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Psychological Readiness to Return to Sport is Associated with Knee Kinematic Asymmetry During Gait Following ACL Reconstruction

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Abstract

Study Design: Controlled laboratory study; cross sectional

Background: Gait asymmetry frequently is observed following anterior cruciate ligament reconstruction (ACLR). Psychological readiness to return to sport is associated with functional and activity related outcomes after ACLR. However, the association between gait asymmetry and psychological readiness to return to sport is unknown.

Objectives: Determine the relationship between kinematic and kinetic measures of knee symmetry during gait and psychological readiness to return to sport following ACLR.

Methods: Seventy-nine athletes (39 women) underwent gait analysis after impairment resolution following ACLR (i.e. full range of motion, minimal or no effusion, quadriceps strength index 80%). Interlimb differences during gait were calculated for sagittal plane knee angles at initial contact (IC), peak knee flexion (PKF), and peak knee extension; and peak knee flexion moment (PKFM) and peak knee adduction moment (PKAM). Athletes completed the Anterior Cruciate Ligament-Return to Sport after Injury Scale (ACL-RSI) to assess psychological readiness to return to sport. Pearson correlations were used to examine the association between ACL-RSI and each gait symmetry variable.

Results: Significant negative correlations were observed between the ACL-RSI and two kinematic variables: knee flexion angle at IC ($r=-.281$, $p=.012$) and PKF ($r=-.248$, $p=.027$). In general, lower scores on the ACL-RSI were associated with greater interlimb asymmetry.

Conclusion: There was a weak association between psychological readiness to return to sport and knee kinematic symmetry during gait.

Level of Evidence: Level III; secondary analysis of prospectively collected data

Key Terms:

anterior cruciate ligament reconstruction; psychological factors; gait biomechanics

Introduction

Gait asymmetries following anterior cruciate ligament reconstruction (ACLR) are evident at 6 months after surgery,⁹ and can persist for years.^{1,5,23} Quadriceps femoris strength deficits also persist after ACLR and are associated with gait deviations seen after ACLR.^{19,26} Participants who have undergone ACLR demonstrate a “stiffened knee” gait pattern characterized by reduced peak knee flexion angles and smaller peak knee flexion moments during the stance phase of gait.^{9,13} Participants who are more successful at restoring quadriceps strength demonstrate more normal gait patterns than participants with greater quadriceps deficits.^{19,26} However, gait asymmetries can exist despite the restoration of symmetrical quadriceps strength 6 months following ACLR.²³ Therefore other factors related to neuromuscular control, such as psychological factors, may be contributing to gait asymmetry after ACLR.

Psychological factors are related to functional and activity related outcomes following ACLR.^{3,4,16} Studies have examined multiple psychological factors such as fear of re-injury, fear of movement, self-efficacy, confidence, and psychological readiness to return to sport.^{4,6,16,18,27,28} Fear of movement and re-injury decrease during the course of post-operative rehabilitation, and are associated with function at a time when athletes return to sport.⁶ In addition, changes in fear of movement/re-injury and self-efficacy for rehabilitation tasks predict change in function during the course of post-operative rehabilitation.⁷ From an activity related outcomes perspective, fear of re-injury is one of the most commonly cited reasons for not returning to sport.^{3,7} Psychological readiness to return to sport (a construct that encompasses emotions, confidence, and risk appraisal) prior to surgery and 4 months following ACLR predict preinjury sport level status 1 year after surgery.⁴ Furthermore athletes who return to their pre-injury level of sports 1 year following ACLR have lower levels of fear of re-injury and movement.¹⁷

Despite the fact that kinematic and/or kinetic asymmetries persist following ACLR and psychological factors affect ACLR outcomes no published studies have examined the association between biomechanical asymmetry and various psychological factors. The Anterior Cruciate Ligament – Return to Sport after injury Scale (ACL-RSI) measures psychological readiness to return to sport with questions regarding emotions, confidence, and risk appraisal. The purpose of this study was to determine if a relationship exists between the ACL-RSI and kinematic and kinetic measures of knee symmetry during gait in patients who have undergone ACLR. We hypothesized that lower scores on the ACL-RSI would be associated with greater kinematic and kinetic asymmetry at the knee during over ground walking.

