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Qualitative and quantitative return-to-sport test battery and second anterior cruciate ligament injury risk factors

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ABSTRACT

Objective To determine risk factors for second anterior cruciate ligament (ACL) injury following primary ACL reconstruction (ACLR) using return-to-sport (RTS) tests consisting of qualitative and quantitative measures in young athletes.

Methods A case–control study design was used, and a retrospective review of adolescent athletes after primary ACLR was performed. All athletes completed an RTS test consisting of qualitative and quantitative assessments and psychological assessments with the Tampa Scale of Kinesiophobia. Athlete demographics, surgical characteristics and sports participation were also examined. A binary logistic regression was performed to verify an independent association between risk factors and second ACL injury using adjusted OR (aORs), 95% CI and $p<0.05$.

Results In 72 eligible athletes, 12 (16.7%) suffered a second ACL injury. The mean Tegner activity level was 8.4+1.1, and the mean time from ACLR to RTS test completion was 10.4+2.9 months. One variable that showed the lowest p-value in the preliminary analysis was entered into the binary logistic regression model, which resulted in that qualitative assessment of knee valgus during the sidestep cut was associated with second ACL injury (aOR=4.64, 95% CI: 1.18 to 18.23, p=0.03).

Conclusion Athletes who demonstrated excessive dynamic knee valgus on the involved limb during the sidestep cut were approximately 4.6 times more likely to suffer a second ACL injury.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Quantitative assessments, such as strength and hop test performance, and psychological assessments are frequently used as part of return-to-sport testing after anterior cruciate ligament (ACL) reconstruction (ACLR) and have been found to predict second ACL injury.

WHAT THIS STUDY ADDS

⇒ This study identifies qualitative risk factors for second ACL injury in adolescent athletes. Excessive knee valgus during a cutting task was associated with second ACL injury after primary ACLR in adolescent athletes.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Return-to-sport tests after ACLR should include a qualitative assessment of knee valgus during a cutting or change of direction task.

INTRODUCTION

Nearly one-quarter of young athletes who return to sport (RTS) after primary anterior cruciate ligament reconstruction (ACLR) sustain a second ACL injury, with 74% occurring within the first 2 years after RTS.[1–3] RTS tests have been developed to determine an athlete's readiness to RTS safely. However, there is a lack of consensus regarding the specific criteria that should be included in the testing.[4] Furthermore, there is mixed evidence on the capacity of an RTS test battery to identify those at an increased risk of suffering a second ACL injury.[5–8] A recent systematic review with meta-analysis reported no reduction in second ACL injury risk for those who passed the RTS test criteria.[6] Another systematic review and meta-analysis found that passing RTS test criteria reduced the risk of graft injury by 60%. However, this study also showed an increased risk of contralateral ACL injury by 235%.[7]

The inconsistent ability of RTS tests to predict a second injury may be related to the lack of studies that consider the quality of movement outcomes. Most RTS tests in the literature include only quantitative assessments such as strength and hop test performance measured with limb symmetry index (LSI).[5 9] However, it has been reported that trunk and lower extremity (LE) biomechanics remain altered for several years after ACLR.[10 11] Furthermore, another study found that deficits in neuromuscular control of the trunk and LE during landings were indicators of risk for second ACL injury.[12] This suggests that quality of movement may be a clinically important component to consider when determining an athlete's readiness to return to their sport safely.

Limited studies of RTS test batteries include quantitative and qualitative assessments to identify second ACL injury risk. Using qualitative criteria, Van Melick *et al* reported a significant association between a single leg hop and hold test and a second ACL injury in 175 athletes.[13] While this test assesses the athlete's ability to hold a position of deep knee flexion while landing, it fails to assess frontal plane trunk and knee alignment, which have been identified as key biomechanical contributors to second ACL injury risk.[10 11 13] Graziano *et al* assessed the effectiveness of the movement assessment quality during various functional tasks. However, this study did not evaluate the relationship between quality of movement criteria and second ACL injury.[14] The evidence related to specific RTS test components associated with second ACL injury is inconsistent and lacks qualitative assessments. Knowledge of specific quantitative and qualitative test criteria that predict second ACL injury risk will help clinicians choose the most appropriate assessments for evaluating readiness for RTS after ACLR. This study aimed to determine the risk factors for second ACL injury following primary ACLR using RTS tests consisting of qualitative and quantitative measures in young athletes. We hypothesised that qualitative RTS test outcomes would be associated with an increased risk for second ACL injury after primary ACLR in adolescent athletes.

