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Activity and Functional Readiness, not Age, are the Critical Factors for Second Anterior Cruciate Ligament Injury-The Delaware-Oslo ACL Cohort Study

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Abstract

Objective: To elucidate the relationships between age, return to level I sport (RTS) within the 1st postoperative year, passing RTS criteria, and 2nd anterior cruciate ligament (ACL) injury.

Methods: In a prospective cohort study, 213 athletes were followed for 2 years after ACL reconstruction to record 2nd ACL injuries. Independent variables were age, passing RTS criteria, and level I RTS within the 1st postoperative year (versus later or no RTS). We defined passing RTS criteria as ≥90 on the Knee Outcome Survey–Activities of Daily Living Scale, global rating scale of function, and quadriceps strength/hop test symmetry.

Results: The follow-up rate was >87% for all outcomes. In multivariable analysis, level I RTS within the 1st postoperative year and passing RTS criteria were highly associated with 2nd ACL injury (level I RTS HR:6.0[95% CI:1.6–22.6], pass RTS criteria HR:0.08 [95% CI:0.01–0.6]), while age was not (age HR:0.96[95% CI:0.89–1.04]). Athletes <25 years had higher level I RTS rates in the 1st postoperative year (60.4%) than older athletes (28.0%). Of those who returned to

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level I sport in the 1st postoperative year, 38.1% of younger and 59.1% of older athletes passed RTS criteria.

Conclusion: High rates of 2nd ACL injury in young athletes may be driven by a mismatch between RTS rates and functional readiness to RTS. Passing RTS criteria was independently associated with a lower 2nd ACL rate. Allowing more time prior to RTS, and improving rehabilitation and RTS support, may reduce 2nd ACL injury rates in young athletes with ACL reconstruction.

INTRODUCTION

The rate of anterior cruciate ligament (ACL) reconstructions in adolescents and young adults is increasing.[1] Those who are younger than 25 years at the time of their first ACL injury have a high rate of 2nd ACL injuries. One in five of these athletes sustain either a graft rupture or a contralateral ACL injury in the first few years after ACL reconstruction.[2] The high rates of 2nd ACL injuries lead to higher rates of 2nd surgeries in younger athletes compared to their older counterparts. For each year increase in age, ACL revision rates are reduced by 9% and contralateral ACL surgery rates are reduced by 4%.[3]

Multiple factors may influence the higher reinjury rate in young athletes. They return to high-level pivoting sports at a higher rate than older athletes.[4] Participation in level I sports (defined as sports with frequent pivoting movements, e.g. football and basketball) after ACL reconstruction is associated with more than 4 times higher risk for knee reinjury.[5] The relationship between age and 2nd ACL injury might therefore be explained by higher exposure to pivoting or cutting movements, which place the ipsi- and contralateral knee at higher risk. Passing functional return to sport (RTS) criteria prior to RTS is also associated with 4–6 times lower reinjury rates in athletes who return to pivoting sport.[5,6] Compared to older athletes, younger athletes have better quadriceps muscle strength,[7] patient-reported knee function, and hop test symmetry.[8] Prior to RTS, however, only 14–20% of young athletes pass RTS criteria consisting of muscle strength tests, hop tests and patient-reported outcome measures.[9,10] The risk for 2nd ACL injury in young athletes may be influenced by the level of functional readiness for the demands of sports.

The purpose of this study was (1) to assess if younger age, passing RTS criteria and returning to level I sports within the 1st postoperative year are independently associated with 2nd ACL injury rates, and (2) to investigate if the proportion of athletes who passed RTS criteria and returned to level I sports within the first postoperative year differ between younger (<25 years old) and older (≥25 years old) athletes.