Methods

Participants

Seventy-nine athletes between the ages of 13–55 who regularly participated in cutting, pivoting, and jumping sports (>50 hours per year) were included in this secondary analysis of a prospective clinical trial ([Clinicaltrials.gov](https://clinicaltrials.gov/ct2/show/study/NCT01773317) Identifier: NCT01773317). All athletes underwent primary ACLR, completed post-operative rehabilitation, and met the following criteria prior to enrollment: full knee range of motion, minimal or no effusion, quadriceps strength index >80%, and initiation of a running progression without increased symptoms. Exclusion criteria included: grade 3 concomitant ligament injury, full-thickness articular cartilage lesions >1 cm², prior ACL injury, or significant previous lower extremity injury. At enrollment, all participants completed gait analysis and the Anterior Cruciate Ligament – Return to Sport after injury Scale (ACL-RSI). This study was approved by the Institutional Review Board at University of Delaware and written informed consent was acquired prior to inclusion.

Gait Analysis

Kinematic and kinetic data were collected during over ground walking. Eight infrared cameras (Vicon, Oxford Metrics LTD, London UK) were used to detect retroreflective markers attached to the base of the 1st and 5th metatarsals, the medial and lateral malleoli, superior and inferior heels, medial and lateral epicondyles of the femurs, greater trochanters, and midline of the iliac crests. Rigid thermoplastic shells with retroreflective markers were attached to the thigh and shank, and the pelvis. Excellent intersession reliability has been established using this marker set.⁸ Kinetic data were collected using an embedded force plate within the walkway (Bertec Corporation, Worthington OH). Kinematic and kinetic data were sampled at 120 and 1080 Hz respectively.

Participants walked at a self-selected speed maintained to within $\pm 5\%$ of the first usable trial along a 6 meter walkway over the force plate. Five trials for each limb were collected. Stance phase joint angles and moments were calculated using rigid body analysis and inverse dynamics equations respectively (Visual 3D software; C-motion, Germantown MD). Kinematic and kinetic data were low pass filtered (6Hz and 40Hz respectively). Initial contact and toe off were defined by a 50N threshold as determined from the force plate. All trials were normalized to 100% of stance. Moment data were normalized by mass (kg) and height (m).

Kinematic variables of interest included sagittal plane knee joint angles at initial contact (IC), peak knee flexion during weight acceptance (PKF), and peak knee extension during stance (PKE). Kinetic variables of interest included peak knee adduction moment (PKAM), and peak knee flexion moment (PKFM) during stance. Inter-limb differences for each kinematic and kinetic variable were calculated for analysis by subtracting the surgical limbs value from the nonsurgical limbs value. Therefore, a positive difference would be indicative of lower value for the surgical limb.

Self-Reported Psychological Measure

The ACL-RSI includes 12 questions, and measures an athlete's psychological readiness to return to sport, which encompasses emotions (including fear of re-injury), confidence, and risk appraisal.^{15,29} The ACL-RSI is scored on a scale from 0–100 with a score of 0 indicating an extremely negative psychological response (i.e., more fear of re-injury, less confidence).²⁹ The ACL-RSI has good face validity, good internal consistency, high construct validity and high test-retest reliability.¹⁵

Statistical Analysis

Pearson product correlations were used to evaluate the association between ACL-RSI score and each symmetry variable of interest. When significant correlations were found, a secondary analysis was performed to provide greater clinical context. For this secondary analysis, participants were split into 3 groups by their respective ACL-RSI scores. Based on the median ACL-RSI score, the lowest 25% of scores were allocated to the LOW ACL-RSI scores group, the middle 50% to the MIDDLE ACL-RSI scores group, and the highest 25% to the HIGH ACL-RSI scores group. A 2 (limb) by 3 (group) mixed-model analysis of variance was used to compare limb differences between the 3 groups. Raw kinematic and kinetic values were used for this analysis rather than inter-limb differences. When significant interactions were found, post-hoc *t* tests with Bonferroni correction were used to examine limb differences within each group. Statistical significance was set at *p* .05.

