

Clinical Tests Can Be Used to Screen for Second Anterior Cruciate Ligament Injury in Younger Patients Who Return to Sport

Kate E. Webster,^{*†} PhD, and Julian A. Feller,[‡] FRACS

Investigation performed at OrthoSport Victoria and La Trobe University, Melbourne, Australia

Background: Younger athletes have high rates of second anterior cruciate ligament (ACL) injury. Return-to-sport criteria have been proposed to enable athletes to make a safe return, but they frequently lack validation. It is unclear whether commonly recorded clinical measures can help to identify high-risk athletes.

Purpose: To explore the association between commonly recorded clinical outcome measures and second ACL injury in a young, active patient group.

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

Methods: Included in this study were 329 athletes (200 males, 129 females) younger than 20 years at the time of first primary ACL reconstruction surgery who had subsequently returned to sport participation. Clinical examination included range of knee motion (passive flexion and extension deficits), instrumented anterior knee laxity, and single- and triple-crossover hop for distance. Patients also completed the subjective International Knee Documentation Committee form. All measures were collected prospectively at a 12-month postoperative clinical review. Patients were evaluated for a minimum 3 years to determine the incidence of subsequent ACL injury.

Results: A total of 95 patients (29%) sustained a second ACL injury following clinical assessment and return to sport. There were 50 graft ruptures and 45 contralateral ACL injuries. Patients with a flexion deficit of 5° had over 2 times the odds of sustaining a graft rupture (odds ratio, 2.3; $P < .05$), and patients with a side-to-side difference in anterior knee laxity of 3 mm or greater had over 2 times the odds of sustaining a contralateral ACL injury (odds ratio, 2.4; $P < .05$). Overall, 29% (94 of 329) of patients met the threshold for satisfactory function on all 6 clinical measures; these patients had a 33% reduction in the risk of sustaining a second ACL injury ($P = .05$) as compared with those who did not meet all clinical thresholds.

Conclusion: Clinical measures of knee flexion and stability may have utility to screen for and identify patients who are at greater risk for a second ACL injury in an already high-risk group (ie, age and activity level).

Keywords: ACL reconstruction; second injury; reinjury; return to sport; younger athlete

Younger athletes who undergo anterior cruciate ligament (ACL) reconstruction surgery have high rates of second ACL injuries. Cohort studies have specifically reported that 20%

to 40% of young athletes sustain a second ACL injury between 1 and 5 years following surgery.^{3,12,19,20,25,28} There are likely multiple reasons why this young group is at such high risk, but current evidence indicates that exposure to strenuous sports is a contributing factor.^{8,28,29} Two recent cohort studies showed that 50% of younger patients return to strenuous sports before the 12-month postsurgical time point,^{2,26} and it is therefore reasonable to hypothesize that this early exposure increases the risk for further ACL injury.

Return-to-sport criteria have been proposed to enable athletes to make a safe return, but they frequently lack validation. Studies also do not typically tailor return-to-sport criteria to the younger athlete, even though younger patients have been shown to score better on a variety of postoperative assessments as compared with older patients.²⁷ Studies that have utilized return-to-sport test batteries to clear athletes to return to sport show that “pass” rates vary considerably in younger athletes and can

*Address correspondence to Kate E. Webster, PhD, School of Allied Health, College of Science, Health and Engineering, La Trobe University, Victoria 3086, Australia (email: k.webster@latrobe.edu.au).

† School of Allied Health, La Trobe University, Melbourne, Australia.

‡ OrthoSport Victoria, Epworth HealthCare, Melbourne, Australia.

The authors declared that there are no conflicts of interest in the authorship and publication of this contribution. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was obtained from the Science, Health and Engineering College Human Ethics Sub-Committee, La Trobe University.