METHODS

This study is a secondary analysis of the Delaware-Oslo ACL Cohort Study. Between 2006 and 2012, athletes were consecutively screened for inclusion at the Norwegian Sports Medicine Clinic and the University of Delaware. Inclusion criteria for the cohort were a complete rupture of the ACL (verified by MRI and ≥3 mm side-to-side difference in anterior laxity as measured by KT-1000 [Medmetrics, San Diego, CA]), age between 13 and 60, and ≥50 hours yearly preinjury participation in level I or II sports.[11] Level I sports are sports

with frequent pivoting movements, e.g. football, floorball, handball, basketball. Level II sports are sports with lateral movements, and less pivoting than level I sports (e.g., racket sports, alpine skiing). Athletes were excluded if they had other grade 3 ligament injuries, current or previous contralateral knee injury, fracture, or full-thickness cartilage lesions. In this cohort, 300 athletes were included (150 in Oslo, 150 in Delaware). Those who had undergone ACL reconstruction within 2 years from inclusion were eligible for this study (n=213, Oslo n=105, Delaware n=108). The current sample includes the 106 athletes in our previous publication.[5] Written informed consent was acquired prior to inclusion and approvals from the Regional Committee for Medical Research Ethics (Oslo) and the Institutional Review Board (University of Delaware) were obtained.

The athletes in the Delaware-Oslo ACL Cohort Study prospectively undergo follow-up testing at regular intervals after ACL reconstruction. All athletes had follow-ups 6, 12 and 24 months after ACL reconstruction, including clinical examination, and new ACL injuries to the contra- or ipsilateral knee were recorded. The diagnosis was confirmed with MRI and/or surgical reports. The athletes reported the time of 2nd ACL injury, and additional information was extracted from medical records if needed. A battery of tests was also performed, consisting of muscle strength measurements, single-legged hop tests, and patient-reported outcome measures. Concentric quadriceps strength was measured with an isokinetic dynamometer (Biodex 6000, Biodex Medical Systems, Shirley, NY) with a speed of 60°/sec for all athletes included in Oslo. The athletes performed 4 submaximal practice trials, followed by one minute rest and then 5 repetitions at maximum effort were recorded. The maximal voluntary isometric quadriceps contraction was recorded at 60 degrees of knee flexion with an isometric dynamometer (Kin-Com, DJO Global, Vista, CA) for all athletes included in Delaware. The athlete performed 3 submaximal trial repetitions for familiarization, after which 3 maximum effort trials were recorded. The uninvolved leg was tested first at both inclusion sites. Single-legged hop tests were performed after strength testing. The single hop for distance, crossover hop for distance, triple hop for distance and 6-m timed hop were performed in the described order.[12,13] The uninvolved leg was tested first. After muscle strength and hop testing, the athletes filled out the Knee Outcome Survey – Activities of Daily Living Scale (KOS-ADLS),[14] and a global rating scale (GRS) for knee function. The KOS-ADLS assesses symptoms and function in activities of daily life and is scored from 0 (worst) to 100 (best). The GRS asked the athlete to rate their knee function from 0 (cannot do daily activities) to 100 (preinjury knee function). Activity level was reported on a project-specific form.[11]

Return to level I sport within the 1st postoperative year was defined as reported participation in at least one level I sport[11] at either the 6 or 12 month follow-up. Athletes who never returned to level I sport, or returned at a later time, were classified as not having returned to level I sport in the 1st postoperative year.

For athletes included in Oslo, the RTS test battery in this paper was not in use. Instead, athletes were generally advised against full participation in level I sports if they had not regained 90% LSI on hop tests and measures of quadriceps and hamstrings strength. In Delaware, athletes were cleared by a surgeon on the basis of the RTS tests. Athletes who did not pass RTS criteria were called back for subsequent tests until they passed. In this study,

we assessed whether athletes had passed RTS criteria *prior* to RTS and possible 2nd ACL injury. For athletes who had returned to level I sport within the 1st postoperative year, we therefore extracted RTS criteria pass status from the 6 month follow-up or from subsequent RTS tests that had been performed prior to RTS but before the 12 month follow-up. If they had not returned to level I sport within the 1st postoperative year, the 12 month follow-up data on RTS criteria pass status were used.

