Are athletes ready to return to competitive sports following ACL reconstruction and medical clearance?

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Abstract: Return to sports after anterior cruciate ligament reconstruction (ACLR) is often based on medical clearance and the rehabilitation teams’ decision regarding the physical readiness of athletes. However, re-injury and contralateral injuries are increasing. The purpose of the study was to assess the readiness for return to sport in a sample of division III athletes following ACLR. Twenty-one collegiate athletes (7 males and 14 females) with ACLR and medical clearance to return to sport were recruited. The functional performance of the athletes and the symmetry of both lower extremity measures were evaluated using motion/force-plate analysis, balance, core strength/endurance and functional knee performance testing. Athlete performance reports were provided with training suggestions. The operated lower extremities had a significant decrease in vertical ground reaction force, less knee flexion and more valgus during a single-leg landing task, lower balance scores and reduced hop distance for the majority of participants. Participants continued to show a reduction in operated legs’ performance despite being medically cleared for sports. Lasting deficiencies and their magnitude may explain the increased tendencies for re-injury following ACLR as reported in the literature. Safe return to sport following ACLR should be based on achieving symmetry of performance of lower extremities. A thorough assessment of an athlete’s performance using a comprehensive examination can identify deficiencies and can be used to guide clinical decision-making.

ABOUT THE AUTHOR
Dr. Schilling and Dr. Radwan are physical therapy and rehabilitation experts with 20 years of clinical and academic experience. Through their work, Dr. Schilling and Dr. Radwan have noticed that participants continue to show a reduction in operated legs’ performance despite being medically cleared for sports which increases the tendency for ACL re-injury. The authors are currently advocating for symmetry of functional performance of lower extremities (detected by comprehensive battery of clinical assessment tests and measures) prior to a safe return to sport following ACL reconstruction. This work has been presented at the Combined Sections Meeting (CSM) of the American Physical Therapy Association (APTA) as well as the World Confederation for Physical Therapy Congress (WCPT).

PUBLIC INTEREST STATEMENT
Return to sports after anterior cruciate ligament reconstruction (ACLR) is often based on medical clearance. However, re-injury and contralateral injuries are increasing. This study shows that participants continued to show a reduction in operated legs’ performance despite being medically cleared for sports. Lasting deficiencies and their magnitude may explain the increased tendencies for re-injury following ACLR as reported in the literature. Safe return to sport following ACLR should be based on achieving symmetry of performance of lower extremities. A thorough assessment of an athlete’s performance using a comprehensive examination can identify deficiencies and can be used to guide clinical decision-making.
1. Introduction

Anterior cruciate ligament (ACL) rupture is a serious injury that can have a lasting impact on the life of an athlete. ACL tears are one of the most commonly reported knee injuries in athletes, with a range of 60,000 to 300,000 ACL reconstructions (ACLRs) reported in the literature yearly in the United States (Cohen & Sekiya, 2007; Herzog et al., 2018; Logerstedt et al., 2017). Of those athletes that suffered an ACL rupture, it has been reported that between 50.7% and 77% of patients returned to some level of sporting activity by 12 months after surgery (Ardern, Webster, Taylor, & Feller, 2011; Czuppon, Racette, Klein, & Harris-Hayes, 2014). It is also important to note that there is an alarming number of athletes get reinjured after having an ACLR with re-tear rates ranging from 9.6% to 41% (Czuppon et al., 2014; Gans, Retzky, Jones, & Tanaka, 2018).

ACL injuries sustained by professional and elite athletes have been studied extensively; however, there is a paucity of literature related to Division III (DIII) collegiate athletes. The DIII population is the largest collegiate athletic population in the United States with 191,398 DIII athletes at 451 institutions reported by the National Collegiate Athletic Association (NCAA) participating in 2015 compared to 180,699 Division I (DI) athletes (Irck, 2018). This large population of athletes should be a focus for injury prevention and targeted in research to identify those that are at risk.