METHODS

Study design and participants

This case–control study was completed through a retrospective chart review of adolescent athletes who underwent ACLR between 2014 and 2021 at one regional paediatric healthcare institution. Patients were included if they underwent ACLR during the defined time, were between the ages of 10 and 18 years at the time of ACLR, completed a formal RTS test, intended to RTS and reported a preinjury Tegner Activity Score greater than or equal to six. Patients with concomitant ligament injuries requiring repair or reconstruction, prior ipsilateral or contralateral LE surgery history, Tegner Activity Scores of five or fewer and those who did not complete formal RTS testing were excluded. ACLR patients with allograft were also excluded due to their known increased risk of graft rupture in paediatric and adolescent populations.[15–18] This study was approved by the Western Institutional Review Board (IRB #2019062RI) before initiation. Given the retrospective study design, a waiver of participant consent was obtained, and patients were not involved.

RTS test

All athletes who underwent ACLR followed the standard rehabilitation protocol provided by the host study institution under the guidance of their physical therapist. After being cleared by their orthopaedic surgeon for testing, all athletes completed an RTS test, which consisted of three single-leg hop tests: the single hop for distance (SHD), triple hop for distance (THD) and triple crossover hop for distance (TCHD). This hop test battery has frequently been cited in the literature for RTS testing after ACLR and has demonstrated strong reliability.[9 19 20] The performance of each hop test was scored using a dichotomous quality of movement assessment tool adapted from the Qualitative Assessment of Single Leg Loading (QASLS).[21 22] The QASLS is a 10-item qualitative scoring tool for the analysis of dynamic single-leg tasks.[21 22] The tool has demonstrated excellent validity compared with three-dimensional motion capture and excellent intrarater and inter-rater reliability for a single-leg squat task.[21 22] More recently, the reliability of the QASLS was assessed during a single-leg landing task with perfect to excellent intrarater agreement (k=0.85–1.0). However, inter-rater reliability was poor (k=0.03–0.17).[23] Parry *et al* also reported a measurement error of 1 between testing timeframes for the QASLS and suggested a change of 1–3 points is required to identify a change in performance.[23] Specifically, the tool used in this study assesses trunk alignment, knee position at take-off and landing for noticeable and significant valgus, stiff landing, use of an arm strategy to recover balance, steady stance and loss of pelvic plane alignment for the SHD (figure 1A). For the THD and the TCHD, pause between hops was also included as a qualitative criterion (figure 1B). Qualitative criteria, including trunk alignment, arm strategy, steady stance and pelvic plane, followed the definitions and scoring system used in the QASLS.[21 22] Two time points were added for knee position, including an assessment at take-off and landing. The definition for knee position followed the criteria used in the QASLS with a movement error scored 'yes' if the patella points towards the second toe (noticeable valgus) or if the patella points past the inside of the foot (significant valgus). Athletes are awarded one point for noticeable valgus and two for significant valgus.[21 22] For the criteria of stiff landing, if the athlete landed with a stiff extended knee posture (observed qualitatively by the examiner), the criteria were scored 'yes', and the athlete was awarded one point. If the athlete landed with a soft flexed knee position (observed qualitatively by the examiner), the criteria were scored 'no', and the athlete was awarded zero points. For the criteria of pause between hops, if the athlete paused between consecutive hops on the THD or the TCHD, the criteria were scored 'yes', and the athlete was awarded one point. If the athlete did not pause between consecutive hops, the criteria were scored 'no', and the athlete was awarded zero points. The total points for each observed movement fault on the single-leg hop tests were summed to create a total score, with higher scores indicating poorer movement quality. Qualitatively, passing was defined as achieving a quality of movement total score less than or equal to two on all three hop tests individually. For quantitative analysis, limb symmetry indices (LSIs) were also calculated for all hop tests using the following equation: LSI = (surgical/uninvolved) x 100%.[24] Quantitatively, passing the hop tests was defined by achieving an LSI≥95%, which was chosen based on the work of Ebert *et al*, who identified mean LSIs of 95%, 96.1% and 95.3% for the SHD, THD