Data management and statistical analysis

For all muscle strength and single-legged hop tests, except the 6-m timed hop test, limb symmetry indexes (LSIs) were calculated as the average involved leg performance in percentage of the average uninvolved leg performance. LSI for the 6-meter timed hop test was calculated as the average uninvolved leg performance in percentage of the average involved leg performance. We classified athletes as having passed RTS criteria if they scored ≥90 on all the following tests: quadriceps strength (LSI), single hop (LSI), crossover hop (LSI), triple hop (LSI), 6-meter timed hop (LSI), KOS-ADLS, and GRS.[5] Failing RTS criteria was defined as failing any one test.

Between-group differences in level I sports participation and RTS criteria status were analyzed with a chi square test. The relationship between age and 2nd ACL injury was analyzed with cox proportional hazards regression. Time after ACL reconstruction was used as the time variable. For the relationship between age and 2nd ACL injury, we expected a hazard ratio of 0.93,[3] and 15 2nd ACL injuries would be needed to detect this association. Multivariable cox proportional hazards regression was also used to assess the relationship between 2nd ACL injury and our three independent variables: age (continuous in years), returning to level I sport within the 1st postoperative year (yes/no), and passing RTS criteria (yes/no). There was no multicollinearity problem (variance inflation factors <1.130). The proportional hazards assumption was supported by non-significant relationships between residuals and time for all analyses (all p>.596). There was no statistically significant interaction between site and pass RTS criteria status (p=0.989). We performed sensitivity analyses where contralateral ACL injuries were excluded. Results were consistent with the results for all 2nd ACL injuries.

RESULTS

Data on return to level I sport and passing RTS criteria were complete for 193 (90.6%) and 187 (87.8%) of the 213 athletes, respectively. Compared with those who were 25 years or older (n=88), athletes under 25 years (n=125) were significantly more likely to participate in level I sports prior to injury, were shorter, weighed less, had a lower BMI, and were less likely to have an allograft (table 1). At the time of ACL reconstruction, 84 of 213 patients (39.4%) had meniscal surgery (33 medial meniscus only, 33 lateral meniscus only, 18 both medial and lateral meniscus). A similar proportion of younger (28 of 123, 22.8%) and older (23 of 88, 26.1%) athletes had had concomitant medial meniscal surgery, with no significant difference in the type of meniscal surgery (p=0.749). The proportion of athletes who had concomitant lateral meniscal surgery was also similar between younger (30 of 123, 24.4%)

and older (21 of 88, 23.9%) athletes, with no significant difference in the type of meniscal surgery (p=0.164).

2nd ACL injuries

The median (Q1-Q3) follow-up time was 24 (24–24) months after ACL reconstruction. We were unable to ascertain the 2-year injury status for 19 (8.9%) of 213 athletes. These athletes were censored at their last follow-up. Over 2 years, 213 athletes sustained 23 (10.8%) 2nd ACL injuries, where 18 were graft ruptures and 5 were contralateral ACL tears. The graft ruptures occurred a median of 12 (minimum 3, maximum 22) months after ACL reconstruction. The contralateral ACL tears occurred a median of 16 (minimum 13, maximum 24) months after ACL reconstruction. Athletes under 25 years (n=125) sustained 18 (14.4%) 2nd ACL injuries, where13 were ACL graft ruptures and 5 were contralateral ACL tears. Those who were 25 years or older (n=88) sustained 5 ACL graft ruptures (5.7%) and no contralateral ACL tears. In univariable analysis, younger age was significantly associated with 2nd ACL injury, with 7% reduction in 2nd ACL injury rate for 1 year older age (HR: 0.93, 95% CI: 0.87–0.99, p=0.026). After adjusting for level I RTS within the 1st postoperative year and passing RTS criteria, there was no clear association between age and 2nd ACL injury (HR: 0.96 [95% CI: 0.89–1.04], p=0.344). Level I RTS within the 1st postoperative year was independently associated with a 6 times higher 2nd ACL injury rate (HR: 6.02 [95% CI: 1.61–22.55, p=0.008]), and passing RTS criteria was independently associated with a 92% lower 2nd ACL injury rate (HR: 0.08 [95% CI: 0.01–0.62, p=0.016]).