The Orthopaedic Journal of Sports Medicine, 7(8), 2325967119863003
DOI: 10.1177/2325967119863003

© The Author(s) 2019

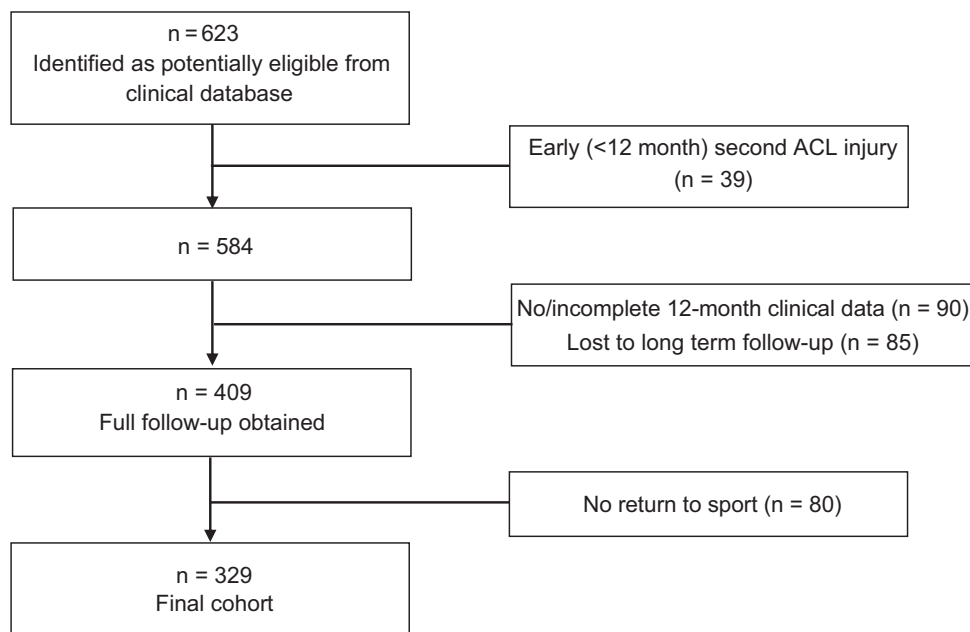


Figure 1. Flow diagram of patient selection. ACL, anterior cruciate ligament.

be as low as 14% and as high as 79%.^{15,24} Furthermore, return-to-sport testing shows that only a quarter of younger athletes who have already returned to strenuous sports meet return-to-sport criteria.^{2,4} There is clearly more work to be done to understand what return-to-sport tests should be used in younger patients who undergo ACL reconstruction and plan a return to strenuous sports, as well as how such criteria should be interpreted for the younger athlete.

Return-to-sport test batteries typically include fixed-unit dynamometry strength tests as well as a variety of functional measures such as hop tests and, more recently, patient-reported outcomes.¹ It is, however, currently unclear whether other clinical measures, such as range of knee motion and knee stability, can help to identify high-risk athletes. The purpose of this study was therefore to explore the association between commonly recorded clinical measures and second ACL injury in a young active patient group. It was hypothesized that patients who met the threshold for satisfactory function on these clinical measures would have a reduced risk for subsequent ACL injury.

METHODS

Patient Selection

The inclusion criteria for the study were as follows: primary single-bundle ACL reconstruction, age younger than 20 years at surgery, normal contralateral knee (no previous knee surgery), routine follow-up at 12 months postoperatively, and a return to preinjury sport at either a lower or the same level at some time following surgery. From a clinical practice database, we identified a cohort of 623 patients who had undergone single-bundle primary ACL

reconstruction surgery between May 2005 and October 2015. There were no or incomplete 12-month clinical follow-up data for 129 patients, of whom 39 had already sustained a second ACL injury prior to the 12-month clinical review (25 ruptures, 14 contralateral ACL). We were unable to contact 85 patients for longer term (+3 years) follow-up to determine if a subsequent ACL injury had occurred. Full data were therefore available for 409 patients, of whom 80 had not made any return to sport, resulting in 329 patients in the final study cohort (Figure 1).