Results

Correlation Analyses

Significant associations were found between ACL-RSI and 2 kinematic symmetry variables: knee flexion angle at IC ($r=-.281$, $p=.012$)(Figure 1A) and PKF ($r=-.248$, $p=.027$)(Figure 1B). There were no associations between ACL-RSI and PKE ($r=-.096$, $p=.398$), PKFM ($r=.114$, $p=.318$), or PKAM ($r=.109$, $p=.340$).

Group Analysis

The median ACL-RSI score was 61. Nineteen Participants made up the LOW ACL-RSI group (ACL-RSI score 47, ACL-RSI mean $\pm$ SD: 34 ± 11), 40 in the MIDDLE ACL-RSI group (ACL-RSI score between 48 and 78, 62 ± 9.0), and 20 in the HIGH ACL-RSI group (ACL-RSI score 79, 90 ± 6.0). There were no group differences in age ($p=0.745$), sex ($p=0.538$), body mass index ($p=0.844$), or weeks from surgery to enrollment ($p=.923$)(Table 1).

Significant limb by group interactions were found for knee flexion angle at IC ($p=.009$) and PKF ($p=.002$)(Table 2). At IC the LOW group displayed less knee flexion in the surgical limb compared to the nonsurgical limb (mean interlimb difference, *p*-value) (LOW: 2.4, $p=.008$; MIDDLE: -0.7 , $p=.225$; HIGH: -1.1 , $p=.269$), while the MIDDLE and HIGH groups did not display inter-limb differences. For PKF the LOW (7.1, $p<.001$), MIDDLE (2.4, $p=.001$), and HIGH (3.3, $p=.001$) groups all displayed less PKF in the surgical limb compared to the non-surgical limb.

Discussion

The purpose of this study was to examine the relationship between psychological readiness to return to sport and kinematic and kinetic measures of knee symmetry during gait in patients who have undergone ACLR. A significant weak relationship was found between ACL-RSI and 2 of the 3 knee kinematic variables evaluated. Less than 10% of the variance in both knee flexion angle at IC and PKF was explained by the ACL-RSI scores (knee flexion angle at IC: $r^2=0.079$; PKF: $r^2=0.062$). No relationships were found for the knee kinetic variables of interest. Additionally, patients with the lowest ACL-RSI scores (LOW group) exhibited the greatest sagittal plane kinematic asymmetries when compared to athletes in the MIDDLE and HIGH groups.

The athletes in the LOW ACL-RSI group exhibited greater side to side differences in knee kinematics as characterized by less knee flexion in the surgical limb at both IC and PKF compared to their nonsurgical limb. In contrast, the MIDDLE and HIGH groups were relatively symmetrical. While the LOW group's between limb differences for knee flexion at IC and PKF were statistically different, only their interlimb difference at PKF exceeded the MCID of 3 degrees.¹⁰ As such, the clinical relevance of these findings could be questioned. However, two previous studies found similar results when analyzing group differences in knee angle at IC.^{9,24} Di Stasi and colleagues compared knee angle at IC between athletes who passed return to sport (RTS) functional testing and athletes that failed RTS testing.⁹ The athletes that failed RTS testing at 6 months after ACLR displayed less knee flexion at IC (mean interlimb difference= 2.2°) in the surgical limb compared to the nonsurgical limb. In contrast, the group that passed RTS testing was symmetrical. Rudolph and colleagues compared knee flexion angles at IC between ACL deficient athletes classified as copers with athletes classified as noncopers.²⁴ The copers from this cohort successfully returned to sport, while the noncopers did not return to sport and reported instability with activities of daily living. Noncopers demonstrated less knee flexion in the surgical limb at IC compared to the nonsurgical limb during walking and jogging. Copers were symmetrical at IC. At PKF the LOW group's interlimb difference (7 degrees less in the surgical limb) in knee flexion angle exceeded the MCID. The MIDDLE group's interlimb difference at PKF did not exceed the MCID while the HIGH group's was approximately at the MCID. Reduced PKF also was found in athletes that failed return to sport testing 6 months after ACLR,²² and non-copers after ACL injury.²⁴ Therefore the LOW group's sagittal plane knee kinematics from the present study are similar to athletes who fail return to sport testing as well as non-copers.

