Quadriceps Strength and Kinesiophobia Predict Long-Term Function After ACL Reconstruction: A Cross-Sectional Pilot Study

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Background: Many patients live with long-term deficits in knee function after an anterior cruciate ligament reconstruction (ACLR). However, research is inconclusive as to which physical performance measure is most strongly related to long-term patient-reported outcomes after ACLR.

Hypothesis: Quadriceps strength would be most strongly associated with patient-reported long-term outcomes after ACLR.

Study Design: Cross-sectional study.

Level of Evidence: Level 3.

Methods: A total of 40 patients (29 female) consented and participated an average of 10.9 years post-ACLR (range, 5-20 years). Patients completed the Lower Extremity Functional Scale (LEFS), the International Knee Documentation Committee (IKDC) Scale, Knee injury and Osteoarthritis Outcome Score Quality of Life (KOOS QoL) and Sport (KOOS Sport) subscales, and the Tampa Scale of Kinesiophobia (TSK-17). Each patient subsequently performed maximal isometric quadriceps contraction, a 60-second single-leg step-down test, and the single-leg single hop and triple hop for distance tests. Multivariate linear and logistic regression models determined how performance testing was associated with each patient-reported outcome when controlling for time since surgery, age, and TSK-17.

Results: When controlling for time since surgery, age at the time of consent, and TSK-17 score, maximal isometric quadriceps strength normalized to body weight was the sole physical performance measure associated with IKDC ($P < 0.001$), KOOS Sport ($P = 0.006$), KOOS QoL ($P = 0.001$), and LEFS scores ($P < 0.001$). Single-leg step-down, single hop, and triple hop did not enter any of the linear regression models ($P > 0.20$). Additionally, TSK-17 was associated with all patient-reported outcomes ($P \leq 0.01$) while time since surgery was not associated with any outcomes ($P > 0.05$).

Conclusion: Isometric quadriceps strength and kinesiophobia are significantly associated with long-term patient-reported outcomes after ACLR.

Clinical Relevance: These results suggest that training to improve quadriceps strength and addressing kinesiophobia in the late stages of recovery from ACLR may improve long-term self-reported function.

Keywords: kinesiophobia; knee; ACL Reconstruction; quadriceps; ACLR

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Over 250,000 anterior cruciate ligament (ACL) injuries occur in the United States annually with approximately 100,000 having an ACL reconstruction (ACLR).[23] Many patients with ACLR live with persistent functional impairments that result in reduced ability to perform activities of daily living.[11,19] Concomitant deficits in quadriceps muscle strength are also common.[4,5] Reduced quadriceps strength may contribute to the fact that only 50% of patients with ACLR return to their preinjury levels of activity[2,34] and is an important risk factor for the development of knee osteoarthritis.[28]

Improvement in quadriceps strength, single-leg step-downs, and hop testing are each associated with better patient outcomes in the first 2 years after ACLR.[16,22,30] However, there is a paucity of literature evaluating the physical performance measures most strongly associated with outcomes in the long term after an ACLR. A recent study showed that single-leg hop test performance was correlated with subjective knee function greater than 5 years after ACLR, but the sample size precluded the use of a regression analysis to examine the predictive effects of multiple physical performance measures.[7] Therefore, a critical need remains to identify the most salient physical performance measure associated with long-term patient-reported outcomes (PROs) after ACLR. This information is needed to guide clinical decision making to improve long-term patient prognosis and function.

Several potential confounding variables may contribute to a patient's long-term outcomes after ACLR. For example, older patients undergoing ACLR often obtain worse functional outcomes than those who are younger.[24,25] Similarly, long-term deficits in function present up to 20 years after ACLR, indicating the important role of time since surgery when accounting for functional outcomes.[36,37] Kinesiophobia (fear of movement) is another important variable that has been associated with worse physical performance, decreased activity levels, and increased risk of secondary injury in the early stages of recovery after ACLR.[18,29,38] While the impact of kinesiophobia on long-term outcomes after ACLR is not well-established, these studies seem to indicate the importance of accounting for patient age, time since surgery, and kinesiophobia when assessing long-term patient outcomes.

