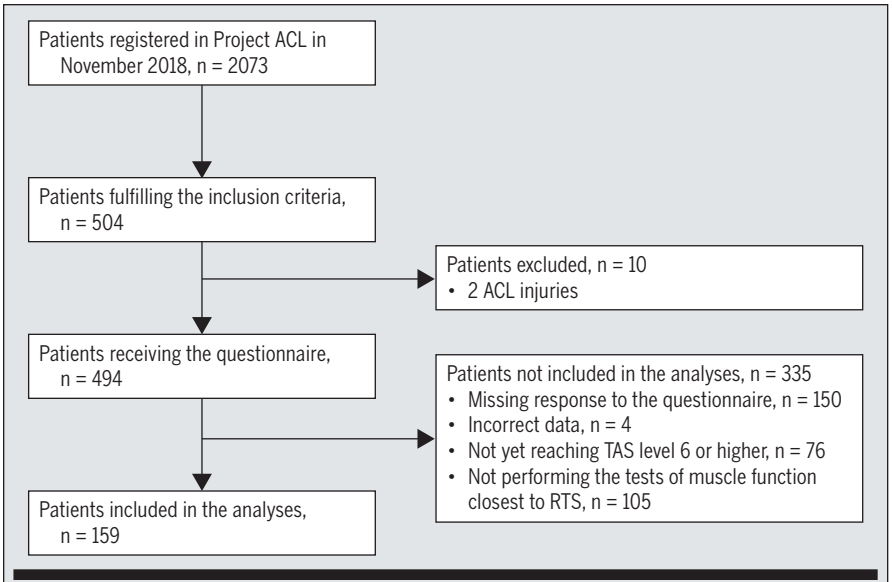

FIGURE 1. Flow chart of inclusion and exclusion. Abbreviations: ACL, anterior cruciate ligament; RTS, return to sport; TAS, Tegner Activity Scale.

Eighteen (11%) athletes sustained a new ACL injury that was registered in Project ACL: 10 graft ruptures and 8 contralateral ACL ruptures (**TABLE 4**) occurred between 9 and 36 months after ACL reconstruction (median, 19 months). Athletes who sustained a new ACL injury returned to knee-strenuous sport, on average, 10.1 ± 3.3 months (range, 7.6-19.4 months) after ACL reconstruction, compared with 12.7 ± 4.8 months (range, 7.5-37.9 months) for athletes with no new ACL injury (**TABLE 5**). Ten of the 33 athletes who returned to knee-strenuous sport earlier than 9 months after reconstruction sustained a new ACL injury. Twelve (67%) of the second ACL injuries occurred in athletes who returned to knee-strenuous sport between 8 and 9 months after ACL reconstruction.

Athletes who returned to knee-strenuous sport at 9 months or later after surgery had a lower rate of new ACL injury compared with those who returned earlier than 9 months after ACL reconstruction (HR = 0.15; 95% confidence interval [CI]: 0.06, 0.39; P<.001) (**TABLE 6, FIGURE 2**). Alternatively expressed, athletes who returned to knee-strenuous sport earlier than 9 months had an approximately 7-fold higher rate of new ACL injury compared with those who returned at 9 months or later after surgery (HR = 6.7; 95% CI: 2.6, 16.7; P<.001).

Achieving symmetrical muscle function in 5 tests (P = .61) or symmetry in quadriceps strength (P = .15) was not associated with new ACL injury (**TABLE 6**).

Sensitivity Analyses

When we excluded 10% of the events with the strongest influence on the analysis of association between time to return to sport and new ACL injury (n = 159), the HR reduced from 6.7 to 5.6 (95% CI: 2.1, 16.7; P<.001).

When data from athletes, irrespective of whether they had performed the tests of muscle function, were analyzed (n =

264; 20 new ACL injuries), athletes who returned to knee-strenuous sport earlier than 9 months after ACL reconstruction had an approximately 3-fold higher rate of new ACL injury compared with those who returned at 9 months or later (HR = 2.7; 95% CI: 1.1, 6.7; P = .027). There was no relationship between time to return to sport and new ACL injury when we excluded the 10% of events with the strongest influence on the analysis. The results from these additional univariable analyses are presented in the **APPENDIX** (available at www.jospt.org).

