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Quadriceps Strength Asymmetry After Anterior Cruciate Ligament Reconstruction Alters Knee Joint Biomechanics and Functional Performance at Time of Return to Activity

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Background: Quadriceps strength deficits are observed clinically after anterior cruciate ligament (ACL) injury and reconstruction and are often not overcome despite rehabilitation. Given that quadriceps strength may be important for achieving symmetrical joint biomechanics and promoting long-term joint health, determining the magnitude of strength deficits that lead to altered mechanics is critical.

Purpose: To determine if the magnitude of quadriceps strength asymmetry alters knee and hip biomechanical symmetry as well as functional performance and self-reported function.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: A total of 73 patients were tested at the time they were cleared for return to activity after ACL reconstruction. Quadriceps strength and activation, scores on the International Knee Documentation Committee form, the hop for distance test, and sagittal plane lower extremity biomechanics were recorded while patients completed a single-legged hop.

Results: Patients with high and moderate quadriceps strength symmetry had larger central activation ratios as well as greater limb symmetry indices on the hop for distance compared with patients with low quadriceps strength symmetry ($P < .05$). Similarly, knee flexion angle and external moment symmetry were higher in the patients with high and moderate quadriceps symmetry compared with those with low symmetry ($P < .05$). Quadriceps strength was found to be associated with sagittal plane knee angle and moment symmetry ($P < .05$).

Conclusion: Patients with low quadriceps strength displayed greater movement asymmetries at the knee in the sagittal plane. Quadriceps strength was related to movement asymmetries and functional performance. Rehabilitation after ACL reconstruction needs to focus on maximizing quadriceps strength, which likely will lead to more symmetrical knee biomechanics.

Keywords: muscle; isometrics; biomechanics; knee; return to activity

Quadriceps strength deficits are commonplace after anterior cruciate ligament (ACL) injury and reconstruction.[37] Despite best efforts during postoperative rehabilitation to overcome this muscle weakness, strength deficits often persist after formal treatment ceases[37] and thus remain a concern at the time patients are cleared to return to sport/activity.

Symmetrical quadriceps strength, defined as equivalent strength between the injured and noninjured sides, should be a rehabilitation goal as greater limb asymmetry after ACL reconstruction (ACLr) is predictive of patients who do not pass return-to-sport criteria[11] and is related to poor self-reported function, functional performance,[41] and altered lower extremity mechanics during gait.[11] Possibly of even bigger concern is that persistent quadriceps muscle weakness after ACLr is related to the life-long consequence of early onset posttraumatic osteoarthritis.[36,48] Given the

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TABLE 1
Participant Demographics[a]

	High Quadriceps (n = 12)	Moderate Quadriceps (n = 12)	Low Quadriceps (n = 42)
Sex, female, n	4	4	17
Age, y, mean ± SD	19.3 ± 6.3	21.58 ± 7.49	21.09 ± 5.05
Height, m, mean ± SD	1.73 ± 0.08	1.74 ± 0.10	1.75 ± 0.12
Mass, kg, mean ± SD	73.0 ± 14.88	71.19 ± 11.64	76.78 ± 14.17
Time to return to activity, d, mean ± SD	212.25 ± 36.43	218.25 ± 35.51	231.33 ± 37.83
Injured limb, left, n	7	8	23
Meniscectomy, n	4	2	4
Meniscal repair, n	1	4	12
Collateral ligament, n	0	1	0
Bone bruise, n	7	8	28
Articular cartilage, n	0	1	2
Mechanism of injury, contact, n	1	5	5
Returned to competitive sport, n	7	12	27

[a]There were no significant differences in age, height, mass, or time to return to activity across groups ($P > .05$).

deleterious effects of quadriceps weakness, it seems crucial to maximize quadriceps strength to preserve knee joint health and functional ability.