Therefore, the primary purpose of this study was to determine whether maximal isometric quadriceps strength, a 60-second single-leg step-down test, or single-leg hop testing was most strongly associated with long-term PROs after ACLR when accounting for age, time since surgery, and kinesiophobia. We hypothesized that greater maximal isometric quadriceps strength normalized to body weight would be most stongly associated with improved PROs.

METHODS

Participants

This study was approved by the University of Kentucky institutional review board and written informed consent was obtained from all study participants. To be eligible for inclusion, patients must have had a unilateral ACLR between 5 and 20 years from the time of consent and be between 18 and 55 years of age. Individuals with the American College of Rheumatism clinical criteria indicative of symptomatic knee osteoarthritis were excluded from this study.[1] Evidence suggests that concomitant meniscal, ligamentous, or chondral injury are not associated with long-term outcomes[34]; therefore, individuals with these injuries were not excluded from this study.

Test and Measures

Predictor Variables

Participants completed maximal isometric strength testing of the quadriceps muscle group using a Biodex System 4 (Biodex Medical Systems, Inc.) bilaterally. Patients were positioned in a seated position with arms crossed over shoulders in 85° hip flexion, 0° hip rotation, 90° knee flexion, and the dynamometer arm secured 5 cm proximal to the malleoli.[15] Consistent with prior testing protocols, 1 submaximal practice trial was followed by 4 maximal isometric contractions each lasting 5 seconds.[15] All tests were followed by a 30-second rest to decrease the likelihood that fatigue influenced the results. The peak force produced in each trial was determined, averaged between the 4 trials, and normalized to the patient's body weight. We decided not to use a limb symmetry index as this has recently been found to overestimate patient recovery after ACLR.[9,39]

Each participant also completed a 60-second single-leg step-down test bilaterally.[16] Patients were positioned on a 20-cm stool standing on 1 leg and asked to perform a squat lowering their contralateral leg to touch a scale on the floor with their heel. Repetitions were counted only when the heel made contact with the scale and no greater than 10% of the patient's body weight registered on the scale to ensure participants were appropriately controlling the eccentric portion of each repetition. Participants then returned to the starting position with the stance leg in full knee extension. Participants were instructed to perform as many repetitions as possible in 60 seconds. Repetitions in which the participant did not touch the scale, placed greater than 10% body weight through the scale, or did not return to full knee extension on the stance leg were not counted. The total number of step-downs completed on each limb in 60 seconds was recorded.

Single-leg single hop and triple hop for distance tests followed previously published guidelines.[22] Each participant was provided as many warm-up repetitions as required to fully acclimate to the testing procedure. Patients then performed 3 trials bilaterally, starting with the single hop on the uninvolved limb followed by the involved limb. A 1-minute break was provided between each trial with a 5-minute break between single- and triple-hop tests. The total distance hopped was recorded as the distance from the toe at starting position to the heel on landing for each trial. Participants were required to stick the landing for each trial; any trials that resulted in double hops, the contralateral foot touching the ground, or hands touching the ground were repeated. The average of all 3 trials for both tests were recorded bilaterally.

Outcome Variables

The participants of this study completed the Sport and Recreation (Sport; 5 items) and Quality of Life (QoL; 4 items) subscales of the Knee injury and Osteoarthritis Outcome Score (KOOS).[32] Higher scores on each subscale indicate greater self-reported knee function (range, 0-100). A KOOS Sport subscale score of 75.0 and QoL subscale score of 62.5 are associated with the Patient Acceptable Symptom State (PASS) for patient status post-ACLR.[27] Individuals that exceed the PASS threshold tend to indicate satisifaction with their outcome.[27]

The International Knee Documentation Committee (IKDC) Subjective Knee Form was used as an additional measure of knee-specific symptoms, function, and sports activity.[14] The instrument contains 18 items, and higher scores indicate better knee symptoms and function (range, 0-100). An IKDC score of 75.9 is associated with the PASS score for patient status post-ACLR.[27]