Identifying key impairments linked to possible re-injury after ACLR is imperative. Patient-related risk factors for ACL reconstruction re-injury and contralateral ACL injury have been examined in the literature (Logerstedt et al., 2017). One of these factors includes athletes being of a younger age when injured. The rate of a second ACL injury has been reported as high as 35% in younger athletes less than 20 years old (Webster & Feller, 2016). Those athletes that return to a sport that involves cutting, jumping and pivoting have been shown to have higher re-injury rates (Webster & Feller, 2016). The presence of neuromuscular impairments with associated abnormal movement strategies has also been linked to increased risk of re-injury in younger athletes (McIntosh, Dahm, & Stuart, 2006). It is imperative that these abnormal movement strategies be identified as part of a movement screening process.

Determinants of successful return to play after ACLR include low levels of knee pain, higher levels of postoperative quadriceps and hamstring torque, low levels of knee effusion, postoperative tibial rotation range of motion, lower episodes of knee instability, higher Marx Activity Scores as well as higher hop testing/functional testing scores, lower levels of kinesiophobia, higher levels of athletic confidence and self-motivation (Czuppon et al., 2014). Commonly cited postsurgical return to play criteria include limb symmetry index for quadriceps strength and hop testing, symmetrical drop-jump testing, single-leg squat test to 90 degrees, assessment of knee laxity and examination of sports-specific drill performance, full knee ROM and the absence of knee effusion (Barber-Westin & Noyes, 2011).

The purpose of the study was to assess the readiness for return to sport in a sample of division III athletes following ACLR and medical clearance. The functional performance of each athlete and the symmetry of both lower extremities was evaluated using a comprehensive examination.

2. Methods

The readiness to return to sport of each athlete after ACLR was evaluated through the use of a battery of clinical tests that included: the triple hops for distance (THFD), the Y balance test (YBT), the side plank test (SPT) as well as the double leg lower test (DLLT) (Gonell, Romero, & Soler, 2015; Hewett, Myer, & Ford, 2005; Myer et al., 2012; Plisky, Rauh, Kaminski, & Underwood, 2006; Schmitt, Paterno, Ford, Myer, & Hewett, 2015; Smith, Chimera, & Warren, 2015; Zazulak, Hewett, Reeves,
Goldberg, & Cholewicki, 2007). Additionally, each athlete performed a single-leg squat (SLS) and a single-leg landing task from a height with a focus on examination of angular displacement and ground reaction force. These single-leg activities were chosen so that limb symmetry could be measured and the presence of abnormal movement strategies of each limb could be identified (Olsen, Myklebust, Engebretsen, & Bahr, 2004). The selected battery of tests can be performed in the clinical environment by physical therapists, medical doctors and athletic trainers and does not require lengthy training. The examination is time efficient and can be completed within a 40-min session with each athlete.

2.1. Subject demographics
Twenty-one Division III collegiate athletes agreed to participate and signed the informed consent. These participants (7 males and 14 females) had a mean age of 20.3 ± 1.7 years, mean weight of 75.1 ± 18.6 kg, mean height of 1.7 ± .11 m and a range of 6 to 71-month period following reconstruction. The range of time since surgery had a high range but a fairly even distribution for this group of athletes (five athletes were <12 months post-op, five were 12–24 months, seven were 24–48 months and four were 48–71 months). Twelve athletes had bone-patellar tendon-bone grafts, six had hamstring (semitendinosus ± gracilis) grafts and three had allografts. Each athlete had participated and completed a postsurgical rehabilitation program and had been cleared to return to sport by their physician. The Institutional Review Board approved this study and athletes were recruited from local Division III colleges.

2.2. Instruments and procedures
Participants completed the Knee injury and Osteoarthritis Outcome Score (KOOS) questionnaire as well as demographic and historical information including age, years of athletic participation, athletes’ primary position on the team and history of knee injury. To reduce the testing order effect, participants were randomly assigned the order of tests performed and the lower extremity being tested first.