A myriad of guidelines have been utilized to define what clinical criterion value should be deemed “adequate” quadriceps symmetry after ACLr, with many suggesting between-limb differences should not be more than 10%,[1,19] while others have defined deficits upward of 20% to be acceptable.[8,23,43] Before clinical recommendations can be made as to an appropriate threshold for quadriceps strength symmetry, a better understanding of how the magnitude of quadriceps strength asymmetry influences factors such as biomechanics and performance (eg, factors related to poor outcomes after ACLr) is needed. Clear clinical guidelines will assist sports medicine professionals in making evidence-based decisions regarding return to sport/activity after ACLr.

Therefore, the primary purpose of this study was to determine if quadriceps strength asymmetry influences knee joint biomechanics and functional performance as well as self-reported function. It was our hypothesis that those with the highest quadriceps indices would have more symmetrical sagittal plane hip and knee biomechanics as compared with those with moderate and low quadriceps strength symmetry. Further, we hypothesized that the patients with the highest quadriceps indices would have the greatest self-reported function and functional performance compared with weaker subjects at return to activity.

METHODS

Participants

Sixty-six patients participated in the study as part of an ongoing investigation examining quadriceps function after ACL reconstruction (Table 1). Patients were eligible for enrollment in the parent study if they (1) were between 14 and 30 years of age, (2) were planning to undergo rehabilitation at our sports medicine clinic, (3) had an acute ACL injury (defined as reporting to a physician within 48 hours from injury), (4) had no previous knee surgeries, (5) had not suffered a previous ACL injury, (6) were not currently or planning to become pregnant, and/or (7) had a known heart condition. We attempted to enroll patients consecutively, but over the course of the parent study there were times enrollment ceased for a variety of reasons (ie, change in personnel, equipment failure, and change in computer systems that manage medical record storage) that prevented us from contacting all patients who may have met study criteria. Patients were retrospectively included in the current investigation if they had quadriceps strength and biomechanical variables collected at the time they were cleared to return to activity (6 patients currently available in our study database did not have biomechanical data collected). Patients were excluded from this study if they had an ACL reconstruction utilizing a graft type other than patellar tendon (23 patients available in our study database had their ACL reconstructed with a graft type other than patellar tendon). The university’s institutional review board approved the study protocol, and all participants provided written informed consent before testing.

Postoperative Rehabilitation and Return to Activity

All participants completed a standard postoperative rehabilitation regimen at a single clinic consisting of 2 to 3 visits per week beginning in the first postoperative week. The rehabilitation protocol emphasized full knee extension range of motion immediately and knee flexion as tolerated, progression of functional exercises, and quadriceps strengthening.

Testing for this study began once the orthopaedic surgeon cleared participants for return to activity (Table 1). In addition to full range of motion and no effusion, return criteria at our clinic require patients to complete a 3-week agility program and pass a leg press test. To successfully complete the leg press test, patients need to finish at least 15 repetitions of the exercise requiring the knee to be moved from neutral to 90° of flexion with their affected limb at 100% of body weight. If either the leg press test was not passed or the agility program was not completed, clearance for return to activity was postponed until criteria were satisfied.

Quadriceps Strength Measurements

Isokinetic quadriceps muscle strength was assessed bilaterally. Briefly, participants were secured in a dynamometer (Biodex System 3; Biodex Medical Systems) with the knee and hip of the test limb flexed to 90°. Participants completed 3 maximum voluntary concentric knee extension contractions at 60 deg/s with 2 minutes' rest between each trial. Oral encouragement and real-time visual feedback of the torque output were also provided. This procedure was completed for both legs, with testing order being counterbalanced so as to minimize the potential of a learning effect. The trial with the largest peak torque in each limb was extracted and used to calculate the quadriceps index ([ACLr leg/uninjured leg] $\times$ 100). The quadriceps index (QI) was then utilized to place patients into groups. Participants with a QI $\geq$90 were placed in the HIGH group, those with a QI <90 but $\geq$80 were placed in the MOD group, and those with a QI <80 were placed in the LOW group. Strength asymmetries of 10% or less are commonly deemed acceptable for return to activity after ACLr[30] and have been used as a cutoff value in similar studies,[27,41] and thus a cutoff value of 90% was selected for our HIGH group. Strength asymmetries 20% or larger are considered abnormal and thus served as the cutoff for the LOW group.[27,40] As for the MOD group, we contend it is important to examine patients falling between the high and low criterion values as it has been suggested that strength indices above 80% can be considered adequate.[23,43] Understanding how the MOD patients compare to those considered to have high and low strength seems important as no universal criterion is followed when returning patients to activity.