The Lower Extremity Functional Scale (LEFS) was also administered to each participant. This is a reliable and valid 20-item questionnaire to measure self-reported function in individuals with lower extremity injuries.[6] Each question is scored on a 4-point Likert-type scale with higher scores indicating better knee function (range, 0-80). The minimal clinically important difference is 9 points.[6,26]

Covariates and Demographic Variables

The Tampa Scale of Kinesiophobia (TSK-17) was completed by each participant. The TSK-17 consists of 17 items measuring an individual's fear of movement.[12] Each question is scored on a 4-item Likert-type scale with greater scores indicating greater kinesiophobia (range, 17-68).

Finally, a number of sociodemographic questions were provided. This included age at time of consent, sex, height, weight, concomitant injury, graft type, mechanisms of injury, time since surgical reconstruction, and Tegner Activity Score at the time of the data collection. The Tegner Activity Score is a means for the patient to report his or her overall level of activity.[35] It is scored on an 11-point Likert-type scale with a score of zero representing disability due to knee problems and 10 representing an elite athlete.[35]

Statistical Analysis

Descriptive statistics were used to summarize each variable in this study. Multiple variable regression analyses were performed to determine which physical performance test was associated with patient-reported KOOS Sport, KOOS QoL, IKDC, and LEFS scores. Each regression model controlled for time since surgery, age at the time of consent, and TSK-17 score (step 1). The model then forward-selected the physical performance measure most strongly associated with each outcome (step 2). The β coefficients, level of significance, and adjusted variance for each variable was recorded based on the final model for each outcome. A 1-way analysis of variance of this cohort demonstrated no difference in PROs by the type of graft used (KOOS Sport, $P = 0.61$; KOOS QoL, $P = 0.43$; IKDC, $P = 0.42$; and LEFS, $P = 0.35$). For these reasons graft type was not used as a covariate in the regression models. To ensure that there was not multicollinearity of data, variance inflation factors were set as less than 10.[13]

Binary logistic regression was subsequently performed to determine the odds ratios to exceed PASS scores for each outcome when controlling for the same variables as the linear regression models. Given that the LEFS does not have a PASS standard, it was dichotomized by subtracting the minimal clinically important difference from the maximum total score (LEFS > 71). Quadriceps strength odds ratios with 95% CIs were recorded for the final logistic regression model for each outcome. Finally, the cutoffs for maximal quadriceps strength and dichotomized questionnaires were evaluated via area under the curve (AUC) analysis. All statistical analyses were made using IBM SPSS Statistics (Version 24).

The minimum number of participants required for this study was 36. This sample size justification was based on including 4 independent variables in each multivariable regression model with a medium effect size anticipated for the physical performance measure, a power of 0.8, and $\alpha < 0.05$.[10]

RESULTS

A total of 40 patients were recruited for this study an average of 10.9 years post-ACLR (range 5-20 years). Demographic characteristics are displayed in Table 1 while the results of physical performance testing and PROs are noted in Table 2. Of note, the average age at time of consent was 34.2 years with the majority of participants being female (72.5%). Overall, 57.5% received a bone–patellar tendon–bone autograft. Slightly more individuals injured their nondominant limb (52.5%) and had concomitant meniscal injury (55%).

The sole physical performance measure associated with each PRO in the multiple linear regression models was maximal isometric quadriceps strength normalized to body weight ($P < 0.01$) (Table 3). Time since surgery was not associated with any outcome measures ($P > 0.05$). Kinesiophobia added a significant amount of variance to each outcome ($P \leq 0.01$). The results of this analysis indicate that each 1 N·m/kg increase in quadriceps strength is associated with an increase of 16.95 points on the KOOS Sport, 17.06 points on the KOOS QoL, 17.60 points on the IKDC, and 6.81 points on the LEFS. In practical terms, an individual with quadriceps peak torque of 3.0 N·m/kg would be expected to have KOOS Sport, KOOS QoL, and IKDC scores that were approximately 17 points higher than an individual with quadriceps peak torque of 2.0 N·m/kg. Single-leg step-down, single hop, and triple hop did not enter any of the linear regression models ($P > 0.20$).

