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Prior History of Anterior Cruciate Ligament (ACL) Reconstruction is Associated with a Greater Risk of Subsequent ACL Injury in Female Collegiate Athletes

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Prior history of anterior cruciate ligament (ACL) reconstruction is associated with a greater risk of subsequent ACL injury in female collegiate athletes

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A B S T R A C T

Objectives: The risk of a subsequent anterior cruciate ligament (ACL) sprain is greater in high school aged female athletes with prior history of ACL reconstruction (ACLR) than in age-matched controls. The risk of a subsequent ACL injury in female collegiate athletes with prior ACLR is unknown. The primary purpose of this study was to determine the relative risk of a subsequent ACL injury in female collegiate athletes with prior ACLR when compared to age-matched controls. The secondary purpose of this study was to evaluate the ability of jump and hop tests to discriminate ACL injury risk.
Design: Prospective cohort.
Methods: Three hundred and sixty female collegiate athletes (mean age 19.3 ± 1.4 years) representing the following sports: volleyball, soccer, and basketball were recruited.

Subjects reported prior history of ACLR and standing long jump (SLJ) and single-leg hop (SLH) scores were collected during the preseason. Noncontact time-loss ACL and lower quadrant (i.e., low back and lower extremities) injuries were tracked by university athletic trainers.
Results: Female collegiate athletes with a prior history of ACLR were 6 times (RR = 6.8 [95% CI: 1.4, 32.9] p-value = 0.007) more likely to experience an ACL injury than controls. Suboptimal performance on a battery of tests (SLJ ≤ 79% height, (B) SLH ≤ 69% height) was associated with a greater risk of lower quadrant injury (RR = 1.6 [95% CI: 1.1, 2.4] p-value = 0.028); however performance on these tests was not associated with ACL injury.
Conclusions: Female collegiate athletes should be screened for history of ACLR.

Practical implications

- Prior history of ACLR is associated with a greater risk of a second ACL injury in female collegiate athletes.
- Preseason performance of the standing long jump and single-leg hop tests are associated with a greater risk of a noncontact time-loss lower quadrant injury; however, these tests do not discriminate risk of ACL injury.
- Prospective evaluation of other potential risk factors for ACL injury is warranted.

1. Introduction

An anterior cruciate ligament (ACL) sprain is a significant injury that usually leads to the end of the athlete's season followed by surgical reconstruction (ACLR). An athlete post-ACLR will require at least nine months of rehabilitation before returning to sport.[1] Many athletes post-ACLR will continue to have deficits 1- to 2-years post-ACLR with some athletes failing to return to competition.[2–4]

Athletes who have had prior ACLR are also at risk for a subsequent ACL injury.[5,6] High school aged females with prior ACLR were 16 times more likely to experience a second ACL injury within 1 year of returning to sport (RTS) and 4.5 times more likely to experience

Table 1
Study demographics: age [mean (SD)], prior history of ACLR, lower quadrant injuries per sport (counts).

Characteristic	Volleyball players (n = 187)	Soccer players (n = 118)	Basketball players (n = 55)	Totals (n = 360)
Age (y)	19.1 (1.1)	19.2 (1.2)	20.2 (2.2)	19.3 (1.4)
Prior history of ACLR (% per sport participation)	6 (3)	10 (9)	4 (7)	20 (6)
Noncontact time-loss injuries per region during study				
Lower quadrant	31	37	5	73
Thigh/knee region	9	21	3	33
Anterior cruciate ligament sprain	3	3	1	7

ACLR = anterior cruciate ligament reconstruction.

a second ACL injury within 2 years of RTS when compared to the risk of an initial ACL injury in counterparts with no prior history of ACLR.[5,6] While the risk of a secondary ACL injury in younger female athletes with a prior history of ACLR has been reported the risk of a subsequent ACL injury in female collegiate athletes with prior ACLR is unknown.[5–7]

An ACL injury for a collegiate athlete has significant implications. The loss of the injured athlete may impact the team's success and may jeopardize an athlete's athletic scholarship. In addition, the injured athlete will require months of rehabilitation services from the university's athletic training staff. While the risk of a subsequent ACL injury in female collegiate athletes is unknown the rate of ACL injury has been reported for many female collegiate sports.[8–10] For example, female basketball players experience 0.20–0.23 ACL injuries per 1000 athletic exposures (AE), female soccer players experience 0.10–0.28 per 1000 AE, and female volleyball players experience 0.06–0.09 per 1000 AE.[8–10] The rate of ACL injury in some female collegiate athletes is higher than the rates in female high school athletes (e.g., basketball: 0.20–0.23/1000 AE college; 0.12/1000 AE high school; soccer: 0.10–0.28/1000 AE college; 0.18/1000 high school).[8–10] It is therefore possible that the risk of subsequent ACL injury in female collegiate athletes is also high.