Surgical and Rehabilitation Details

Most patients had an arthroscopically assisted 4-strand hamstring tendon graft ($n = 323$) with use of the semitendinosus and gracilis tendons with transportal drilling of the femoral tunnel. Medial meniscal tears were present in 75 (23%) patients. Of these tears, 29 were repaired, 26 were partially resected, and 20 were stable and not addressed surgically. Lateral meniscal tears were present in 111 (34%) patients; of these, 11 were repaired, 49 were partially resected, 47 were not addressed surgically, and 4 had previously been partially resected. Chondral damage was present in 35 patients (International Cartilage Repair Society grade 2, $n = 27$; grade 3, $n = 5$; grade 4, $n = 3$). Suspensory proximal fixation was used on the femoral side and interference screw fixation on the tibial side. Postoperatively, all patients followed the same rehabilitation protocol, which encouraged immediate full knee extension and the restoration of quadriceps function as soon as possible. Weightbearing was allowed on an as-tolerated basis from the first postoperative day. No braces or splints were used. Progression was guided by the presence and degree of pain and swelling. The minimum requirements for a return to sport were no effusion, an essentially full range of motion (passive extension deficit and

flexion deficits $<5^\circ$ vs contralateral knee), good quadriceps strength and control of a single-legged squat—all determined by the treating surgeon in the clinic—unrestricted running and landing, and at least 4 weeks of full and unrestricted training. The earliest that these criteria were met was between 9 and 10 months from surgery. Only those patients who were cleared to return by the treating surgeon were eligible for this study.

Data Collection and Procedures

At 12 months after surgery, patients had a routine clinical follow-up appointment where the following evaluations took place. Assessments were completed by a number of trained clinical assessors.²⁷ Passive knee flexion of both knees was recorded with a goniometer, with the patient in the lateral decubitus position. For comparative purposes, the deficit (in degrees) of the operated limb relative to the contralateral limb was used. Extension deficits were recorded with the method described by Sachs et al.²² With the patient prone, the difference in heel height was converted to an extension deficit in degrees by a formula based on the difference in heel height and the patient's height. This method recorded the deficit relative to the normal hyperextension, if any, of the contralateral limb rather than relative to an arbitrary zero degrees.

Measurements of side-to-side differences in anterior tibial displacement were made with a KT-1000 arthrometer (MEDmetric Corp) at 134 N. Three measures were taken from both knees, and the average displacement in millimeters was recorded. The side-to-side difference was recorded as the operated knee score minus the contralateral knee score.

Patients completed both a single hop for distance and a triple crossover hop for distance. They were instructed that they must hop as far as possible but control their landing. A familiarization trial was permitted, and any trial where the landing was not controlled (ie, touchdown with the opposite foot) was excluded. Two successful trials from both limbs were recorded, and the average was used to calculate a limb symmetry index (LSI; operated side score divided by contralateral side score $\times 100\%$). An LSI <100 indicated a deficit in the operated limb.

Patients also completed a self-administered questionnaire that included the International Knee Documentation Committee (IKDC) 2000 subjective knee evaluation score¹¹ and the level of their preinjury sport to which they had returned, based on the following categories: *no return*, *return to training*, *return to lower level*, or *return to same level*.

At a minimum of 3 years after surgery, (mean, 5 years; range, 3-9 years), patients were contacted to determine the occurrence of further ACL injury. This was done via an online survey or telephone interview in which patients responded to structured questions regarding any further injuries to the ACL-reconstructed knee or the contralateral knee as well as the level of sport to which they had returned (same categories as before). To meet the study eligibility criteria, patients must have returned to preinjury sport at either a lower or the same level at some time following their surgery (12-month or follow-up assessment).

Data and Statistical Analysis

Patients were grouped according to whether they had sustained a further ACL injury, and between-group differences were compared with independent-samples *t* tests for each of the measured variables. This was performed for the entire group (all second ACL injuries) and then separately for those who sustained a graft rupture or contralateral ACL injury.