A Single Leg Hop for Distance
Passing Criteria: Score ≤2

Faults	Right	Left
Arm strategy	Yes (1) No (0)	Yes (1) No (0)
Trunk alignment	Yes (1) No (0)	Yes (1) No (0)
Pelvic plane	Yes (1) No (0)	Yes (1) No (0)
Steady stance	Yes (1) No (0)	Yes (1) No (0)
Stiff landing	Yes (1) No (0)	Yes (1) No (0)
Knee position (take off) noticeable valgus	Yes (1) No (0)	Yes (1) No (0)
Knee position (take off) significant valgus	Yes (1) No (0)	Yes (1) No (0)
Knee position (landing) noticeable valgus	Yes (1) No (0)	Yes (1) No (0)
Knee position (landing) significant valgus	Yes (1) No (0)	Yes (1) No (0)
Minimal score = 0* Maximum score = 9 for each limb**		

B Triple Hop and Triple Crossover Hop for Distance
Passing Criteria: Score ≤2

Faults	Right	Left
Arm strategy	Yes (1) No (0)	Yes (1) No (0)
Trunk alignment	Yes (1) No (0)	Yes (1) No (0)
Pelvic plane	Yes (1) No (0)	Yes (1) No (0)
Steady stance	Yes (1) No (0)	Yes (1) No (0)
Stiff landing	Yes (1) No (0)	Yes (1) No (0)
Pause between hops	Yes (1) No (0)	Yes (1) No (0)
Knee position (take off) noticeable valgus	Yes (1) No (0)	Yes (1) No (0)
Knee position (take off) significant valgus	Yes (1) No (0)	Yes (1) No (0)
Knee position (landing) noticeable valgus	Yes (1) No (0)	Yes (1) No (0)
Knee position (landing) significant valgus	Yes (1) No (0)	Yes (1) No (0)
Minimal score = 0* Maximum score = 10 for each limb**		

C 45-degree Sidestep Cut
Passing Criteria: Score ≤2

Faults	Right	Left
Trunk lean to opposite direction of cut	Yes (1) No (0)	Yes (1) No (0)
Pelvic plane	Yes (1) No (0)	Yes (1) No (0)
Static/dynamic valgus on the weight bearing limb	Yes (1) No (0)	Yes (1) No (0)
Decreased knee flexion angle	Yes (1) No (0)	Yes (1) No (0)
Decreased plantarflexion angle	Yes (1) No (0)	Yes (1) No (0)
Foot position excessively inverted or everted	Yes (1) No (0)	Yes (1) No (0)
Increased cut width	Yes (1) No (0)	Yes (1) No (0)
Minimal score = 0* Maximum score = 7 for each limb**		

D Lateral Step-Down Test
Passing Criteria: Score ≤1

Faults	Right	Left
Arm strategy	Yes (1) No (0)	Yes (1) No (0)
Trunk alignment	Yes (1) No (0)	Yes (1) No (0)
Pelvic plane	Yes (1) No (0)	Yes (1) No (0)
Steady stance	Yes (1) No (0)	Yes (1) No (0)
Knee position noticeable valgus	Yes (1) No (0)	Yes (1) No (0)
Knee position significant valgus	Yes (1) No (0)	Yes (1) No (0)
Minimal score = 0* Maximum score = 6 for each limb**		