2.2.1. Kinematics and kinetics during a single-leg squat and single-leg landing task
Participants were asked to perform two tasks while being recorded using two iPads™ utilizing the Dartfish Express—Sport Video Analysis App™ for data analysis of the motion capture. The iPads were located 9 ft. (2.74 m) from the edge of the force plate with the camera lens at 46 inches (116 cm) height from the floor. One iPad was placed in an anterior and another in a lateral location to successfully capture the peak angular movement in the sagittal and frontal planes. The first task the participants performed was a single maximum single-leg squat test (SLST) while standing on a 12 in.-high step (30.48 cm) (Livengood, DiMattia, & Uhl, 2004; Zeller, McCrory, Kibler, & Uhl, 2003). The participants were then asked to perform a single-leg landing task from the step and land on a Bertec™ force plate that was located 12 inches away from the step (Myer et al., 2015). During the single-leg squat the following peak angles were measured using the Dartfish App™: knee flexion, hip flexion, trunk flexion and knee valgus. The same peak angles were measured during the single-leg landing on the force plate in addition to force data. All measurements on the force plate were taken at peak landing vertical ground reaction force values (VGRF). The subjects were allowed to perform two practice trials followed by three trials that were recorded and the mean was calculated for both the operated and non-operated lower extremities. The SLST and the single-leg landing task were allowed at a self-selected pace of the participant.

Analysis of the recorded video of the landing activity enabled researchers to determine the degree of symmetry between the lower extremity values in terms of trunk, hip and knee joint peak angular displacement. Video analysis of each task was performed by the same researcher to improve the reliability of each of the above-mentioned frontal, sagittal and force plate capturing data. Interrater and intrarater reliability values using 2-D video for measuring hip and knee flexion angles as well as frontal plan projection angles during functional tasks have been reported as moderate to excellent (ICC = 0.74 to 0.99) (Lopes et al., 2018; Munro, Herrington, & Carolan, 2012).
2.2.2. Core endurance: side plank test
To perform the SPT, each participant laid on their side with one forearm placed under the lowermost shoulder (90 degrees of abduction) with their trunk and legs straight. The examiner then asked the participant to lift their hips off the ground as high as possible (Chan, 2005; McGill, Childs, & Liebenson, 1999). A rigid marker was aligned at the iliac crest (closest to the ceiling) to provide tactile feedback at the position of maximum hip elevation. A practice trial was allowed, followed by the test trial on each side, which was recorded in seconds. The duration of the test was started when maximum hip elevation reached the marker and stopped when the participant’s hip lost contact with the marker. Encouragement and feedback were given at 20-s intervals. The side plank test has been shown in the literature to have good intrarater reliability (ICC = .89) (Chan, 2005).

2.2.3. Core strength: double-leg-lowering test
When performing the DLLT, participants lied on their back with a standard blood pressure cuff centered in the lumbar curve and was inflated to a baseline of 40 mmHg with the knees fully extended and the participants’ hips bent to 90 degrees. The degree to which the participant could lower their legs (hip extension), while maintaining the same pressure measured on the blood pressure cuff was recorded using an Absolute Plus Axis Digital Goniometer. The participant was instructed to pause and attempt to return the pressure to baseline if the pressure dropped below 40 mmHg. If the participant was unable to return the pressure to baseline after verbal and visual cueing utilizing the blood pressure cuff dial, the test was discontinued. If the participant was able to achieve 40 mmHg, the test continued until the pressure dropped below this baseline again, which indicated the end of the test (Krause, Youdas, Hollmand & Smith, 2005 & Lanning et al., 2006). Participants who can lower their legs further towards the ground without spinal movement were determined to have greater core stability. A numeric grading system was utilized where the score is reflective of the ability to lower their legs to a set number of degrees from the table prior to the pelvis tilting: 5 = 0°-15°, 4 = 16°-45°, 3 = 46°-75°, 2 = 75°-90°, 1 = unable to hold pelvic position (Reese, 1999). The intrarater reliability of the DLLT has been reported to be moderate to excellent (ICC = .63-.98) (Krause, Youdas, Hollmand & Smith, 2005 & Lanning et al., 2006).