Arbitrary but commonly used threshold values for the various tests were then used to indicate a satisfactory result. A flexion deficit of $\leq 5^\circ$, an extension deficit of $\leq 3^\circ$, a side-to-side difference in anterior knee laxity of <3 mm, LSIs of $\geq 90\%$ for the hop tests, and an IKDC score of ≥ 90 were considered indicators of a satisfactory outcome.¹⁰ It is important to note that these criteria were from routine 12-month follow-up testing and were not used to clear a patient to return to sport. The number of patients who met each of these criteria was calculated and compared between groups with contingency tables and odds ratios to determine if there was an association between meeting the criteria and having a second ACL injury. The number of patients meeting all 6 criteria was also calculated, and these data were used to determine the risk ratio (RR) for second ACL injuries. The predictive validity of any variable that significantly differed between groups was further assessed by use of receiver operating characteristic (ROC) curve statistics. All data were analyzed with SPSS statistics software (v 23; IBM Corp). A *P* value $\leq .05$ was used to indicate statistical significance.

RESULTS

The study patients consisted of 200 males and 129 females with a mean (SD) age of 17.2 (2) years. The mean time between injury and surgery was 4 (8) months. A total of 95 patients (29%) sustained a second ACL injury following the 12-month clinical assessment. There were 50 graft ruptures, which occurred at a mean of 2.8 (1.9) years after surgery, and 45 contralateral ACL injuries, which occurred at a mean of 3.8 (1.8) years. At the 12-month assessment, 47% of patients had returned to full competition sport, and patients who later sustained a second ACL injury had the same return rate at this time point as those who did not sustain further injury (47% for both groups).

Between-group comparisons for all 12-month follow-up measures are shown in Table 1. Patients who sustained a second ACL injury had significantly greater passive knee flexion deficits ($P = .005$) and greater anterior knee laxity ($P = .03$) than those who did not. When analyzed according to the type of second ACL injury, a greater knee flexion deficit was significantly associated with graft rupture ($P = .009$), whereas greater anterior knee laxity ($P = .02$) was significantly associated with contralateral ACL injury. Hop test symmetry scores, extension deficits, and IKDC subjective knee scores were not significantly different between the patient group that went on to a further ACL injury and the group that did not.

Patients with a flexion deficit of $>5^\circ$ had 2.3 times the odds of sustaining a graft rupture. Patients with a side-to-side

TABLE 1
Mean Values for the Clinical Criteria, Percentage That Met the Satisfactory Threshold,
and Odds Ratios Comparing the Injured and Uninjured Groups^a

Variable	No Further Injury (n = 234)	Second ACL Injury		
		All (n = 95)	Graft Rupture (n = 50)	Contralateral ACL Injury (n = 45)
Passive flexion deficit, deg				
Mean (SD)	2.9 (4.3)	4.5 (4.6) ^b	4.8 (4.9) ^b	4.1 (4.4)
Satisfactory percentage	84	74	70	78
Odds ratio (95% CI)		1.9 (1.1-3.4) ^c	2.3 (1.1-4.6) ^c	1.5 (0.7-3.3)
Extension deficit, deg				
Mean (SD)	0.42 (2.2)	0.19 (2.1)	0 (1.8)	0.51 (2.3)
Satisfactory percentage	90	93	96	89
Odds ratio (95% CI)		0.7 (0.3 -1.7)	0.4 (0.1 -1.6)	1.1 (0.4-3.0)
KT-1000 side-to-side difference, mm				
Mean (SD)	0.97 (2.1)	1.52 (2.2) ^c	1.28 (2.1)	1.78 (2.3) ^b
Satisfactory percentage	78	71	80	60
Odds ratio (95% CI)		1.5 (0.9-2.6)	0.9 (0.4 -1.9)	2.4 (1.2-4.7) ^c
Single hop for distance, LSI, %				
Mean (SD)	96.3 (11)	95.1 (10)	95.3 (8)	94.7 (11)
Satisfactory percentage	78	79	79	79
Odds ratio (95% CI)		0.9 (0.5 -1.7)	0.9 (0.4-2.0)	1.0 (0.4-2.1)
Triple hop for distance, LSI, %				
Mean (SD)	98.0 (10)	97.7 (11)	98.4 (9)	96.8 (12)
Satisfactory percentage	84	84	83	84
Odds ratio (95% CI)		1.1 (0.6-2.1)	1.1 (0.5-2.5)	1.0 (0.4-2.5)
IKDC subjective score (0-100)				
Mean (SD)	89.7 (9.6)	87.9 (10.0)	86.7 (11.2)	89.1 (8.5)
Satisfactory percentage	59	51	53	48
Odds ratio (95% CI)		1.4 (0.9-2.3)	1.3 (0.7-2.4)	1.6 (0.8-3.1)