DISCUSSION

Young athletes who returned to knee-strenuous sport earlier than 9 months after ACL reconstruction had approximately 3 to 7 times the rate of new ACL injury compared with those who delayed return to sport until at least 9 months after surgery. Eighteen (11%) athletes sustained a second ACL injury. Ten of the 33 athletes who returned to knee-strenuous sport earlier than 9 months after reconstruction sustained a new ACL injury. There were no associations between sustaining a subsequent ACL injury and achieving symmetrical muscle function or quadriceps strength.

Time to Return to Sport

Athletes who had returned to knee-strenuous sport before 9 months after reconstruction had an approximately 7-fold higher rate of second ACL injury compared with those who returned at 9 months or later. The analysis that included data from athletes irrespective of whether they had performed the tests of muscle function (n = 264) revealed a similar result, even though the HR was somewhat lower, showing a 3-fold higher rate of second ACL injury in athletes who had returned to knee-strenuous sport earlier than 9 months after surgery. Even though some of the included athletes returned to sports that were less demanding of knee function than in other studies,[6,10] our results mirror the findings of previous research.

Achieving Symmetrical Muscle Function

We did not find an association between achieving symmetrical muscle function and sustaining a second ACL injury. However, only 5 (28%) of the athletes who sustained a second ACL injury, and 33 (23%) of the athletes who did not, regained symmetrical muscle function close to return to sport. The fact that few athletes had symmetrical muscle function, in combination with a relatively limited population (n = 159), may explain

TABLE 4 Baseline Demographics, Stratified by Athletes With and Without Subsequent ACL Injury[a]

	Subsequent ACL Injury (n = 18)	No Subsequent ACL Injury (n = 141)	*P* Value
Patient sex, n (%)			.63
Female	13 (72)	89 (63)	
Height, cm	171.2 ± 8.3	174.7 ± 9.5	.13
Weight, kg	67.2 ± 8.5	71.2 ± 12.5	.21
Preinjury TAS score, n (%)			.029
6	0 (0.0)	6 (4.3)	
7	2 (11.1)	18 (12.8)	
8	3 (16.7)	43 (30.5)	
9	5 (27.8)	51 (36.2)	
10	8 (44.4)	23 (16.3)	
Graft choice, n (%)			.099
Hamstring	13 (72.2)	120 (87.0)	
Patella	4 (22.2)	17 (12.3)	
Quadriceps	1 (5.6)	0 (0)	
Allograft	0 (0)	1 (0.7)	
Age at index ACL reconstruction, y	20.3 ± 3.4	21.7 ± 4.5	.21
Time from ACL injury to reconstruction, mo	4.3 ± 4.8 2.8 (0.1-20.8)	6.4 ± 8.1 3.9 (0.2-58.7)	.041
Time of follow-up, mo	11.1 ± 10.0 7.6 (0.4-28.4)	19.4 ± 11.1 16.5 (2.5-46.5)	NA

Abbreviations: ACL, anterior cruciate ligament; NA, not applicable; TAS, Tegner Activity Scale.
[a]Values are mean ± SD or mean ± SD and median (range) unless otherwise indicated. For comparison between groups, Fisher's exact test (lowest 1-sided P value multiplied by 2) was used for dichotomous variables, the Mantel-Haenszel chi-square test was used for ordered categorical variables, and the Mann-Whitney U test was used for continuous variables.

TABLE 5 Postoperative Outcome in Patients With and Without a Subsequent ACL Injury[a]

	Subsequent ACL Injury (n = 18)	No Subsequent ACL Injury (n = 141)
Time to RTS, mo	10.1 ± 3.3 8.6 (7.6-19.4)	12.7 ± 4.8 11.0 (7.5-37.9)
Symmetrical muscle function[b] closest to RTS, n (%)	5 (27.8)	33 (23.4)
Quadriceps LSI, %	92.3 ± 12.1 93.2 (56.9-112.0)	95.7 ± 9.4 96.5 (74.6-121.3)

Abbreviations: ACL, anterior cruciate ligament; LSI, limb symmetry index; RTS, return to sport.
[a]Values are mean ± SD and median (range) unless otherwise indicated.
[b]All 5 tests of muscle function: LSI of 90% or greater.

why there was no association between new ACL injury and muscle function.