Quadriceps Activation

Quadriceps activation was measured utilizing the burst superimposition technique and quantified with the central activation ratio (CAR).[44] Burst superimposition procedures require subjects to complete maximal voluntary isometric knee extension contractions (MVICs), and they completed these contractions until no improvement in torque was noted.[22] Subjects always completed a minimum of 3 MVICs. Once it was apparent that participants were no longer increasing torque between trials, an additional trial was initiated and participants were asked to maintain this contraction for approximately 5 seconds. A custom written program (LabVIEW v 8.5; National Instruments) was set to deliver a supramaximal stimulus (Grass S88 Dual Output Square Pulse Stimulator/SIU8T Stimulus Isolation Unit; Grass Technologies) to the quadriceps via 2 self-adhesive electrodes (Dura-Stick II [7 $\times$ 13 cm]; Chattanooga Group) that were placed over the vastus lateralis and the vastus medialis. The stimulus was delivered once the MVIC was reached and subsequently dropped by 1 N·m.[44] Automated stimulus delivery was utilized because it has been shown to improve stimulus timing and thus reduce measurement error.[21] The CAR was then calculated (CAR = [MVIC/MVIC + superimposed burst] $\times$ 100), and a value of 100 was used to represent complete quadriceps activation.[20] The trial with the largest CAR (ie, least amount of activation failure) was used for statistical analysis.

Single-Legged Landing Task

Three-dimensional biomechanical data were collected for the knee and hip during a single-legged landing task using a motion capture system (Vicon; Oxford Metrics) sampling at 240 Hz and synchronized with analog data sampling at 1200 Hz. The task required patients to perform a single-leg forward hop onto a force platform (OR 6-7; Advanced Medical Technology Inc) with the ACL-reconstructed limb. The distance to hop was determined by each participant's leg length, defined as the tip of the greater trochanter to the tip of the lateral malleolus.[49] Trials were collected until at least 3 successful trials were captured. A trial was considered successful when participants landed on the force platform and were able to balance on their take-off limb without touching the floor with the contralateral limb. Data were collected for both limbs, with the limb subjects were required to land on first being randomized.

Kinematic and Kinetic Data Processing

Lower limb joint rotations were defined based on the 3-dimensional coordinates of 32 retroreflective markers (right and left limb; anterior and posterior superior iliac spines, iliac crest, greater trochanter, distal thigh, medial and lateral femoral epicondyles, tibial tuberosity, distal shank, lateral shank, medial and lateral malleoli, calcaneus, dorsal navicular, head of first and fifth metatarsal). A static trial of each participant aligned with the laboratory coordinate system was recorded, allowing a kinematic model composed of 7 skeletal segments (bilateral foot, shank, and thigh segments and the pelvis) and 24 degrees of freedom to be created (Visual3D v 4; C-Motion).[34] Marker trajectories recorded during each trial were subsequently processed within the respective subject's Visual3D model to solve for the generalized coordinates of each frame. Rotations were calculated utilizing the Cardan rotation sequence[7] and were expressed relative to each subject's neutral static position.[31] Ground-reaction force data were sampled and synchronized with the kinematic data, and both were filtered using a fourth-order, zero-lag, low-pass Butterworth filter at 12-Hz cutoff frequency.[35] Filtered kinematic and ground-reaction force data were then submitted to a standard inverse dynamics approach within Visual3D.[51] Segmental inertial properties were defined based on the previous work of Dempster et al.[9] The intersegmental moments at the knee and hip joints were expressed as flexion-extension with respect to the Cardan axes of the local joint coordinate system.[31,33] Joint moments were normalized to subject body height and mass and expressed as external moments.