^aA flexion deficit of $\leq 5^\circ$, an extension deficit of $\leq 3^\circ$, a side-to-side difference in anterior knee laxity of < 3 mm, LSIs of $\geq 90\%$, and an IKDC score of ≥ 90 were considered indicators of a satisfactory outcome. ACL, anterior cruciate ligament; IKDC, International Knee Documentation Committee; LSI, limb symmetry index.

^b $p < 0.01$.

^c $p < 0.05$.

difference of ≥ 3 mm in anterior knee laxity had 2.4 times the odds of sustaining a contralateral ACL injury (Table 1). ROC analysis showed that a passive flexion deficit of $> 5^\circ$ had fair predictive ability for graft rupture (area under ROC curve = 0.6; 95% CI, 0.51-0.68; $P = .4$; specificity = 0.82, sensitivity = 0.32) as did a difference in laxity ≥ 3 mm for contralateral ACL injury (area under ROC curve = 0.6; 95% CI, 0.49-0.68; $P = .7$; specificity = 0.82, sensitivity = 0.38).

Overall, 29% (94 of 329) of patients met the satisfactory threshold for all 6 criteria. These patients had a 33% reduction in the risk of sustaining a second ACL injury compared with patients who did not meet all clinical thresholds (RR, 0.67; $P = .05$; second ACL injury rate: 21% "satisfactory" group, 32% "not satisfactory" group). Meeting the satisfactory threshold for all 6 criteria reduced the risk of a contralateral ACL injury by 54% (RR, 0.46; $P = .036$) and a graft rupture by 20% (RR, 0.8; $P = .4$).

DISCUSSION

The current study confirms the high second ACL injury rate in younger athletes who undergo ACL reconstruction

surgery and shows that commonly used clinical measures may have utility for assessment of the risk of future ACL injury. Of the 6 clinical measures that were utilized in the study, having a flexion deficit of $> 5^\circ$ was most strongly associated with graft rupture, whereby patients who had such deficits had over twice the odds of this occurring. Greater laxity in the reconstructed knee was also shown to increase the risk of sustaining a contralateral ACL injury. The present results therefore highlight the importance of achieving a good range of motion and a stable knee following reconstruction surgery and the potential negative consequences when this is not achieved.

Functional hop tests are a common component of return-to-sport test batteries.⁵ It is therefore notable that the scores of these tests alone did not distinguish between patients who did and did not have a second ACL injury. As in recent studies, we employed a 90% limb symmetry threshold as indicative of a satisfactory performance.^{2,4,7,16,24} The overall rate of satisfactory performance was high (on average, 79% for single-limb hop and 84% for triple hop for distance), and mean LSIs were all above 90%. This most likely reflects our young patient cohort, as it has been shown that younger patients tend to have higher LSI scores than older patients.²⁷ This

criterion and a 90% threshold may therefore be less sensitive in a younger cohort, in which most patients do well.