Our results contradict previous research that has supported a relationship between muscle function and new knee injury.[10,19] The discrepancies in results might be explained by different athlete populations (we studied a mixed group of professional and nonprofessional athletes; Kyritsis et al[19] only included male professional athletes) and by all athletes in our study having achieved an average LSI of 90% or greater (athletes in the study by Grindem et al[10] had an average LSI of between 75% and 84%). The higher LSI in our study might have been protective against a second ACL injury, and was partly explained by our criteria for patients to participate in completing the muscle function tests.

Approximately 1 in every 10 athletes in our study sustained a new ACL injury, which is lower than the proportion found in other reports.[6,26,28] Our results might be explained by the fact that the athletes were repeatedly assessed with tests of muscle function and patient-reported outcomes. Structured and progressive preoperative and postoperative rehabilitation, combined with clear goal setting and detailed patient information, may improve rehabilitation outcomes.[9]

TABLE 6 HRs Associated With a Subsequent ACL Injury (n = 159)

		Univariable Analysis		
Value	**Event Rate**	**HR of Subsequent Injury[a]**	***P* Value**	**Generalized R^2**
Patient sex		0.55 (0.20, 1.55)	.26	0.009
Female	9.2			
Male	4.8			
Height (cm), HR per 10 units		0.96 (0.91, 1.01)	.14	0.014
150-<171	8.1			
171-<179	8.8			
179-200	5.2			
Weight (kg), HR per 10 units		0.97 (0.93, 1.01)	.19	0.012
45-<66	7.2			
66-<76	9.4			
76-115	4.2			
Age at index operation (y), HR per 1 unit		0.91 (0.81, 1.03)	.13	0.016
15.2-<18.5	7.5			
18.5-<23.8	12.8			
23.8-29.9	2.3			
Time to surgery (mo), HR per 1 unit		0.93 (0.82, 1.07)	.32	0.010
0.1-<3.0	11.5			
3.0-<5.1	5.2			
5.1-58.7	5.0			
Preinjury TAS score		2.09 (1.22, 3.56)	.007	0.052
6	0.0			
7	5.4			
8	3.7			
9	6.0			
10	24.4			
Time to RTS (mo), HR per 1 unit		0.15 (0.06, 0.39)	<.001	0.088
8-<9	24.8			
9-<38	3.9			
Symmetrical muscle function		1.31 (0.47, 3.67)	.61	0.002
No	6.9			
Yes	9.0			
Quadriceps LSI (%), HR per 10 units		0.96 (0.92, 1.01)	.15	0.013
57-<90	7.7			
90-121	6.7			

Abbreviations: ACL, anterior cruciate ligament; HR, hazard ratio; LSI, limb symmetry index; RTS, return to sport; TAS, Tegner Activity Scale.
[a]*Values in parentheses are 95% confidence interval.*

Patient Demographics

Higher preinjury physical activity level was associated with a higher rate of subsequent ACL injury. Our results support previous research[10] in which patients returning to level 1 sport (eg, soccer and team handball) had a 4-fold increase in the risk of a subsequent knee injury compared with those who did not participate in level 1 sport (29.7% versus 6.9%). In the present study, the rate of second ACL injury was approximately 25% in athletes with a preinjury Tegner Activity Scale score of 10, which is in accordance with previous studies.[2,8,16,22,26,28]

Younger age has been reported as a risk factor for subsequent ACL injury.[10,20] We did not find an association between second ACL injury and patient demographics. This may be because we studied a young group of patients, and the rate of new ACL injuries was low.

Limitations

Only one third of the 494 eligible athletes responded to the study-specific questionnaire and had attended a follow-up of muscle function testing close to the time of return to sport. New ACL injuries were diagnosed clinically by the responsible physical therapist or orthopaedic surgeon. Because magnetic resonance imaging verification of injury was not mandatory, some ACL injuries might have been missed. The mean follow-up time of 15.5 months to re-

cord second ACL injury must be considered as short. In addition, time to return to sport was collected retrospectively, meaning that there is a risk of recall bias.