2.2.4. Triple hop for distance test
The athlete started by balancing on one leg and then performed the THDT in a forward direction as far as they could while maintaining control and balance on the final landing. The total distance jumped was a measure from the zero mark to the place where the back of the subject’s heel hit the ground upon completing the final jump using a tape measure fixed to the ground (Bolgla & Keskula, 1997). This test was repeated three times and then completed on the opposite limb to calculate limb symmetry with the average of the three trials used. The THDT has been shown to have good intratester reliability during rehabilitation after ACL reconstruction with an ICC of .88 (Reid, Birmingham, Stratford, Alcock, & Giffin, 2007). Longitudinal validity was reported as low to moderate (r = .26-.44) when comparing change in hop performance and self-reported measures (global rating of change and lower extremity functional scale scores) (Reid et al., 2007).

2.2.5. Y balance test
Prior to performing the YBT, each athlete’s limb length was measured (right side from ASIS to medial malleolus) which was used to calculate the composite score of the YBT. The goal of this test was to maintain single-leg balance on one leg while pushing a target as far as possible with the contralateral leg in three different directions with their hands on their hips (Gribble, Hertel, & Plisky, 2012). The three directions the participant moved the target were anterior, posteromedial and posterolateral. Each participant was given one practice trial and then three trials were measured. To reduce fatigue subjects alternated limbs when each of the three directions was tested (Plisky et al., 2009; Robinson & Gribble, 2008). Attempts were discarded and repeated if the subject failed to maintain unilateral stance on the platform, failed to maintain the foot contact with the reach indicator on the target area while the reach indicator was in motion, used the reach indicator for stance support, or failed to return the reach foot to the starting position under control. The mean values for displacement of the target plate in each direction were combined with the length of the lower extremity to
calculate the YBT composite score for each side according to the following formula; YBT composite score = \([(\text{Anterior} + \text{Posteriormedial} + \text{Posteriorlateral displacements})/3 \times \text{Limb Length} \times 100]\). The YBT was been shown to have good to excellent interrater reliability of the average of three reaches in the literature (ICC of 0.85–0.93) (Shaffer et al., 2013).

2.2.6. Athlete performance report

Following data collection and analysis, a detailed report was given to each participant that included the results of each test. The report also included a comparison of the athlete’s performance related to published normative values (Supplemental Table 1) when available and limb symmetry of their operated and non-operated lower extremities. The athlete was given training recommendations to improve their performance in the measured areas of balance, core stability, symmetry of squatting/landing and functional performance based on their examination scores.

A 1-year follow-up questionnaire was sent to each participant (Supplemental Table 2) to identify their highest level of activity in the last year and sports participation. The questionnaire also included questions regarding injury status in the last year and compliance with training recommendations given including which specific areas of training they focused on.

3. Results

All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS™) version 25 software package with an initial alpha level setting of 0.05 to control for type I error. Prior to final analysis, all data were screened for transcription errors, bivariate correlation, normality assumptions and homogeneity of variance, as prerequisites for parametric calculations of the analysis of difference.

The KOOS questionnaire is widely used as an instrument to assess the patient’s opinion about their knee and associated problems (Logerstedt et al., 2017). The mean KOOS sub-scale scores (see Figure 1) indicate that the athletes in this study on average are still experiencing some knee symptoms, have some decrease in quality of life related to their knee function and report some difficulty with higher level sport and recreation activities after ACLR. The athletes reported low levels of pain and a high level of function with activities of daily living at this point in their recovery.

Multiple paired T-tests were used (with appropriate inflation adjustment) to evaluate the intra-subject difference between operated and non-operated lower limbs in regard to functional performance data, core stability data, balance data and motion analysis/ground reaction force data (see Table 1). The results of the T-tests performed were as follows (see Table 2). There was a significant decrease in vertical ground reaction force (VGRF) of landing on the operated sides.
compared to the non-operated sides ($t = -2.86$, $p = 0.01$). The decrease in VGRF was observed to be secondary to the altered landing effort of participants and their acceleration pace while landing on the operated leg. Most of the athletes' operated lower extremities ($n = 15$) had less knee flexion and more knee valgus on landing compared to non-operated sides; however, the differences were not statistically significant.