Level I RTS within the 1st postoperative year and passing RTS criteria

Of 111 athletes under 25 years, 67 (60.4%) returned to level I sport within the 1st postoperative year. Only 23 (28.0%) of the 82 older athletes returned to level I sport (p<0.001) in the 1st postoperative year. A comparable proportion of younger (42 of 108; 38.9%) and older (25 of 79; 31.6%) athletes had passed RTS criteria (p=0.308). Of the athletes who returned to level I sport in the 1st postoperative year, 38.1% (24 of 63) of those under 25 years passed RTS criteria, and 59.1% (13 of 22) of the older athletes passed RTS criteria (p=0.087).

DISCUSSION

This study mirrors previous studies[2,3] and confirms that 2nd ACL injury rates are higher in younger athletes than in older athletes. After adjusting for level I RTS within the 1st postoperative year and whether athletes passed RTS criteria, there was no longer a clear association between age and 2nd ACL injury. These findings indicate that (1) level I RTS within the 1st postoperative year and passing RTS criteria explain a substantial part of the association between age and 2nd ACL injury, and (2) returning to level I sport and failing RTS criteria are more potent risk factors for 2nd ACL injury than age.

Compared to older athletes, the younger athletes had lower BMI and were less likely to receive an allograft. Despite these positive prognostic factors, young athletes had higher rates of 2nd ACL injury than their older counterparts. These high injury rates could be explained by the high frequency of RTS in young athletes.[4,8] Younger athletes more than

twice as frequently returned to level I sports within the 1st postoperative year – a factor that increased the 2nd ACL injury rate 6 times. Passing RTS criteria was associated with a 92% lower 2nd ACL injury rate in this young cohort. When we analyzed athletes irrespective of RTS status, younger athletes were not less likely to pass RTS criteria than older athletes (39% vs 32%, respectively). But in those athletes who returned to level I sports in the 1st postoperative year, 38% of younger and 59% of older athletes had passed RTS criteria. Because of the high frequency of RTS in young athletes, the mismatch between sports demands and functional readiness for sports is far larger in younger than in older athletes. These results have important implications for clinicians who treat younger athletes. First, taking up sports with lower exposure to cutting and pivoting movements would likely reduce the currently high 2nd ACL injury rates. The athlete (and parents/guardians if underage) should therefore make an informed choice of whether they accept the increased risk associated with returning to level I sports or if they wish to change activity patterns. Second, improved rehabilitation and RTS support may be needed to increase the athlete's functional readiness for sports prior to RTS.

Webster and Feller[8] recently found that, compared to older athletes, younger athletes suffered a higher number of 2nd ACL injuries in spite of having higher hop symmetry indexes and IKDC2000 scores. They therefore suggested that thresholds for RTS criteria might need to be adjusted based on age. Very few athletes pass existing, more stringent, RTS criteria prior to RTS.[9,10] While adjustments to the content and thresholds of RTS criteria can lead to better predictive accuracy, the more immediate challenge is how to improve functional readiness to sport so a higher number of athletes pass the existing criteria. The fact that some athletes returned without passing RTS criteria in our study is not surprising, as the RTS test battery under investigation was not in use in Oslo. Athletes in Oslo were not called back for tests between 6 and 12 months postoperatively. It is likely that the functional performance of some of these athletes improved between the test and exact time of RTS, which would underestimate the true proportion that passed RTS criteria prior to RTS. Still, our results indicate that some athletes are returning to sport in a phase where their functional readiness to RTS is still improving. A simple way to improve functional readiness to RTS might be to allow for a longer period of rehabilitation prior to RTS. In the current study, our RTS variable was return to level I sport within the 1st postoperative year (versus either a later RTS or no RTS). This study, therefore, does not answer the question of whether the more substantial risk factor is RTS (at all) or the timing of RTS. In our previous publication,[5] athletes who returned to level I sports had higher rates of knee reinjuries than those who never returned, and, within those who returned, later RTS was associated with lower knee reinjury rates, until 9 months after ACLR. From the current state of knowledge, we recommend that both time-based (>9 months) and functional RTS criteria are used to clear an athlete to RTS after ACL reconstruction.