Not all athletes with prior ACLR experience a second ACL injury. However, the ability to identify athletes at risk for ACL injury is warranted. One functional performance test (FPT), the drop vertical jump (DVJ), had demonstrated early promise as a screening tool to discriminate ACL injury risk in female high school athletes and in athletes with prior history of ACLR.[11,12] For example, Hewett et al found high school female athletes who suffered an ACL injury had a significantly greater knee abduction angle, a greater knee abduction moment, had a greater ground reaction force, and had shorter stance time during DVJ testing.[11] However, subsequent prospective cohort studies have either failed to validate initial predictors of injury associated with DVJ performance or have reported different associations between DVJ performance and injury.[13–15] Krosshaug et al. reported that DVJ variables did not discriminate injury risk in athletes with no prior history of ACL injury.[13] For athletes with a prior history of ACLR only medial knee displacement was associated with a subsequent ACL injury.[13] Leppanen et al. reported two variables that were associated with a greater risk of ACL injury in female athletes: less hip flexion ROM and a greater peak external knee flexion moment.[14] In a separate study Leppanen et al reported that a stiff landing from a DVJ with less knee flexion and a greater vertical ground reaction force was associated with a greater risk of ACL injury.[15] These inconsistent findings challenge a clinician's ability to use the DVJ to discriminate ACL injury risk; therefore additional studies utilizing different FPTs to discriminate ACL injury risk is warranted.

Two FPTs, the standing long jump (SLJ) and the single-leg hop (SLH) for distance, have demonstrated promise as preseason screening tools for lower quadrant (i.e., low back and lower extremities) injury in female collegiate athletes.[16–18] These aforementioned FPTs are frequently used to assess an athlete's readiness to return to sport after ACLR[19–21]; however, they have not been prospectively assessed for their ability to discriminate ACL injury.

The ability to identify athletes at risk for an ACL injury followed by applying an injury prevention training program may help reduce the risk of injury.[22] Therefore, evaluating additional risk factors for ACL injury is warranted. The primary purpose of this study was to determine the risk of an ACL sprain in a population of female collegiate athletes. It was hypothesized that female collegiate athletes with prior history of ACLR would be at a greater risk of a noncontact time-loss ACL injury than their counterparts. The secondary purpose of this study was to evaluate the ability of the SLJ and the SLH tests to discriminate lower quadrant (i.e., low back and lower extremities) and ACL injury risk in female collegiate athletes. It was hypothesized that athletes with shorter normalized SLJ and/or SLH tests would have a greater risk of noncontact time-loss lower quadrant or ACL injury.

2. Methods

A total of 360 female collegiate athletes (mean age = 19.3 ± 1.4 years) were recruited between the years of 2009–2017 to participate in a larger on-going study investigating risk factors for noncontact time-loss injury during sport. Athletes were recruited from National Collegiate Athletic Association (NCAA) Division II (volleyball = 31), Division III (volleyball = 131, soccer = 101, basketball = 19), and National Athletic Intercollegiate Association (volleyball = 25, soccer = 17, basketball = 36) universities/colleges. Twenty athletes (6% of the population) reported a prior history of ACLR (Table 1).

The recruitment process was performed in two steps. The primary investigator (PI) would first recruit team participation by contacting a team's head coach and athletic trainer (ATC) via email or phone. If the head coach and ATC agreed to participate the PI would next recruit athlete participation via email. An athlete was included in this study if they were not restricted from preseason sport participation due to injury. An athlete was restricted from study participation if she was under the age of 18 at the time of testing. The Institutional Review Board of George Fox University (Newberg, OR, USA) approved this study. Informed consent was collected from each athlete prior to study participation.

Athletes completed an injury history questionnaire, had their height measured, and performed the FPTs during a testing session at the start of the preseason. The following information was collected from each athlete: age and prior history of ACLR. Height was collected using a cloth measuring tape affixed to a wall. Next, athletes performed a 5-min dynamic warm-up prior to SLJ and SLH testing. The dynamic warm-up, performed in a hallway adjacent to the lab or across the width of a basketball court, consisted of the following movements: forward walking, backward walking, heel walking, tip toe walking, forward lunging, backward lunging, and high knee marching (athletes were instructed to perform each movement 3 to 4 times).[16] Three submaximal SLJ were performed as a continuation of the warm-up prior to maximal effort jump and hop testing.