The balance index scores were significantly lower on the operated sides ($t = 3.95$, $p = 0.001$) as detected by the YBT. Participants have not yet regained full balance performance capabilities of their operated lower extremities when compared to the non-operated sides. The THDT distance of the operated lower extremity was significantly reduced compared to the non-operated lower extremity for most athletes ($t = 2.57$, $p = 0.01$). Participants had an average grade of 3 out of 5 for core strength as measured by the DLLT and decreased core endurance as measured by their SPT time. Core stability deficiencies have been correlated with the development of a variety of upper and lower extremity injuries including ACL tears (Hibbs, Thompson, French, Wrigley, & Spears, 2008; Radwan et al., 2014).

It is clear that the majority of participants operated lower extremities have not yet regained symmetrical performance to that of the non-operated lower extremity despite an average of 28 months of recovery since surgery, rehabilitation and medical clearance to return to sports. This may explain the increased risk of ACLR re-injuries and contralateral ACL injuries as will be discussed later.
3.1. One-year follow-up questionnaire

There was an 81% (n = 17) response rate of the 1-year follow-up questionnaire that was sent electronically to each athlete. Of the athletes that responded only one student reported an ACL injury to the contralateral lower extremity and no athletes reinjured the reconstructed ACL in the 1 year following the testing. The majority of the athletes (53%, n = 9) considered themselves as active as they were when first tested while 35% (n = 6) of them felt more active and 12% (n = 2) were less active. The athletes reported their highest level of activity in the last year using the Tegner Activity Scale (Tegner & Lysholm, 1985) with 70% (n = 12) reporting a level of equal to or greater than 7% and 30% (n = 5) of them ranked their activity at a level of 5 or 6. Sixty percent (n = 10) of the athletes that responded reported that they had changed their training regime as a result of the testing that was performed and the training recommendations that were given based on the results from this testing. Most of the athletes (80–90%) that changed their training regime focused on additional lower extremity strengthening and core exercises as part of this program over the last year. Forty percent of those athletes that changed their training program incorporated additional balance training, exercises focusing on power and landing strategies with their affected lower extremity.

3.2. Injured athlete at 1-year follow-up

There was only one contralateral ACL injury reported at the 1-year follow-up to initial testing. This participant was a 20-year-old female collegiate basketball player with a BMI of 32.1. At the time of initial assessment, this athlete was 32 months post-op and had returned to a competitive level of sport participation. This athlete’s performance upon initial examination revealed significant balance deficits compared to normal values, asymmetrical angular displacement (sagittal and frontal planes with 5 degrees or more of difference between limbs) as well as ground reaction force values during landing. This athlete also had one of the lowest scores on the double leg lowering test and side plank test as a measure of poor core strength and endurance. This athlete had reported on the 1-year follow-up questionnaire that she had changed her training regime after being tested and receiving recommendations. Her new program had included additional leg strengthening, balance training and practiced landing activities. She did not report addressing core strength or jumping/plyometric training.

4. Discussion

Each of the athletes recruited for this study had been released to return to sports. Upon assessment of these athletes, the following impairments and functional asymmetries were discovered and were of both clinical and statistical significance to report.

4.1. Vertical ground reaction force deficits

When examining the VGRF, it was found that the majority of athletes had not yet regained symmetrical performance in VGRF upon landing. This statistically significant decrease in performance of the operated lower extremity could be attributed to decreased acceleration, protective deceleration or both. This finding is consistent with limb asymmetries in landing found in female athletes 2 years following ACLR (Paterno, Ford, Myer, Heyl, & Hewett, 2007). This asymmetrical VGRF could lead to increased load (overload) on the non-operated limb when performing landing activities which may predispose the athletes to contralateral injuries. There is currently a high number of contralateral injuries reported following return to sports including the one female participant in this study as mentioned in the results section of this manuscript (Wright, Magnussen, Dunn, & Spindler, 2011).