*lower scores are indicative of good quality of movement
**higher scores are indicative of poor quality of movement

Figure 1 Qualitative assessments. Qualitative assessment for single-leg hop for distance testing (A), qualitative assessment for triple hop for distance and triple crossover hop (B), qualitative assessment for 45° sidestep cut (C) and qualitative assessment for the lateral step-down test (D).

and the TCHD, respectively, in participants 9–12 months after ACLR.[25]

Additionally, participants performed a 45° sidestep cut (SSC) task, which was scored using a quality of movement checklist established by Butler *et al*.[26 27] The SSC task was performed using the testing protocol described by McLean *et al*.[28] Athletes were instructed to run at 80% of their maximum speed in a forward direction toward an 'opponent cone', to pivot and perform the cut, running between cones placed along a 45° line of progression.[28] The cutting assessment checklist assessed for a trunk lean to the opposite direction of the cut, increased cut width, static and dynamic valgus on the weight-bearing limb, loss of pelvic plane position, decreased knee flexion angle, decreased plantarflexion angle and foot position excessively inverted or everted (figure 1C). The criteria for trunk lean to the opposite direction of the cut, increased cut width, decreased knee flexion angle and decreased plantarflexion angle followed the definitions and scoring criteria of the Expanded Cutting Alignment Scoring tool (E-CAST).[26 27] Static/dynamic valgus on the weight-bearing limb included the static and dynamic evaluation used in the E-CAST.[26] Specifically, the movement criteria were scored 'yes'. They awarded one point if, during the plant phase of the cut, the weight-bearing limb demonstrated valgus (thigh adduction, genu valgum or knee abduction). The E-CAST has demonstrated moderate to good evidence for concurrent validity with three-dimensional motion capture during a SSC task and good intrarater and moderate inter-rater reliability.[26 27] The pelvic plane criterion was added and is defined by the work of Almangoush *et al*.[21] The criterion of foot position excessively inverted or everted was added based on the work of Kristianslund *et al* and is defined as follows: at the time point of initial contact, if the athlete's foot is excessively inverted or everted score 'yes' and award one point.[29] If the athlete's foot is not excessively inverted or everted, score 'no' and award zero points. The total points for each observed movement fault were summed to create a total score, and higher scores indicated poorer quality of movement. Passing was defined as achieving a total score less than or equal to two. Participants completed a lateral step-down (LSD) test consisting of five repetitions of a single-leg LSD from a 6-inch step, which was scored with a qualitative checklist assessing for knee position (noticeable or significant valgus), trunk alignment, steady stance, use of arm strategy to recover balance and loss of pelvic plane alignment (figure 1D). All criteria for the LSD followed the definitions and scoring system of Almangoush *et al*, with higher scores indicating poorer performance.[21 22] Passing the LSD was defined as a score less than or equal to one. Finally, the participants performed the Tuck Jump Assessment with a passing score of less than or equal to five points and completed a psychological assessment with the Tampa Scale of Kinesiophopia 11 (TSK-11).[30 31]

A physical therapist conducted all testing at one of seven different outpatient centres, all associated with the primary institution. In total, seven physical therapists administered the RTS tests. Tests were video recorded with one frontal plane view, which was scored using the qualitative assessment. All videos were scored by one of three senior physical therapists associated with the primary institution. Given that testing occurred at multiple locations and included athletes receiving physical therapy inside and outside the host institution, the physical therapist who scored the RTS test may or may not have been the treating physical therapist for the athlete. When an athlete failed to meet the RTS test criteria, the testing physical therapist advised the athlete to continue with physical therapy and return for a new RTS test when their physical therapist felt they were ready. In these cases, the most recent RTS test results were used for analysis (n=23). The second ACL injury was identified by reviewing the physician follow-up visit notes from the medical record within the first 3 years after primary ACLR. All second ACL injuries were confirmed with MRI and documented by the physician in the medial record.