Jump and hop testing was conducted either in the research laboratory or on a basketball court. The SLJ test was performed first (3 trials) followed by SLH testing (3 trials per lower extremity).[19,23,24] [Note: The SLJ test was performed prior to the SLH tests because

Table 2
Relative risk of injury per functional performance test (FPT) scores and prior history of anterior cruciate ligament reconstruction (ACLR).

Risk factor	N at risk	All LQ injuries N (%)	Relative risk (95% CI)	Thigh and knee injuries N (%)	Relative risk (95% CI)	ACL injuries N (%)	Relative risk
Standing long jump							
80% or more	196	38 (19)	1.0 (Reference)	18 (9)	1.0 (Reference)	4 (2)	1.0 (Reference)
79% or less	164	35 (21)	1.1 (0.7, 1.7)	15 (9)	1.0 (0.5, 1.9)	3 (2)	0.9 (0.2, 3.9)
(R) Single-leg hop							
70% or more	177	32 (18)	1.0 (Reference)	14 (8)	1.0 (Reference)	4 (2)	1.0 (Reference)
69% or less	183	41 (22)	1.2 (0.8, 1.9)	19 (10)	1.3 (0.7, 2.5)	3 (2)	0.7 (0.2, 3.2)
(L) Single-leg hop							
70% or more	156	29 (19)	1.0 (Reference)	13 (8)	1.0 (Reference)	4 (3)	1.0 (Reference)
69% or less	204	44 (22)	1.2 (0.8, 1.8)	20 (10)	1.2 (0.6, 2.3)	3 (2)	0.6 (0.1, 2.5)
Performance on all 3 FPT							
All 3 FPT below cutoff scores*	119	32 (27)	1.6 (1.1, 2.4)†	15 (13)	1.7 (0.9, 3.2)	2 (2)	0.8 (0.2, 4.1)
All Other Athletes	241	41 (17)	1.0 (Reference)	18 (8)	1.0 (Reference)	5 (2)	1.0 (Reference)
Limb asymmetry between SLH							
Asymmetry > 10 percent	270	53 (20)	1.0 (Reference)	27 (10)	1.0 (Reference)	5 (2)	1.0 (Reference)
Asymmetry ≤ 10 percent	90	20 (22)	1.1 (0.7, 1.8)	6 (7)	0.7 (0.3, 1.6)	2 (2)	1.2 (0.2, 6.0)
Performance on All 3 FPT and SLH asymmetry							
All 3 FPT below cutoff Scores* and asymmetry >10%	31	8 (26)	1.3 (0.7, 2.5)	2 (7)	0.7 (0.2, 2.7)	1 (3)	1.8 (0.2, 14.2)
All other athletes	329	65 (20)	1.0 (Reference)	31 (9)	1.0 (Reference)	6 (2)	1.0 (Reference)
Prior history of ACLR							
Yes	20	3 (15)	0.7 (0.3, 2.1)	3 (15)	1.6 (0.5, 4.9)	2 (10)	6.8 (1.4, 32.9)††
No	340	70 (21)	1.0 (Reference)	30 (9)	1.0 (Reference)	5 (2)	1.0 (Reference)
ACLR and FPT scores							
Prior ACLR and all 3 FPT below cutoff scores*	6	1 (17)	0.8 (0.1, 5.0)	1 (17)	1.8 (0.3, 11.4)	0 (0)	Not calculated**
All other athletes	354	72 (20)	1.0 (Reference)	32 (9)	1.0 (Reference)	7 (2)	

FPT = functional performance test; SLJ = standing long jump; SLH = single-leg hop; ACLR = anterior cruciate ligament reconstruction; N = number.
* SLJ ≤ 79% height, (B) SLH ≤ 69% height.
** No injuries in the at-risk group.
† p-value = 0.028.
†† p-value = 0.007.