It has been reported in the literature that individuals with decreased quadriceps strength after ACLR who had completed rehabilitation and had been cleared for return to high-level athletic activities demonstrated greater limb asymmetry in peak VGRF’s and peak loading rates compared to a control group (Schmitt et al., 2015). Similarly, Myer et al. (2012) found that there was a significant asymmetry between limbs of the ACLR group and that of the control group that was independent of time after reconstruction. These asymmetries were especially evident by the difference in force absorption when landing on the ACLR lower extremity. These athletes demonstrated that up to 11 months after surgery and after release to sport, there were still significant
deficits between the reconstructed limb and non-injured limb, as well as significant limb asymmetry compared with non-injured matched controls. Persistent asymmetries may increase the risk of contralateral and/or ipsilateral injury (Myer et al., 2012).

4.2. Kinetic deficiencies
The kinetic assessment portion of the comprehensive examination was focused on measuring the amount of knee flexion, hip flexion and knee valgus during two closed chain activities. When performing the drop landing task 15 participants in this study had less knee flexion and more knee valgus on landing compared to the non-operated side; however, the differences were not statistically significant. Although this was qualitatively and clinically meaningful, the absence of a statistical difference could have been due to adapting a two-dimensional method of data collection of joints' angular displacement. Two-dimensional video analysis should not be dismissed as there is a growing body of literature demonstrating its clinical utility (Lopes et al., 2018). Three-dimensional methods of kinematic assessment may have higher levels of reliability and validity when compared to 2D but are not easily accessible for data collection in the clinical setting.

An upright or extended posture when contacting the ground (less knee flexion) during the early stages of deceleration tasks has been associated with non-contact ACL injury mechanism (Decker, Torry, Wyland, Sterett, & Richard Steadman, 2003; Pollard, Sigward, & Powers, 2007; Schmitz, Kulas, Perrin, Riemann, & Shultz, 2007; Utturkar et al., 2013). It has also been found that increased frontal plane knee rotation (dynamic valgus) has also been prospectively linked with ACL injury (Hewett et al., 2005). Dinenen et al. (2015) conducted a prospective study and found that 2D video analysis of increased knee valgus and ipsilateral trunk motions during a single-leg drop vertical jump can be used to help identify female athletes with increased non-contact knee injury risk. This helps illustrate that 2D movement assessment is a valuable tool that is less expensive, less time consuming and may be easier for clinicians to interpret when testing athletes.

4.3. Balance test deficits
The Y-balance test has been shown to have a level of predictive validity for injury risk in athletic populations (Smith et al., 2015). Participants in this study not only had a significantly lower YBT score on their operated leg compared to their non-operated leg, but also had a significantly lower mean composite score on the YBT compared to the recommended norms for athletes in their matched physical and developmental status. The average reported composite YBT score (% of limb length) for individuals aged 18–29 was 85.3 ± 6.0 (dominate lower extremities) and 85.5 ± 6.1 (non-dominant lower extremities) (Alnahdi, Alderaa, Aldali, & Alsobayel, 2015). Female collegiate volleyball players have been reported to have even higher composite balance scores with 94.1 ± 6.6% on the dominant limb and 93.9 ± 6.2% on the non-dominant limb (Hudson, Garrison, & Pollard, 2016). Several studies have reported that anterior reach asymmetry more than 4 cm is associated with an increased risk of LE injury (Gonell et al., 2015; Plisky et al., 2006; Smith et al., 2015). There were 33% (n = 7) of the athletes in this study that had greater than 4 cm of anterior reach asymmetry during the YBT. Gonell et al. (2015) showed that professional soccer players were 3.86 times more likely to sustain a lower extremity injury with postero lateral reach asymmetry of more than 4 cm, but they found no significant risk in the anterior or posterolateral reach directions with the YBT. There were 48% (n = 10) of the athletes in this study that had greater than 4 cm of posteromedial reach asymmetry during the YBT.

Persistent lower balance scores may explain the increased incidents of re-injuries and in contralateral injuries reported after return to sports (Webster & Feller, 2016; Wright et al., 2011). The one athlete in this study that sustained a contralateral ACL tear nearly 3.5 years after her ACLR had asymmetry in her composite YBT score (operated lower extremity 81.8 compared to non-operated 77.1). This athlete's anterior reach asymmetry on the YBT was significantly higher than any of the other athletes in this study at 10 cm (operated lower extremity 62 cm, non-operated lower extremity 52 cm). Plisky et al. (2006) identified that players with a decreased normalized composite right reach distance (≤94% of their limb length) are 3 times more likely to sustain a LE
injury, with the risk being 6.5 times more likely in females (Plisky et al., 2006). This increased level of injury risk may have played a part in this one female subject contralateral ACL injury.