We defined return to sport as the first time of returning to knee-strenuous sport. Therefore, data relating to exposure were lacking—we did not know the frequency of participation, or whether the athlete participated in modified or unrestricted training/competition. Time 0 was set to return to sport, defined as a Tegner Activity Scale score of level 6 or above, and none of the eligible athletes sustained a second ACL injury prior to return to sport, which eliminates the risk of immortal time bias. Therefore, the use of the Tegner Activity Scale (level 6 or above) may be an appropriate proxy for the risk exposure for ACL injury.

A comparison analysis of demographics between athletes with complete data and those lost to follow-up revealed no significant differences, except for the time between ACL injury and ACL reconstruction. There is no reason to believe that this influenced the results. However, we cannot rule out bias in the results due to unmeasured factors.

We used 2 different modes of strength testing (isometric and isokinetic). As previous studies have demonstrated a moderate to high correlation between isometric and isokinetic tests of knee strength,[14,18] we suggest that using results from 2 different tests had no or only minor influence on the conclusions drawn. We did not account for other factors that might further explain the risk of second ACL injury, such as differences in rehabilitation protocols, surgical techniques of ACL reconstruction, the treatment of concomitant injuries, contextual and social factors, and psychological factors.

CONCLUSION

Returning to knee-strenuous sport before 9 months after ACL reconstruction was associated with a 7-fold increased rate of sustaining a second ACL injury. Achieving symmetrical muscle function or quadriceps strength was not associated with new ACL injury in young athletes. ◉

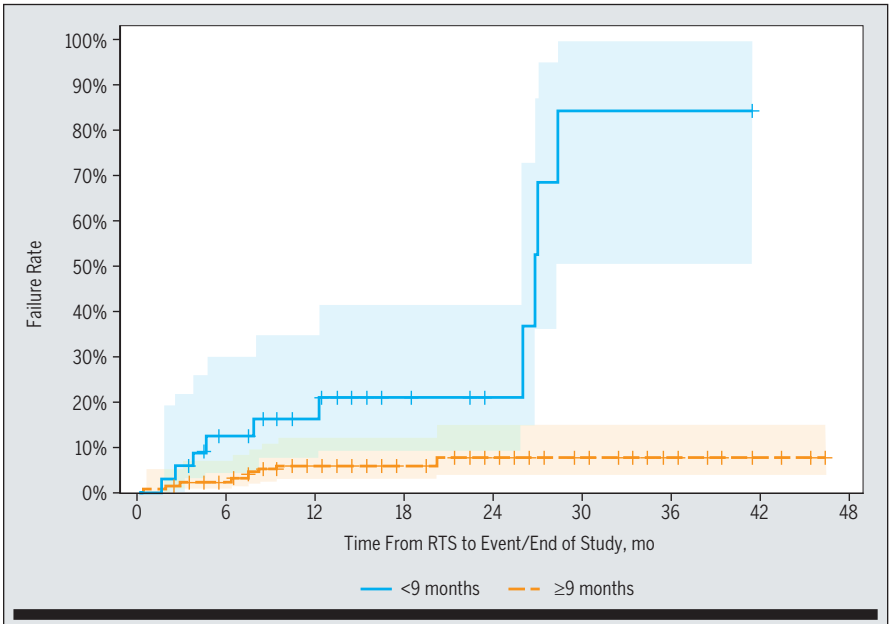

FIGURE 2. Kaplan-Meier curve showing the failure rate (rate of subsequent anterior cruciate ligament injury) in athletes after anterior cruciate ligament reconstruction who returned to knee-strenuous sport, prior to 9 months and at 9 months or after. Plus signs represent censored data. The numbers of patients at risk for each group at each time point from RTS to an event/end of study are as follows: those who returned less than 9 months after reconstruction: 0 months, n = 33; 6 months, n = 24; 12 months, n = 18; 18 months, n = 9; 24 months, n = 5; 30 months, n = 1; 36 months, n = 1; 42 months, n = 0 and those who returned at or later than 9 months after reconstruction: 0 months, n = 126; 6 months, n = 112; 12 months, n = 91; 18 months, n = 64; 24 months, n = 41; 30 months, n = 27; 36 months, n = 12; 42 months, n = 5; 48 months, n = 0. Abbreviation: RTS, return to sport.