While knee flexion and laxity were the measures most associated with second ACL injury, the patient group that sustained a further ACL injury tended to score lower on all measures that were used in this study. When combined, only 29% of patients had satisfactory results for all 6 tests. This is consistent with other studies that have utilized return-to-sport test batteries^{7,23} and with a recent review and meta-analysis that reported that only 23% of patients passed return-to-sport test batteries after ACL reconstruction surgery.³⁰ Such low pass rates are of concern and, from an injury prevention perspective, suggest that many patients return to play without “normal or near normal” knee function and control. In the current study, patients who had satisfactory results for all 6 tests had a 33% reduced risk of second ACL injury compared with patients who did not meet all of the clinical thresholds. The risk was reduced for both the reconstructed knee (20% reduction in risk) and the contralateral knee (54% reduction in risk) but was statistically significant for only the contralateral side. Previous studies have tended to show mixed findings in terms of passing return-to-sport criteria and subsequent ACL injury.³⁰

Only 2 cohort studies have shown a significant effect of passing criteria and subsequent injury, and the results are contradictory. Kyritsis et al¹⁴ recorded graft ruptures in elite male athletes and reported that those who did not meet all return criteria had a 4-times greater risk of graft rupture. In comparison, Sousa et al²³ did not find a reduced risk for graft rupture in their group who passed criteria, but they did find a significantly increased risk for contralateral injuries. The current data show yet another finding, which is that meeting specific thresholds for selected clinical criteria may be protective against future contralateral ACL injury in young patients who return to sport. Importantly, meeting the thresholds for the criteria used in this study was not shown to increase the risk of graft rupture, and as such, it seems sensible to recommend that such thresholds be used as a guide during rehabilitation.

There are, however, several methodological differences among these studies that are worth noting. The tests used in the current study were different from those in the previous studies, which used a range of strength and agility tests. The time frames for assessment and patient cohorts were also notably different. Sousa et al²³ performed their testing at an earlier time point (6 months), and not all patients in their cohort were active in sport prior to their original ACL injury. Kyritsis et al¹⁴ did not explicitly state the time after surgery at which testing was performed on their all-elite athlete group. Finally, it should once again be emphasized that in this study, unlike those by Sousa et al and Kyritsis et al, patients were not given clearance to return to sport based on their meeting the thresholds of the various clinical criteria, which were recorded at routine 12-month follow-up. The merit of using such criteria for this purpose therefore needs further evaluation.

The results of the current study are generally similar to those of Graziano et al,⁶ who studied a small group (N = 42) of skeletally immature athletes following ACL

reconstruction surgery. In their study, patients who passed return-to-sport tests, which were conducted throughout the rehabilitation phase, had fewer second ACL injuries (11%) than those who failed criteria (25%). Interestingly, the percentage difference in reinjury rates was similar to that of the current study, where 21% of patients who reached the satisfactory threshold for all the clinical tests sustained a further ACL injury, as opposed to 32% who did not have a further injury.

In the current study, strict inclusion criteria were applied to reduce the number of potential confounders. Along with criteria that are commonly applied (eg, normal contralateral knee), we required patients to have returned to sport. Subsequent ACL injuries are substantially less likely to occur in patients who do not return to sport, so this was felt to be particularly important. Many previous studies have not specifically applied this criterion or stated that all patients in their cohort had indeed returned to sport. We also specifically focused on younger athletic patients. This is the age and activity group that is most at risk for a second ACL injury, and previous studies have suggested that the reason is that younger athletes more frequently return to strenuous sports and consequently have a higher level of exposure.¹³

While we found that those patients who demonstrated satisfactory performance of selected clinical criteria at a 12-month postoperative assessment had a reduced risk for further ACL injury, we do not know the mechanism by which this contributed to the reduction in risk. It is reasonable to suggest that movement biomechanics may be influenced, and this is supported by previous studies that have shown that certain biomechanical variables can predict the risk of ACL injury.^{9,21} In terms of why increased graft laxity may increase the risk of contralateral ACL injury, biomechanical findings have demonstrated increased loading of the contralateral limb at the time of return to sport.¹⁷ Increased laxity might exacerbate this increased loading of the contralateral limb, which may also account for the increased risk in contralateral ACL injury. A similar mechanism could occur for the ipsilateral limb wherein a reduced range of motion may contribute to altered knee biomechanics during functional tasks. This is, however, highly speculative.