4.4. Functional performance test asymmetries
A significant reduction in the triple hop for distance test scores of the operated sides compared to non-operated sides was found in all participants of this study. There were six athletes (29%) in this study that had a limb symmetry index (LSI) on the THDT of less than 90%. Single-leg hop tests are functional tests that have been used to identify individuals who can regain dynamic knee stability after an ACL injury. Some of the participants reported not performing hop tests or similar functional testing before as part of their rehabilitation. Researchers have found that THDT was a strong predictor of lower limb strength and power further validating its clinical usefulness as a screening test for collegiate athletes (Hamilton, Shultz, Schmitz, & Perrin, 2008). Limb symmetry indexes can be used to objectify performance and provide guidelines for readiness to safely return to sport (Engelen-van Melick, van Cingel, Tijssen, & Nijhuis-van der Sanden, 2013).

Single-leg hop tests have been correlated with self-reported function and have been shown to be predictive of future outcomes as hop tests at 6 months post ACLR can predict knee function within or below normal ranges of function at 1-year follow-up (Loperstedt et al., 2012). Our subjects initially reported a mean KOOS sub-scale score of 94/100 for function in daily living with an average LSI of 90.2% on the THDT (Grindem et al., 2011).

4.5. Core strength and endurance deficits
Participants in this study had core strength deficits as determined by the DLLT. None of the participants had a grade five in this test with all scores ranging from two (including the one case of contralateral injury) to four. The average degree of hip flexion prior to pelvic movement during the DLLT was 17° demonstrating impaired core strength when compared to uninjured collegiate athlete’s performance reported in the literature (Men = 46°, Women 52°) (Lanning et al., 2006). A recent systematic review examined the role of core stability as a risk factor in the development of lower extremity injuries in an athletic population (De Blaiser et al., 2018). Core strength, core proprioception and neuromuscular control of the core were found to be risk factors in the development of lower extremity injuries in the studies included in the review. Similarly, athletes who experienced an injury over the course of the season generally demonstrate lower core stability measures than those who did not in a cohort of collegiate athletes (Leetun, Ireland, Willson, Ballantyne, & Davis, 2004).

4.6. Limitations of the study
The number of participants and the lack of homogeneity of graft type, chronicity of time since surgery and unequal representation of gender can all affect the generalizability of the findings of this study. However, such a wide range of participants’ demographics enabled researchers to assess patients at different stages of recovery and spectra of healing.

The use of 2D motion analysis could be considered a limitation in this study. The validity of this measurement tool has been questioned when compared to 3D systems in the literature; however, it has been shown to be a reliable measure (ICC of 0.99; 95% CI: 0.97, 1.00) for knee sagittal and frontal plane angular displacement measures (Lopes et al., 2018). The researchers believe that 2D movement assessment can be a valuable tool to identify abnormal lower extremity movement patterns and is convenient in everyday clinical setting due to its low cost and ease of use.

5. Conclusion and clinical relevance
Despite being medically cleared to return to sports, and different levels of chronicity since surgery the athletes in this study never regained functional symmetry of performance of their lower extremities. These findings may question the validity of the return to sport decision for these athletes and the lasting deficiencies and their magnitude may explain the increased tendencies for ACLR reinjury as reported in the literature. The authors conclude that for a safe return to sport following ACLR, the symmetry of performance should be the focus of return to sport criteria.
A thorough assessment of athletes’ performance using a comprehensive examination can identify deficiencies and can be used to guide the decision of a safe return to sport. Future research is needed to identify multivariate models that can accurately predict ACLR injury in athletes returning to sport or have returned to sport and continue to have deficits.

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Supplementary material
Supplemental data for this article can be accessed here.

Correction
This article has been republished with minor changes. These changes do not impact the academic content of the article.

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