Biomechanical data were time normalized to 100% of the stance phase for graphical purposes, with initial contact equating to the time when the vertical ground-reaction force first exceeded and fell below 10 N[4,31] and the end of the landing equating to 250-ms postinitial contact,[10] as ACL injury is thought to occur within this window of time.[14] Ensemble averages were calculated across stance for all rotations and moments.[32] To assess symmetry of kinematics and kinetics between limbs, the peak angles and moments for the ACL reconstructed limb were normalized to the contralateral noninjured limb utilizing the limb symmetry index ([injured limb angle or moment/uninjured limb angle or moment] × 100), with a value 100 reflecting perfect symmetry. Given that healthy individuals have been shown to display nearly identical between-limb mechanics,[47] asymmetrical mechanics in our ACLr patients should reflect a difference that was a result of the injury/reconstruction and/or inadequate rehabilitation.

One-Legged Hop for Distance. We used a 1-legged hop for distance as a clinical assessment of functional performance. To complete this task, subjects stood on their test leg and hopped forward as far as possible landing only on the same leg. The distance was quantified with a tape measure that was fixed to the ground and recorded to the nearest tenth of a centimeter. Patients were allowed to practice the hop until they felt comfortable and/or until no improvement was seen in the hop distance and then asked to complete 3 successful trials. A limb symmetry index (distance of involved limb/distance of uninvolved limb × 100) was calculated and used in statistical analysis.[3] Participants completed this task for both the affected and healthy limbs, and testing order was counterbalanced. Intrarater reliability of this test has been shown to be high in patients who have undergone ACL reconstruction.[2,15,16]

International Knee Documentation Committee Form. Self-reported knee function was quantified using the International Knee Documentation Committee (IKDC) subjective knee evaluation form. The form is scored on a scale of 0 to 100, with 100 representing highest knee function. The IKDC score has been shown to be a reliable and valid measure of function in persons after ACL injury.[18]

Statistical Analysis. One-way analyses of variances (ANOVAs) were performed to determine if the groups (HIGH, MOD, LOW) were different on demographic parameters such as age, height, mass, and time to return to activity. Multivariate analyses of covariance were utilized to examine group differences for all dependent variables (QI, CAR, IKDC, and limb symmetry indices for the hop for distance, sagittal plane knee and hip angles and moments). Covariates included in the analysis were sex, meniscal status (eg, whether or not meniscal repair or meniscectomy were performed), age, mass, and time to return to activity. Where appropriate, post hoc Bonferroni multiple comparison procedures were used. To examine the factors that would predict biomechanical symmetry for the knee and hip, hierarchical linear regressions were used to evaluate the influence of age, mass, sex, time to return to sport, meniscal status, and QI (independent variables) on knee flexion angles and moment symmetry indices (dependent variables). QI was entered into the model last so that we could ascertain the influence that QI had on our dependent measures above the influences of age, mass, sex, time to return to sport, and meniscal status. The alpha level was set a priori at $P \leq .05$. SPSS version 22 (IBM Corp) was used to perform all analyses.

RESULTS

Patient Demographics

No significant differences were identified between groups in terms of age ($P = .66$), height ($P = .95$), mass ($P = .95$), and/or time of return to activity ($P = .09$) (Table 1).