From an individual perspective, interlimb differences beyond the MCID were present in both directions at IC and PKF as evident in Figures 1A and 1B. At IC, approximately half of the cohort ($n=37$) displayed an interlimb difference that exceeded the MCID while the remainder did not ($n=42$). Of the 37 patients that demonstrated interlimb differences at IC, 18 patients had less knee flexion in the surgical (vs. nonsurgical) limb while 19 had more knee flexion in the surgical limb. At PKF 53 patients demonstrated an interlimb difference that exceeded the MCID, with the majority of these patients ($n=46$, 87%) demonstrating less knee flexion in the surgical limb. The LOW ACL-RSI group had the highest percentage of patients that demonstrated less knee flexion in the surgical limb at both IC (37%) and PKF

(89%) compared to the MIDDLE (IC: 18%, PKF: 45%) and HIGH (IC: 20%, PKF: 55%) groups.

No relationships were found between our kinetic symmetry variables of interest and psychological readiness to return to sport. A recent systematic review and meta-analysis found strong evidence that peak knee flexion moments are reduced following ACLR compared to the contralateral limb and healthy controls and remain lower for up to 6 years.¹³ Additionally, athletes with quadriceps strength deficits demonstrate lower external knee flexion moments in the surgical limb during gait and a drop vertical jump.^{19,25} All athletes in the present study had adequate quadriceps strength (i.e. quadriceps index > 80%). The present cohort's homogeneity with quadriceps strength may have contributed to the lack of group differences in the kinetic symmetry variables.

The prevalence of knee osteoarthritis (OA) after ACLR is high with a recent systematic review indicating 44% of patients after ACLR develop OA.²¹ Altered biomechanics have been implicated as a factor contributing to the increased risk of OA.^{2,12} A recent study found that asymmetrical loading (i.e. underloading the surgical limb) during gait early after ACL injury and 6 months after ACLR were associated with radiographic signs of OA 5 years after surgery.³⁰ Additionally, altered kinematics with normal loads may contribute to OA risk development by loading structures that are not conditioned to withstand forces.¹⁴ A reduction of knee flexion during weight acceptance shifts loads to the anterior surface of the medial compartment of the knee.³¹ The change in contact location may contribute to degenerative changes in cartilage.¹⁴ The group with LOW ACL-RSI scores from our study demonstrated less knee flexion in the surgical limb and may therefore be at greater risk for knee OA. However, future research is needed.

Quadriceps femoris muscle weakness is common after ACLR.^{11,22} Studies have examined the relationship between quadriceps strength and biomechanics with mixed findings. Two studies found a relationship between quadriceps strength and gait symmetry indicating better quadriceps strength contributes to better symmetry.^{19,26} Conversely, Gokeler et al found no correlation between quadriceps strength and gait analysis parameters. Roewer et al found gait asymmetries were present during weight acceptance despite restoration of quadriceps strength.²³ Our cohort had to demonstrate adequate (> 80% quadriceps index) prior to enrollment. Our findings, therefore, suggest that gait asymmetries are present in athletes with LOW ACL-RSI scores even among athletes with adequate quadriceps strength.

There are limitations to our study. The study design was cross sectional in nature and we are therefore unable to determine cause and effect. Future research should determine if specific interventions directed at psychological factors lead to improvements in gait asymmetry after ACLR, or vice versa. A second limitation is that we formed groups based on quartiles of the subject's ACL-RSI scores. Using a different method to divide our cohort into groups could affect the findings. However, the group analysis allowed us to provide greater context to our findings.