Psychological factors have also been shown to be associated with return to sport after ACL reconstruction and have been suggested to be included in injury risk prediction screening.^{5,18} However, such factors were not assessed in the current study. While the present study found a potential usefulness of commonly used clinical tests, it is not being suggested that they replace other types of return-to-sport tests, such as assessment of strength, which have also been shown to have utility for the identification of those at risk for knee reinjury.^{7,14} Rather, we hope that the current findings add to the tools that a clinician can use throughout rehabilitation and in the return-to-sport decision-making process.

The current study has several limitations. Given that the clinical criteria were not applied to clear patients to return to sport, the cohort was mixed in terms of whether the patients had returned to sport at the time of clinical testing.

Patients who had sustained a second ACL injury before 12 months were also not able to be included, as we did not collect their 12-month clinical data. While we asked patients if they had returned to their prior sport and level of participation, this does not equate to an assessment of exposure to risk, and it is therefore possible that those patients who were reinjured had a different level of sport exposure after their return than those who did not sustain further injury. The absolute magnitudes in the differences seen between groups for the significant measures were not large, and when we take measurement error into account, it would be difficult to identify further injury risk at an individual patient level. A recent study has, however, identified patients who have high risk profiles for second ACL injury based on patient demographics (age and sex) and clinical measures such as hop tests.¹⁸

It is also unknown whether requiring that patients delay their return to sport until they have met certain criteria makes a difference in terms of reducing the risk of reinjury. Furthermore, although the minimum 3-year follow-up time allowed us to capture further ACL injuries, it is unclear for how long meeting certain criteria has an effect on the risk of reinjury. If patients are reinjured during their first couple of sport exposures, it would be logical to verify whether they had passed return-to-sport testing or not. However, if a patient has played for several full seasons, it may not be meaningful to relate an injury that occurs after this time back to testing that occurred years earlier.

CONCLUSION

This study showed that commonly used clinical measures of knee flexion and instrumented anterior knee laxity were significantly different between younger patients who went on to a second ACL injury and those who did not. Patients with a flexion deficit had over 2 times the odds of sustaining a graft rupture, and patients with greater laxity had over 2 times the odds of sustaining a contralateral ACL injury. Functional hop tests were not discriminative, and most younger patients scored well on these tests. Patients who were assessed as being satisfactory on all 6 clinical tests that were used had a 33% reduction in the risk for second ACL injury. This study results indicate that these clinical measures may have utility in identifying patients who are at even greater risk of a second ACL injury in this cohort who are already at high risk owing to their age and activity level.