Quadriceps Strength and Activation

As expected, the QI differed among groups, with the HIGH group displaying the largest QI (102.48 ± 9.31), the MOD group displaying the middle QI (84.71 ± 2.44), and the LOW group displaying the smallest QI (58.80 ± 15.02) ($P \leq .0001$) (Figure 1A). Further, there was a significant group difference identified for the CAR, with the LOW group displaying a smaller CAR (89.53 ± 5.78) when compared with the HIGH (93.49 ± 4.83) and MOD (93.77 ± 3.31) groups ($P = .05$) (Figure 1B).

Hop for Distance and IKDC

No significant differences were noted between groups for the IKDC score (HIGH: 86.30 ± 6.23; MOD: 82.07 ± 10.03; LOW: 79.84 ± 11.91) ($P = .20$) (Figure 1D). However, a statistically significant group difference was detected for the hop index with the LOW group displaying less symmetry between sides (80.75 ± 9.65) compared with patients in the HIGH (92.62 ± 9.00) or MOD (86.62 ± 10.03) groups ($P =.049$) (Figure 1C).

Kinematics and Kinetics

Statistically significant differences were noted for the peak knee flexion symmetry index (Figure 2A). The HIGH (limb symmetry index [LSI] = 85.82 ± 4.80) and MOD (LSI = 87.67 ± 4.80) groups were not different in terms of knee flexion symmetry ($P > .999$) but were found to have statistically greater symmetry than the LOW group (LSI = 73.95 ± 2.56) ($P < .05$). Similar results were noted for the external knee flexion moment, wherein the HIGH (73.98 ± 5.77) and MOD (67.79 ± 5.82) groups had greater symmetry when compared with the LOW group (59.79 ± 4.06) ($P < .05$), but no differences were noted between the HIGH and MOD ($P = .86$).

Regression Analyses

Meniscal status, mass, and time to return to activity were not found to be significant predictors of biomechanical symmetry for peak knee flexion angle ($P > .05$), while age ($P = .013$) and sex ($P = .049$) were predictors. After controlling for all these variables in the model, however, the QI was a significant predictor for knee flexion angle symmetry (R^2 change = 0.285). With regard to knee flexion moment symmetry, only age ($P = .042$) and QI ($P = .008$)