Our study includes a large, multinational sample of consecutively and prospectively included athletes who all participated in pivoting sport prior to ACL injury. This sample represents a diverse group of pivoting sport athletes who have had ACL reconstruction with different grafts. The age and sex distributions in our sample also correspond to registry data.[15] Although our sample has high external validity, our athletes under 25 years of age had a much higher rate of passing RTS criteria and a lower 2nd ACL injury rate than previous

studies.[2,9,10] The Delaware-Oslo ACL Cohort Study is distinctive in that all athletes received rehabilitation at one of the two study centers, which may have contributed to better outcomes.

Due to the limited number of 2nd ACL injuries in this study, the confidence intervals from our multivariable analysis are wide. This study included prospective functional testing of 213 athletes with ACL reconstruction, but a larger sample would be needed to produce more precise estimates of the magnitudes of risk, and to investigate other potentially contributing factors such as BMI, graft type, and sex. Further, there is a risk of sparse-data bias as few athletes who either passed RTS criteria or did not return to level I sports within the 1st postoperative year sustained 2nd ACL injuries.[16] The results also demonstrate the strong relationship between return to level I sport within the 1st postoperative year and a 2nd ACL injury. Future studies on 2nd ACL injuries should therefore prospectively record the number of hours spent in level I sports to more accurately measure and account for risk exposure.

CONCLUSION

After adjustment for level I RTS within the 1st postoperative year and whether athletes had passed RTS criteria, there was no clear association between age and 2nd ACL injury. Independent of age, level I RTS within the 1st postoperative year was associated with six times higher 2nd ACL injury rates, and younger athletes were more than twice as likely to return to level I sport than older athletes. Passing RTS criteria prior to RTS was independently associated with a lower 2nd ACL rate. These results suggest two promising avenues to decrease the high 2nd ACL injury rate in our youngest athletes: (1) serious consideration of activity modification or delayed return to pivoting sports, and (2) increased rehabilitation and support in the RTS phase to ensure athletes achieve a satisfactory level of functional readiness to RTS.

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What are the new findings:

- Age was not a risk factor for 2nd ACL injury when return to level I sport within the 1st postoperative year and passing RTS criteria were accounted for
- Return to level I sports within the first postoperative year was independently associated with 6 times higher 2nd ACL injury rate, and athletes under 25 years had higher RTS rates (60.4%) than older athletes (28.0%)
- In athletes who returned to level I sport in the 1st postoperative year, 38% of athletes under 25 years and 59% of older athletes passed RTS criteria
- Passing RTS criteria was independently associated with a 92% lower 2nd ACL injury rate

How might it impact on clinical practice in the future?

- Instead of age, clinicians should focus on the sporting demands and functional readiness of their patients when they evaluate the risk for 2nd ACL injuries
- Stricter clearance prior to return to level I pivoting sports, activity modifications, or allowing for more time before RTS could reduce the currently high rates of 2nd ACL injury seen in adolescents and young adults with ACL reconstruction

Table 1

Descriptive characteristics of younger and older athletes

	Under 25 years (n=125)	25 years or older (n=88)	p-value
Female/male, n (% female)	59/66 (47.2)	33/55 (37.5)	0.159
Preinjury activity level I/II, n (% level I)	107/18 (85.6)	53/35 (60.2)	<0.001
Age, years (SD, min-max)	18.8 (2.8, 13.0–24.5)	33.6 (7.2, 25.0–52.3)	<0.001
BMI, kg/m^2	24.0 (4.1)	25.9 (3.8)	0.001
Height, cm	173.1 (9.2)	176.4 (8.2)	0.006
Weight, kg	72.1 (15.1)	81.1 (16.2)	<0.001
Days from injury to surgery, median (Q1-Q3)	111.0 (70.5–196.5)	127.5 (82.5–207.3)	0.785
Graft type			0.018
Allograft, n (%)	27 (22.0)	35 (39.8)	
Patellar tendon autograft, n (%)	26 (21.1)	16 (18.2)	
Hamstring autograft, n (%)	69 (56.9)	37 (42.0)	

Data are reported as mean (SD) unless otherwise indicated. Missing data: weight n=1, BMI n=1, graft type n=4. BMI: Body mass index