KEY POINTS

FINDINGS: The rate of a subsequent anterior cruciate ligament (ACL) injury was approximately 7 times higher in athletes who returned to knee-strenuous sport earlier than 9 months after ACL reconstruction compared with athletes who returned to sport at or later than 9 months. There were no associations between sustaining a subsequent ACL injury and achieving symmetrical muscle function or quadriceps strength.

IMPLICATIONS: Clinicians should inform young athletes who undergo ACL reconstruction that delaying return to knee-strenuous sport until at least 9 months after ACL reconstruction confers a reduction in subsequent ACL injury rate.

CAUTION: This study only included 18 athletes who sustained a subsequent ACL injury, which limited the opportunities for in-depth analyses and assessment of multiple risk factors. The nonsignificant association between achieving symmetrical muscle function and a subsequent ACL injury may be attributed to low statistical power and to the fact that 68% of the athletes had missing data from the muscle function tests.

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STUDY DETAILS

AUTHOR CONTRIBUTIONS: All authors contributed to project planning. Drs Beischer, Hamrin Senorski, and Thomeé and Ms Gustavsson and Mr Thomeé acquired the data. Drs Beischer, Hamrin Senorski, and Thomeé and Ms Gustavsson interpreted data. Dr Beischer and Ms Gustavsson drafted the manuscript. All authors critically revised the manuscript and approved the final version.

DATA SHARING: Individual participant data that underlie the results reported in this article (text, tables, figures, and appendix) are available, after deidentification, for researchers who provide a methodologically sound proposal. Proposals should be directed to the corresponding author.

PATIENT AND PUBLIC INVOLVEMENT: The patients and the public were not involved as research partners.

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APPENDIX

HRS OF EACH OF THE INDEPENDENT VARIABLES FOR THE SENSITIVITY ANALYSES (N = 264)

			Univariable Cox Regression		
Value	**Event Rate[a]**	**n**	**HR of Subsequent Injury[b]**	***P* Value**	**Generalized R^2**
Patient sex			0.52 (0.19, 1.43)	.21	0.009
Female	5.8	177			
Male	2.8	87			
Height (cm), HR per 10 units			0.95 (0.91, 1.00)	.043	0.014
150-<171	6.0	95			
171-<179	4.9	81			
179-200	2.8	87			
Weight (kg), HR per 10 units			0.96 (0.92, 1.00)	.069	0.012
45-<66	5.8	75			
66-<76	5.6	85			
76-115	2.3	79			
Age at index operation (y), HR per 1 unit			0.92 (0.82, 1.03)	.13	0.016
15.2-<18.5	3.9	89			
18.5-<24.2	7.6	93			
24.2-29.9	1.5	77			
Time to surgery (mo), HR per 1 unit			0.91 (0.79, 1.04)	.16	0.010
0.1-<3.0	7.2	90			
3.0-<5.1	4.3	75			
5.1-<58.7	2.4	98			
Preinjury TAS score			2.01 (1.20, 3.36)	.008	0.052
6	0.0	13			
7	3.6	30			
8	2.3	69			
9	3.7	102			
10	14.0	50			
Time to RTS (mo), HR per 1 unit			0.37 (0.15, 0.89)	.027	0.088
8-<9	7.9	81			
9-<38	3.0	183			
Symmetrical muscle function			1.31 (0.47, 3.67)	.61	0.002
No	6.9	121			
Yes	9.0	38			
Quadriceps strength LSI (%), HR per 10 units			0.96 (0.92, 1.01)	.14	0.013
57-<90	7.7	42			
90-121	6.7	118			

Abbreviations: HR, hazard ratio; LSI, limb symmetry index; RTS, return to sport; TAS, Tegner Activity Scale.
[a]*Per observed 100 patient-years.*
[b]*Values in parentheses are 95% confidence interval.*