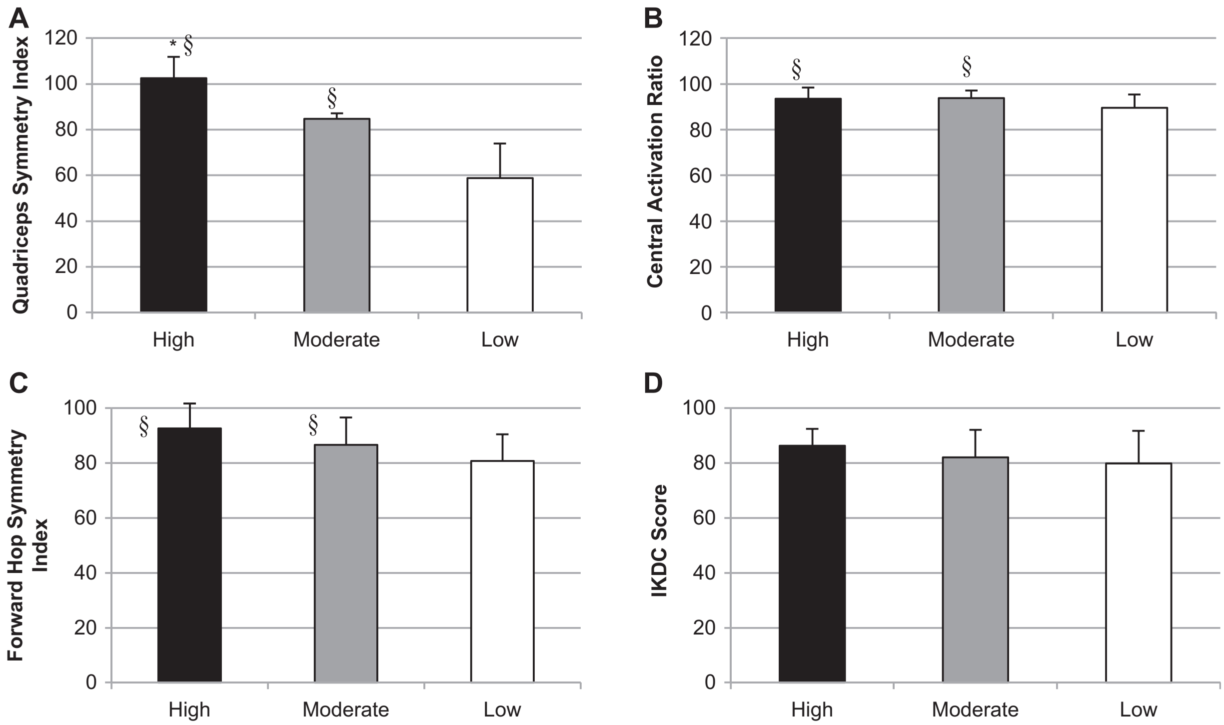

Figure 1. (A) Quadriceps index, (B) central activation ratio, (C) forward hop symmetry index, and (D) International Knee Documentation Committee score for high, moderate, and low quadriceps groups. *Statistically significant difference from moderate group. §Statistically significant difference from low group.

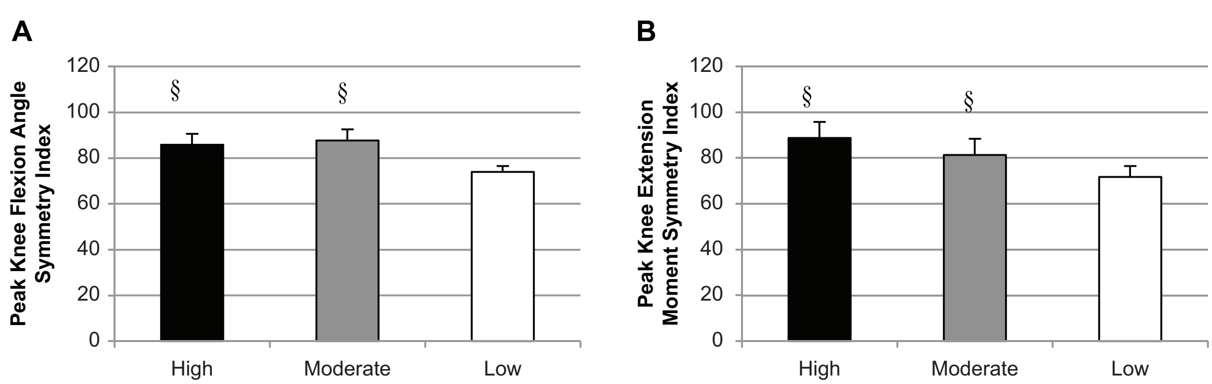

Figure 2. Symmetry indices for knee flexion (A) angles and (B) moments for high, moderate, and low quadriceps groups. §Statistically significant difference from low group.

were significant predictors (R^2 change = .250 for QI). Lastly, only QI was a predictor of hop symmetry (R^2 change = 0.251) ($P < .002$).

DISCUSSION

The goal of the current work was to examine whether quadriceps strength asymmetry influenced functional performance and knee and hip biomechanics at the time patients were cleared to return to activity after ACLr. The data partially supported our initial hypotheses in that patients with LOW quadriceps symmetry performed worse on hop testing and landed with less peak knee flexion angle symmetry and external knee flexion moment symmetry than patients with HIGH and MOD quadriceps symmetry. In contrast, no differences in knee flexion angle or extension moment limb symmetry were detected between the HIGH and MOD quadriceps strength groups.