Conclusion

The results of this study indicate that there is a weak relationship between psychological readiness to return to sport and sagittal knee kinematics during gait in athletes attempting to return to sport after ACLR. Lower ACL-RSI scores were associated with greater interlimb knee kinematic differences at IC and PKF. However, less than 10% of the variance could be explained by the ACL-RSI. Future research should determine where other psychological factors contribute to the asymmetrical gait following ACLR, including kinesiophobia, self-efficacy, and motivation. Future research should also elucidate the relationship between psychological factors and movement to determine if addressing psychological factors leads to improved symmetry or if addressing gait asymmetries leads to changes in psychological factors.

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This study was approved by the Institutional Review Board of the University of Delaware and is registered on IRBNet (ID: 225014–15).

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Key Points

Findings

A weak relationship was found with between psychological readiness to return to sport and interlimb knee kinematic differences during gait. Lower ACL-RSI scores were associated with greater knee interlimb differences.

Implications

The ACL-RSI, a tool to evaluate psychological readiness to return to sport, may provide insight into asymmetrical movement following ACLR.

Caution:

This was a cross-sectional study. We are therefore unable to determine cause and effect between psychological readiness to return to sport and kinematic gait asymmetry.

Figure 1A:
Relationship between ACL-RSI score and peak knee flexion angle @ initial contact (IC) symmetry

Figure 1B:
Relationship between ACL-RSI score and peak knee flexion angle @ peak knee flexion (PKF) symmetry

Table 1.

Participant Demographics for Group Analysis

Variable	Group			p-value model
	LOW ACL-RSI [†] N=19	MIDDLE ACL-RSI [†] N=40	HIGH ACL-RSI [†] N=20	
Age (years)	22.3 ± 6.5	20.7 ± 7.7	21.0 ± 8.7	0.745
Sex	9 women, 10 men	22 women, 18 men	8 women, 12 men	0.538
BMI (kg/m ²)	25.9 ± 4.0	26.3 ± 3.3	25.9 ± 3.0	0.844
Weeks from Surgery to Enrollment	24.1 ± 8.8	23.3 ± 7.1	23.3 ± 9.2	0.923

[†] values are mean ± SD

Table 2:

Significant limb by group interactions were found for knee flexion angle at IC (p=.009) and at PKF (p=.002).

Biomechanical Variable	Group	Surgical Limb [†]	Nonsurgical Limb [†]	Interlimb Difference [†]	p-value [‡]
Knee Flexion Angle @ IC (°)	LOW ACL-RSI N=19	6.1 (4.4, 7.7)	8.5 (6.8, 10.3)	2.4 (0.7, 4.2)	0.008
	MIDDLE ACL-RSI N=40	7.3 (6.2, 8.5)	6.6 (5.4, 7.8)	-0.7 (-2.0, 0.5)	0.225
	HIGH ACL-RSI N=20	7.4 (5.8, 9.0)	6.3 (4.7, 8.2)	-1.1 (-2.7, 0.8)	0.263
Knee Flexion Angle @ PKF (°)	LOW ACL-RSI N=19	18.9 (16.4, 21.6)	26.0 (24.0, 27.9)	7.1 (4.9, 9.2)	<0.001 [*]
	MIDDLE ACL-RSI N=40	20.5 (18.7, 22.3)	22.9 (21.4, 24.4)	2.4 (1.0, 3.7)	0.001
	HIGH ACL-RSI N=20	21.3 (18.8, 23.9)	24.6 (22.5, 26.7)	3.3 (1.4, 5.2)	0.001 [*]

[†] Values are mean (95% confidence interval).

[‡] p-values for post-hoc *t* tests with Bonferroni correction to examine interlimb differences in each group.

^{*} Interlimb difference exceeded minimal clinically important difference of 3 degrees

Abbreviations: IC, initial contact; PKF, peak knee flexion; ACL-RSI, Anterior Cruciate Ligament-Return to Sport after Injury Scale