Primary outcome variables included the results of each qualitative and quantitative RTS test assessment and the TSK-11 score, which were analysed by the participants' reinjury status (second ACL injury including graft rupture, contralateral ACL injury and no second injury). Additionally, demographics, sports participation and surgical data, including age at surgery, sex, body mass index (BMI), primary sport, and graft choice, were evaluated.

Statistical analysis

Potential risk factors, including the results of each qualitative and quantitative RTS test assessment, the TSK-11 score, patient characteristics and surgical data, were compared between those who sustained second ACL injuries and those who did not. The demographic, sports participation and surgical variables were analysed using descriptive statistics. RTS criteria were compared using bivariate, unadjusted analyses for athletes who sustained a second ACL tear and those who did not. An independent t-test was used to compare continuous variables that were normally distributed. Mann-Whitney U test was used for non-normal data. A χ^2 test was used to compare categorical variables. All variables that appeared different between the two groups (second ACL injury sustained and no second ACL injury sustained) with a significance of p<0.20 in the preliminary analysis were identified. A parameter with the lowest p-value was entered in a binary logistic regression model among the identified variables. A binary logistic regression model was then used to determine the independent association between each RTS criteria and the second ACL injury, generating adjusted ORs (aORs) and a 95% CI. Any variables with values of 0 (zero) or 100% were not entered in the binary logistic regression model since statistical calculations cannot be done on an association in a table with an empty cell. Significance was defined as 95% CI of aORs that did not cross one. Given the study's retrospective nature and the lack of prior data regarding many of the qualitative RTS variables, a power analysis was not performed. All analyses were performed using SPSS V.28.

RESULTS

A total of 180 athletes who underwent primary ACLR with two surgeons during the study period and completed an RTS test were identified in the medical record. Missing data were identified in 20 records; three athletes sustained concomitant injuries and 85 patients underwent reconstructions with allograft tissue and were excluded, leaving 72 athletes for the analysis (figure 2). The mean athlete age was 16.1±1.6 years, with 47 males and 25 females. The most frequent graft type was quadriceps tendon autograft (41.7%), followed by hamstring autograft (36.1%). Soccer was the most frequent primary sport (41.7%), followed by football (23.6%) and basketball (19.4%). The mean preinjury Tegner score was 8.4±1.1, and the mean time from ACLR to RTS was 10.4±2.9 months (table 1). Among 72 athletes, 12 athletes (16.7%) suffered a second ACL injury, including graft ruptures (n=8) and contralateral injuries (n=4). Ten athletes suffered a second ACL injury within 24 months of primary ACLR, and two suffered a second ACL injury within 36 months of primary ACLR. Among the criteria examined in the bivariate unadjusted preliminary analyses, seven variables were significant at p<0.20, excluding variables that had values of 0 (zero) or 100% (online supplemental appendix 1–7). Among the seven variables, those who sustained a second ACL injury demonstrated deficits, including excessive knee valgus on the SSC, demonstrating the lowest p-value (p=0.020) (online supplemental appendix 1–7). Therefore, this variable was entered in a binary logistic regression model. The binary logistic regression analysis identified an association between the incidence of second ACL injury and static/dynamic knee valgus on the weight-bearing limb during the SSC on the involved limb (table 2).

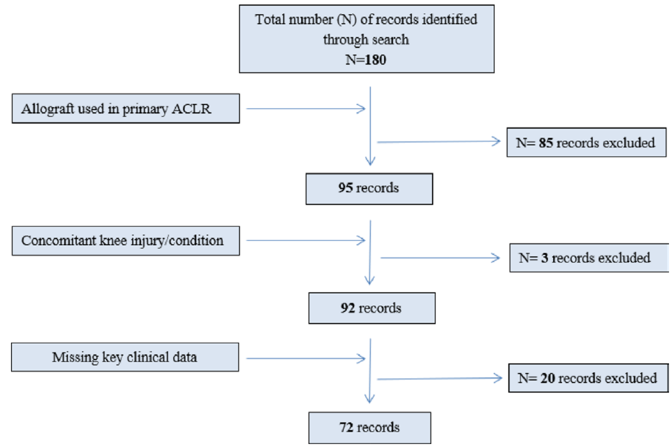

Figure 2 Flowchart demonstrating exclusion criteria. ACLR, anterior cruciate ligament reconstruction.