The asymmetrical knee flexion angles and moments demonstrated by the LOW group during the single-legged landing are consistent with the literature. Xergia et al[52] noted that men 6 to 9 months after ACL reconstruction with a bone patellar tendon bone autograft demonstrated lower knee flexion angles in the injured limb compared with the noninjured limb during hopping. While the relationship between quadriceps strength and biomechanics was not established in this study,[52] the isokinetic quadriceps indices calculated from their data revealed values less than 80%, supporting the premise that residual quadriceps weakness in the ACLr limb likely contributed to the reduced knee flexion angles that were observed. Lewek et al[27] reported that patients with weak quadriceps, defined as a QI less than 80%, walked and jogged with lower flexion angles and moments than those with high isometric quadriceps strength (ie, QI >90%) after ACLr with a semitendinosus/gracilis autograft or allograft. Likewise, Di Stasi and colleagues[11] noted that ACL patients reconstructed with a semitendinosus/gracilis autograft or allograft not passing return-to-play criteria, which included having an isometric quadriceps index below 90%, had less symmetrical knee flexion angles and moments than patients passing return criteria. We contend the asymmetry noted in our work and that of others suggests that at return to play patients often do not have adequate eccentric quadriceps strength and/or control to resume normal knee mechanics during functional activity. The reduced knee flexion in the reconstructed limb or a stiffening strategy in an attempt to control body weight upon landing may also be problematic as these alterations in movement are thought to contribute to the early onset posttraumatic osteoarthritis associated with ACL injury. Chaudhari et al[6] proposed that altered knee motion after ACL injury or reconstruction could load cartilage in unfamiliar ways and perpetuate cartilage degradation. Following this proposed framework, it is indeed possible that the altered mechanics noted in our study population could have serious consequences for the long-term health of the affected knee joint. Therefore, it seems critical that rehabilitation after ACLr aims to achieve quadriceps symmetry, thereby leading to more symmetrical movement patterns in the sagittal plane.

While the LOW group displayed less knee flexion angle and moment symmetry than the HIGH and MOD groups, there was no difference in symmetry when comparing the HIGH to the MOD groups. While quadriceps symmetry of 90% is recommended as a clinical criterion for return to activity after ACLr,[30] the empirical evidence supporting that 90% is necessary to achieve acceptable symmetry in joint mechanics and functional performance is sparse. Current trends in ACL rehabilitation promote using objective return to activity guidelines rather than the subjective criteria of time after surgery, which has been classically used as a marker for patient clearance. As such, it is critical that the objective data put forth are backed with strong experiential support as to why the criterion were chosen. While biomechanical symmetry is not the only factor rehabilitation professionals are aiming to achieve, it could be critical for long-term joint health[6] and prevention of reinjury[38] and thus should be considered. In the current study, it appears that an 80% to 89% QI was equivalent to a 90% to 100% QI in terms of elucidating biomechanical symmetry. While neither group had complete symmetry, they were not statistically or clinically different from each other, suggesting that at least in terms of sagittal plane knee symmetry a QI of 80% may lead to similar biomechanical outcomes. The design of our study, however, is not adequate to delineate a specific criterion value, and thus future research should focus on establishing evidence-based criteria. Furthermore, the number of participants for the HIGH and MOD groups is rather small and thus the lack of significant difference between these groups could be due to inadequate statistical power. It is also important to discuss that factors other than quadriceps strength, such as fear of reinjury, joint range of motion, and core muscle and other lower extremity strength, are likely important in achieving movement symmetry after ACLr, and these factors should be established and considered when developing return to activity guidelines. This contention is supported by our study in that quadriceps strength only accounted for a small part of the variance in knee flexion angle and moment symmetry (R^2 change = 25% for both variables).