it is an easier test for athletes to "stick" their landing (i.e., not lose their balance during the landing or to make extra hops after landing). It is not uncommon for athletes to require additional trials to successfully complete three SLH per extremity].[19,23] Athletes were instructed to stand with feet positioned shoulder width apart behind a piece of athletic tape (or to stand on one foot behind the tape when hopping). An athlete was required to clasp her hands behind her back during each jump or hop.[19,23] A coin-flip was performed to determine which lower extremity was hopped off first, during SLH testing, with subsequent hops alternating between each leg. For a jump or hop trial to count the athlete had to land under control holding the landing for 5 s.[19,23] A trial was repeated if the athlete failed to stick the landing or if she failed to maintain her hands clasped behind her back.[19,23,24] Athletes were allowed a 30 s rest between jumps/hops. Mean scores for the SLJ and SLH were normalized to height (normalization formula: athlete's mean FPT score / athlete's height). The SLJ and SLH have excellent inter- and intrarater reliability.[24] The PI's test-retest reliability ($ICC_{3,3}$) has been previously reported: SLJ (0.96, 95% CI: 0.83, 0.97); (R) SLH (0.95, 95% CI: 0.89, 0.98); (L) SLH (0.96, 95% CI: 0.89, 0.98).[25]

Noncontact time-loss lower quadrant injuries were maintained by each team's ATC. The operational definition of an injury for this study was any muscle, joint, or bone injury to the lower quadrant region that occurred during practice or a game via a noncontact mechanism that required the athlete to be removed from that day's event or prevented the athlete from participating in the subsequent event.[16,18,26] The surveillance period for injury was limited to only the immediate season associated with preseason testing. The PI collected injury data (i.e., diagnoses) on a weekly basis.

An *a priori* sample size estimation of 132 subjects was calculated based on the proportion of ACL injuries in a population of female athletes with (29%) and without (8.5%) a prior history of ACLR.[6] Descriptive statistics were calculated for age (mean ± SD) and prior injury history (counts). Jump and hop measures were normalized as a percentage of height.

Receiver operator characteristic (ROC) curves were calculated to determine potential cutoff scores per each FPT. ROC curves failed to identify cutoff scores that maximized sensitivity (Sn) and specificity (Sp); therefore previously reported cutoff scores were used to discriminate athletes into at risk and reference (i.e., lesser risk) groups.[16–18]

Relative risk (RR) and 95% confidence intervals (CI) were calculated per ACLR history, per individual FPT score, per a battery of FPT scores, and per FPT scores combined with prior ACLR history. Athletes with prior history of ACLR were categorized as at risk with all other athletes comprising the reference group. Individual FPT score categorization was as follows: SLJ ≥ 80% one's height (reference)/SLJ ≤ 79% one's height (at risk); SLH ≥ 70% one's height (reference)/SLH ≤ 69% one's height (at risk); limb asymmetry between SLH > 10 percent (at risk)/limb asymmetry ≤ 10% (reference). Three risk profiles categories, based on FPT scores on a battery of tests were analyzed: Category 1: athletes with SLJ ≤ 79% height and (B) SLH ≤ 69% height (at risk)/all other athletes (reference); Category 2: athletes with SLJ ≤ 79% height, (B) SLH ≤ 69% height, and limb asymmetry between SLH > 10% (at risk)/all other athletes (reference); Category 3: athletes with prior history of ACLR and a SLJ ≤ 79% height and (B) SLH ≤ 69% height (at risk)/all other athletes (reference). Data analysis was performed using SPSS Statistics 24 (Chicago, IL) with the alpha level set at 0.05.

3. Results

A total of 73 noncontact time-loss lower quadrant injuries occurred during the study with 33 injuries occurring in the thigh and knee region with 7 of those injuries ACL sprains (Table 1).

The relative risk of injury based on preseason functional performance test (FPT) measures and/or prior history of ACLR is presented in Table 2. Individual preseason functional test scores (e.g., SLJ only or SLH only) or limb asymmetry during the SLH (i.e., the difference in hop distance between lower extremities) were not associated

with injury. Suboptimal performance on a battery of FPTs (SLJ ≤ 79% height, bilateral SLH ≤ 69% height) was associated with a greater risk of a noncontact time-loss lower quadrant injury (RR = 1.6 [95% CI: 1.1, 2.4] p-value = 0.028). The sensitivity (Sn) and specificity (Sp) associated with this risk profile was 43.8 (95% CI: 32.2, 56.0) and 69.7 (95% CI: 64.0, 75.0) respectively. Prior history of ACLR was associated with a significantly greater risk of a noncontact time-loss ACL sprain (RR = 6.8 [95% CI: 1.4, 32.9] p-value = 0.007). The Sn and Sp associated with this risk profile was 28.6 (95% CI: 3.7, 71.0) and 94.9 (95% CI: 92.1, 97.0) respectively. Prior history of ACLR was not associated with a greater risk of lower quadrant injury or an injury to the thigh and knee region. Combining risk factors of prior ACLR and suboptimal FPT performance was also not associated with a greater risk of injury.