DISCUSSION

Clinical implications

This study aimed to evaluate risk factors for second ACL injury following primary ACLR using RTS testing that included qualitative and quantitative measures. Our study identified static/dynamic knee valgus on the weight-bearing limb during the SSC on the involved limb as a risk factor for a second ACL injury, supporting our hypothesis that qualitative RTS measures can predict a second injury and are important to include in the evaluation for

Table 1 Athlete demographics

Demographics	Overall, n=72
Physical characteristics	
Age*	16.1 (1.6)
BMI*	23.6 (4.0)
Sex	
Male	58 (80.6%)
Female	14 (19.4%)
Physical Activity Scale	
Tegner score*	8.4 (1.1)
Graft type	
Quadriceps tendon autograft	30 (41.7%)
Hamstring autograft	26 (36.1%)
BTB autograft	6 (8.3%)
Other	10 (13.9%)
Timeline following ACLR	
Time from ACLR to RTS*	10.4 (2.9)
Primary sport types	
Soccer	30 (41.7%)
Football	17 (23.6%)
Basketball	14 (19.4%)
Volleyball	6 (8.3%)
Baseball	2 (2.8%)
Wrestling	1 (1.4%)
Recreation/PE	1 (1.4%)
Other	1 (1.4%)

*Mean (SD).
ACL, anterior cruciate ligament; ACLR, ACL reconstruction; BMI, body mass index; BTB, bone (patellar) tendon bone; RTS, return-to-sport.

readiness for sports. Athletes who demonstrated involved limb static/dynamic knee valgus during the SSC were approximately 4.6 times more likely to suffer a second ACL injury (aOR=4.64, 95% CI: 1.18 to 18.23, p=0.03)

Table 2 Results of binary logistic regression model of RTS variables on second ACL injury

Predictor	aORs (95% CI)	P value
SSC static/dynamic valgus on the weight-bearing limb on the involved limb	4.64 (1.18 to 18.23)	0.03*

*Statistically significant p<0.05. The full model containing all risk factors was statistically significant (Omnibus test, p=0.03), indicating that the model could distinguish between those with and without second ACL injury. The model explained between 6.2% (Cox and Snell R^2) and 10.4% (Nagelkerke R^2) of the second ACL injury status variance and correctly classified 83.3% of cases.
ACL, anterior cruciate ligament; aORs, adjusted OR; RTC, return-to-sport; SSC, sidestep cut.

than their peers. This is consistent with studies of primary ACL injury, which have found that knee valgus places excessive strain on the knee during jumping and cutting tasks and is a risk factor for ACL injury.[5 12 32] Our study suggests that dynamic knee valgus may also be one of the most important variables to consider for secondary ACL injury risk reduction. Interestingly, dynamic knee valgus on the involved limb during the SSC was a predictor of graft rupture and contralateral injuries. The native ACL has a mechanoreceptor that, once torn, alters the individual's feedback system.[33] This reduced efferent feedback has been reported to contribute to increased knee valgus on the involved limb. It is possible that the higher propensity of knee valgus on the involved limb may alter LE loading on the uninvolved limb during a SSC task in a way that increases the risk of both graft rupture and contralateral ACL injury.[33] Frontal plane trunk compensations in all tasks were not found to be predictive of a second ACL injury. This is likely due to this study's high percentage of male subjects. While poor frontal plane trunk control has been associated with higher knee abduction moments in females, this same compensation is not predictive of ACL injury in males.[34–36]