Hop distance symmetry was worse in patients in the LOW group compared with those in the MOD and HIGH groups. In a similar study, Schmitt et al[41] noted patients with lower quadriceps strength, having a QI <85%, had greater asymmetry in hop distance for the single and triple hop tests when compared with patients with higher quadriceps strength, QI >90%, at the time they returned to sport. Further, similar to our results, they note the QI was significantly associated with hop performance, albeit that both studies revealed modest R^2 values (0.14 for Schmit et al[41] and 0.25 for the current study). Other studies[39,50] have revealed correlations ranging from 0.3 to 0.7 for quadriceps strength and hop symmetry, but due to methodological differences, direct comparisons between our work and theirs is difficult. There is no doubt that additional factors also contribute to hop symmetry, such as fear of reinjury, effusion, knee pain, lower extremity range of motion, among others, and require consideration in future studies.

The HIGH and MOD groups had higher scores on the IKDC when compared with the LOW group, although this did not reach statistical significance (P = .20). Similar results were seen by Schmitt et al,[41] with a trend toward differences between groups with higher and lower quadriceps strength. We believe failure to reach statistical significance is due to a lack of statistical power rather than there being no true differences between groups. Many studies[5,12,24,28,42,50] have revealed that quadriceps strength influences self-reported knee function, although the strength of the relationship has varied.

Patients in the LOW group displayed lower CAR values, suggestive of increased quadriceps muscle inhibition, when compared with the MOD or HIGH groups. The larger magnitude of inhibition in the LOW group may have contributed to the lower overall strength values in this group. Muscle inhibition prevents complete voluntary activation of the quadriceps. As such, if higher levels of inhibition were noted before reconstruction or soon after reconstruction among our LOW group, this may have prevented patients from activating their musculature to the same degree as patients in the MOD or HIGH groups, thereby impeding rehabilitation. Hurley et al[17] showed an inverse relationship between muscle inhibition and quadriceps strength and also revealed that larger magnitudes of inhibition have the ability to negatively influence strength gains through rehabilitation after traumatic knee injuries. We did not quantify the CAR before or soon after reconstruction, so we are unable to determine if patients in the LOW group did indeed have greater amounts of inhibition than the HIGH or MOD groups and thus cannot be certain this was the case in our subject population.

In our sample, only ~20% of patients (13/66) were able to achieve 90% quadriceps strength symmetry between limbs. Ninety percent symmetry in quadriceps (and hamstring) strength was recently identified by a consensus as a measure important for achieving successful outcome after ACLr.[30] As such, our patients may be primarily viewed as unsuccessful when this criterion is considered. Our patients undergo standardized rehabilitation[26] similar to what would be seen in most outpatient rehabilitation clinics, with 2 to 3 visits per week and where quadriceps strengthening is emphasized. Despite this, symmetrical muscle strength is still not achieved and is rather poor with an average QI in our sample (across all 3 groups) of 71.25 $\pm$ 21.8. This reinforces that standard rehabilitation and clearance around the time of 6 to 7 months is not adequate to generate a successful outcome after ACLr. Rehabilitation programs including high-intensity neuromuscular electrical stimulation and perturbation training along with aggressive quadriceps strengthening have been proven successful in restoring limb symmetries and should strongly be considered for inclusion in postoperative rehabilitation.[29,45,46] Further, eccentric exercise has been shown to improve quadriceps strength compared with standard of care or electrical stimulation.[13,25] Six weeks of eccentric exercise in addition to standard of care has been able to more effectively restore quadriceps strength at time of return to activity.[25] Therefore, alternative methods to achieve maximal quadriceps strength, such as those mentioned previously, need to become the standard rather than the exception when it comes to ACL rehabilitation.

CONCLUSION

Isokinetic quadriceps strength deficits after ACL reconstruction negatively influence sagittal plane knee movement symmetry and functional performance. Specifically, patients with QIs <80% had smaller knee flexion angles and moments in the involved compared with the uninvolved sides. Furthermore, quadriceps strength was shown to be associated, with hop performance and sagittal plane knee symmetry accounting for a significant portion of the variance. Rehabilitation programs after ACL reconstruction need to focus on restoring symmetrical quadriceps strength before clearing patients to return to activity.

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