REFERENCES

1. Barber-Westin SD, Noyes FR. Factors used to determine return to unrestricted sports activities after anterior cruciate ligament reconstruction. *Arthroscopy*. 2011;27(12):1697-1705.
2. Beischer S, Hamrin Senorski E, Thomeé C, Samuelsson K, Thomeé R. Young athletes return too early to knee-strenuous sport, without acceptable knee function after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(7):1966-1974.
3. Dekker TJ, Godin JA, Dale KM, Garrett WE, Taylor DC, Riboh JC. Return to sport after pediatric anterior cruciate ligament reconstruction and its effect on subsequent anterior cruciate ligament injury. *J Bone Joint Surg Am*. 2017;99(11):897-904.
4. Ebert JR, Edwards P, Yi L, et al. Strength and functional symmetry is associated with post-operative rehabilitation in patients following anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(8):2353-2361.
5. 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(1):192-199.
6. Graziano J, Chiaia T, de Mille P, Nawabi DH, Green DW, Cordasco FA. Return to sport for skeletally immature athletes after ACL reconstruction: preventing a second injury using a quality of movement assessment and quantitative measures to address modifiable risk factors. *Orthop J Sports Med*. 2017;5(4):2325967117700599.
7. 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.
8. Hamrin Senorski E, Svantesson E, Beischer S, et al. Low 1-year return-to-sport rate after anterior cruciate ligament reconstruction regardless of patient and surgical factors: a prospective cohort study of 272 patients. *Am J Sports Med*. 2018;46(7):1551-1558.
9. 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(4):492-501.
10. International Knee Documentation Committee Knee Form. <https://www.aaos.org/uploadedFiles/PreProduction/Quality/Measures/IKDCEnglishUS.pdf>. Accessed November 2018.
11. 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.
12. Kamath GV, Murphy T, Creighton RA, Viradia N, Taft TN, Spang JT. Anterior cruciate ligament injury, return to play, and reinjury in the elite collegiate athlete: analysis of an NCAA Division I cohort. *Am J Sports Med*. 2014;42(7):1638-1643.
13. Kay J, Memon M, Marx RG, Peterson D, Simunovic N, Ayeni OR. Over 90% of children and adolescents return to sport after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(4):1019-1036.
14. 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.
15. Luo TD, Ashraf A, Dahm DL, Stuart MJ, McIntosh AL. Femoral nerve block is associated with persistent strength deficits at 6 months after anterior cruciate ligament reconstruction in pediatric and adolescent patients. *Am J Sports Med*. 2015;43(2):331-336.
16. Nawasreh Z, Logerstedt D, Cummer K, Axe M, Risberg MA, Snyder-Mackler L. Functional performance 6 months after ACL reconstruction can predict return to participation in the same pre-injury activity level 12 and 24 months after surgery. *Br J Sports Med*. 2018;52(6):375.
17. Paterno MV, Ford KR, Myer GD, Heyl R, Hewett TE. Limb asymmetries in landing and jumping 2 years following anterior cruciate ligament reconstruction. *Clin J Sport Med*. 2007;17(4):258-262.
18. Paterno MV, Huang B, Thomas S, Hewett TE, Schmitt LC. Clinical factors that predict a second ACL injury after ACL reconstruction and return to sport: preliminary development of a clinical decision algorithm. *Orthop J Sports Med*. 2017;5(12):2325967117745279.
19. Paterno MV, Rauh MJ, Schmitt LC, Ford KR, Hewett TE. Incidence of contralateral and ipsilateral anterior cruciate ligament (ACL) injury after primary ACL reconstruction and return to sport. *Clin J Sport Med*. 2012;22(2):116-121.
20. Paterno MV, Rauh MJ, Schmitt LC, Ford KR, Hewett TE. Incidence of second ACL injuries 2 years after primary ACL reconstruction and return to sport. *Am J Sports Med*. 2014;42(7):1567-1573.

21. 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(10):1968-1978.
22. Sachs RA, Daniel DM, Stone ML, Garfein RF. Patellofemoral problems after anterior cruciate ligament reconstruction. *Am J Sports Med.* 1989;17(6):760-765.
23. 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(5):1356-1363.
24. Toole AR, Ithurburn MP, Rauh MJ, Hewett TE, Paterno MV, Schmitt LC. Young athletes cleared for sports participation after anterior cruciate ligament reconstruction: how many actually meet recommended return-to-sport criterion cutoffs? *J Orthop Sports Phys Ther.* 2017;47(11):825-833.
25. 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.
26. Webster KE, Feller JA. Return to level I sports after anterior cruciate ligament reconstruction: evaluation of age, sex, and readiness to return criteria. *Orthop J Sports Med.* 2018;6(8):2325967118788045.
27. Webster KE, Feller JA. Younger patients and men achieve higher outcome scores than older patients and women after anterior cruciate ligament reconstruction. *Clin Orthop Relat Res.* 2017;475(10):2472-2480.
28. Webster KE, Feller JA, Leigh W, Richmond AK. Younger patients are at increased risk for graft rupture and contralateral injury after anterior cruciate ligament reconstruction. *Am J Sports Med.* 2014;42(3):641-647.
29. Webster KE, Feller JA, Whitehead TS, Myer GD, Merory PB. Return to sport in the younger patient with anterior cruciate ligament reconstruction. *Orthop J Sports Med.* 2017;5(4):2325967117703399.
30. Webster KE, Hewett TE. What is the evidence for and validity of return-to-sport testing after anterior cruciate ligament reconstruction surgery? A systematic review and meta-analysis. *Sports Med.* 2019;49(6):917-929.