4. Discussion

To our knowledge this is the first study to prospectively evaluate the ability of prior ACLR history and/or preseason SLJ and/or SLH scores to discriminate ACL injury risk in female collegiate athletes. This study found that female collegiate athletes with prior history of ACLR were six times more likely to experience a subsequent ACL injury during sport compared to athletes with no prior history (i.e., initial ACL injury). This finding is consistent with prior reports by Paterno et al.[5,6] who found a significantly greater risk of a secondary ACL injury in high school aged females 1- and 2-years after RTS when compared to the risk of initial ACL injury in counterparts with no prior history of ACLR.[5,6] This study illustrates that the risk of a noncontact ACL injury is still a concern for collegiate athletes.

There are a few potential reasons for the findings in this study. The association between prior ACLR history and subsequent ACL injury is consistent with prior studies that have identified this relationship in high school females.[5,6] It is possible that the female athletes who experienced a subsequent ACL injury still possessed anatomic or other risk factors for an ACL injury and/or had failed to return to their pre-injury status after rehabilitation of their initial injury.[27–29] This study was not able to show the benefit of using the SLJ and SLH tests as screening tools for ACL injury in athletes with or without prior history of ACL. The SLJ and SLH appear to be effective at helping to identify athletes who may be at a greater risk for a noncontact time-loss injury to the lower quadrant region; however, they are not specific for discriminating ACL injury risk.

As a "screening tool" for a subsequent ACL sprain, identifying prior history of ACLR has a Sn of 28.6 (95% CI: 3.7, 71.0) and a Sp of 94.9 (95% CI: 92.1, 97.0). The specificity associated with one having a prior history of ACLR was high. Using the mnemonic SpPin, a positive test (i.e., "yes" to prior ACLR) helps to "rule in" the potential for a subsequent ACL injury.

Sports medicine professionals who work with female collegiate athletes should consider implementing an injury prevention/reduction program for athletes with prior ACLR to reduce the risk of a subsequent ACL sprain.[30–32] Injury prevention programs performed three times a week for either six weeks[33] or 12 weeks[34] have demonstrated a lower incidence of ACL injury for those who participate in the training sessions when compared to control groups. A university sports medicine professional should prescribe an injury prevention training program to at risk athletes (i.e., athletes with prior ACLR) during the off-season. If the SpPin mnemonic had been applied to the athletes in this study then 20 at risk females (i.e., those with prior ACLR) would have been prescribed a six- or 12-week injury prevention program. It is important to highlight that five athletes who sustained an initial ACL injury would not have been identified as "at risk" because they did not have a prior history of ACLR and because the functional tests evaluated in this study were not effective in discriminating ACL injury risk. Future research in the form of prospective cohort studies are warranted to improve the effectiveness of preseason screening programs to identify athletes at risk for ACL injury. It is possible that many tests will need to be administered in the preseason (e.g., prior history of injury, functional tests, isokinetic strength tests, evaluation of kinetic and kinematic variables in a motion capture lab) to improve our ability to identify athletes at risk for an initial or a subsequent ACL injury.

The strengths and limitations of this study should be addressed. The strengths associated with this study include the prospective cohort design and the large sample size. There are a couple limitations to this study that could be addressed in future investigations. First, the sample size estimation for this study was calculated based on prior ACLR. This may explain why no association was found between FPT performance and ACL injury risk. For example, it should be noted that the percentage of ACL injuries per the population in this study (1.9%) was less than the percentage of ACL injuries per the population (4.3%) in Hewett et al.[11] (a study that evaluated DVJ performance and ACL injury risk). Therefore a larger sample size may be necessary to determine if FPTs, like SLJ or the SLH, can discriminate ACL injury risk. Second, this study included athletes from 3 sports: volleyball, basketball, and soccer. Even though 3 out of the 7 ACL injuries that occurred during this study were experienced by volleyball players these athletes traditionally have a lower risk of ACL injury (0.9 per 1000 athletic exposures (AE)) when compared to female basketball players (0.23 per 1000 AE) and female soccer players (0.28 per 1000 AE).[10] Future investigations should evaluate ACL injury risk based on preseason tests and measures in homogeneous sport populations.

5. Conclusion

There was a higher risk of subsequent ACL injury in female collegiate athletes with prior history of ACLR when compared to the risk of an initial ACL injury in their counterparts. Sports medicine professionals who work with female collegiate athletes should identify athletes with prior ACLR and consider administering an injury prevention program. Functional performance tests did not discriminate ACL injury risk in this population.

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