Although age at ACLR surgery was not entered in the binary logistic regression model, this variable demonstrated the second lowest p-value in our preliminary analysis, which showed those who sustained a second ACL injury were younger at the time of surgery. This is consistent with prior work, which found that increased age decreased the odds of ACL graft rupture.[37] Another variable that demonstrated the cut-off value of p<0.2 in our preliminary analysis was the TSK-11, which showed lower fear among athletes who sustained a second ACL injury than those who did not sustain a second ACL injury. Our findings contrast with the work of Paterno *et al*, who reported that a higher fear of reinjury at the time of RTS was associated with an increased risk of a second ACL injury.[38] In Paterno's work, the patients who went on to suffer a graft rupture had significantly greater TSK-11 scores at the time of RTS (19.8±4.0) compared with those who did not (16.4±3.6) (p=0.03).[38] Specifically, patients who were classified as having high fear were 13 times more likely to suffer a graft rupture (relative risk (RR), 13.0; 95% CI: 2.1 to 81.0).[38] Paterno *et al* reported that fear of reinjury was not associated with contralateral second ACL injury (p=0.652).[38] There are important differences in study design that may have contributed to the findings between the current study and that of Paterno *et al*. First, in the current study, all second injuries were grouped into one category, including both contralateral and ipsilateral reinjury. This suggests the relationship between fear of reinjury and second ACL injury may be limb-dependent. The work of Paterno *et al* was also limited to a smaller sample, and the authors' knowledge is that no other studies have explored this area. Future works should continue to explore the relationship between fear of reinjury and second ACL injury risk between ipsilateral and contralateral limbs. Furthermore, several works have suggested fear of reinjury as a contributing factor for patient failure to RTS.[39–42] In this study, we only assessed an intent to RTS and could not determine if the athlete returned to their sport and at what competitive level they returned to. Thus, it is plausible that those with high fear either did not return or did not return at their previous level of function, which may have contributed to our findings.

Limitations

This study has a few limitations. First, we could not control for the physical therapy treatment that each athlete received up until the time of the RTS test. Although each athlete received the host institution's standard postoperative ACLR protocol, many received physical therapy services at outside facilities. Next, the RTS test was administered by seven physical therapists at different locations, which might have impacted the reliability of the test, especially inter-rater reliability. However, only three physical therapists scored on each test. Given the one-point measurement error reported for the QASLS, this may have impacted the results for the LSD test and the single-leg hop tests, as the qualitative variables included in this study for those respective tasks were primarily based on the definitions of the QASLS.[23] However, this variability is likely representative of actual clinical practice and improves the generalisability of the study findings. Importantly, there are no studies of the reliability of the qualitative variables included in the RTS testing. While all therapists involved in the study work together and are trained in evaluating these movement factors, the potential subjectivity and reliability are another limitation. Given the retrospective nature of this study, we were also unable to confirm the presence or absence of reinjury in the no second ACL injury group. It is possible that some patients with a second ACL injury may have followed up with a different physician, which may have under-represented second ACL injury in our study.[14] We also only assessed an intent to RTS and were unable to determine what competitive level they returned to, which can also impact second injuries. However, we confirmed that all athletes had an intention to return to their original sports at the time of RTS testing.

CONCLUSION

This study identified qualitative knee valgus during a cutting task as a risk factor for second ACL injury after primary ACLR in adolescent athletes, suggesting approximately 4.6 times greater odds of sustaining a second ACL injury. Including quality of movement assessments that identify knee valgus during a cutting or change of direction task is recommended when implementing RTS tests to identify better those at an increased risk of a second injury and implement training during rehabilitation that can improve these mechanics. Future studies should continue exploring RTS test criteria, specifically qualitative ones, that predict second ACL injury risk.

Contributors LB: conceptualisation, investigation, original draft, table and figure developments, revisions and final approval; AM: conceptualisation, investigation, original draft, table and figure developments and final approval; ME: original draft and final approval; GC: formal analysis, original draft, revisions and final approval; MW: original draft and final approval; DS: conceptualisation, original draft, table developments, revisions and final approval. Guarantor: LB.

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Patient consent for publication Not applicable.

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