In the the logistic regression models, greater maximal isometric quadriceps strength normalized to body weight was significantly associated with exceeding the PASS standard for each outcome ($P < 0.01$) (Table 4). Each 1 N·m/Kg increase in quadriceps strength is associated with a 6.0 to 29.4 increase in odds to exceed the PASS standards for each outcome measure when controlling for time since surgery, age, and TSK-17 score ($P < 0.01$) (Table 4).

Table 1. Patient demographics (N = 40)

Characteristic	Number (%) or Mean ± SD
Age, y	34.2 ± 11.2
Sex	
Female	29 (72.5)
Male	11 (27.5)
Body mass index, kg/m^2	24.9 ± 3.2
Injured side	
Left	22 (55.0)
Right	18 (45.0)
Dominant leg injured	
Yes	19 (47.5)
No	21 (52.5)
Meniscal injury	
Yes	22 (55.0)
No	18 (45.0)
Mechanism of injury	
Contact	10 (25.0)
Noncontact	30 (75.0)
Graft type	
Bone–patellar tendon–bone autograft	23 (57.5)
Hamstring autograft	9 (22.5)
Allograft	8 (20.0)
Years since surgery	10.9 ± 4.6
Tegner Activity Score	5.7 ± 1.3

The AUC analysis, sensitivity, specificity, and corresponding quadriceps strength threshold values associated with improved PROs are presented in Table 4. Acceptable discrimination was noted between each dichotomized outcome measure and maximal quadriceps contraction. The Youden Index yielded optimal quadriceps strength cutoff scores ranging from 2.18 to 2.62 N·m/kg.

DISCUSSION

The novel findings of this study show that maximal isometric quadriceps strength is more strongly associated with the patient's perception of function in the long term after ACLR than 60-second single-leg step-down and hop testing. Time since surgery did not significantly contribute to the overall variance of the multivariate models. Interestingly, kinesiophobia significantly contributed to all the outcomes. Finally, after controlling for baseline variables, each 1 N·m/kg increase in maximal isometric quadriceps strength carried moderate to strong odds of exceeding PASS threshold standards. These findings provide preliminary evidence that rehabilitative efforts geared toward maximizing quadriceps strength should be associated with better long-term PROs after ACLR.

Maximal isometric quadriceps strength was more strongly associated with patient-reported function than dynamic movement assessments in the long term after ACLR. These results are consistent with other research indicating the critical role quadriceps strength contributes to long-term recovery of function after ACLR. For example, maximal isometric quadriceps strength was a strong predictor of IKDC score in patients with an average of 4.5 years post-ACLR.[31] In addition, work by Lepley et al[20] reported that, when normalized to body weight, greater quadriceps strength was associated with greater self-reported function. In other patient populations, such as those with knee osteoarthritis, quadriceps strength is associated with improved ability to carry out physical performance measures such as a 6-minute walk test and a timed stair ascent.[21] While the average Tegner Activity Score totals of patients in this study were lower than patients who were returning to sport after ACLR,[17,30] they were consistent with those reported in patients who were 20 years post-ACLR.[36] These results, in light of similar research studies, indicate that dynamic, athletic movements such as hop testing are not routinely performed in patients as they progress further from ACLR, and therefore they may not be reflective of current perceived function.

Interestingly, time since surgery was not statistically associated with PROs, indicating that patients between 5 and 20 years post-ACLR may possess similar self-reported recovery characteristics. In a cohort study of 1592 patients with ACLR, Spindler et al[33] reported that there were no statistical differences in either IKDC or KOOS scores between 2-, 6-, and 10-year follow-up. Therefore, while time since surgery is still an important consideration for clinical decision making and formulating a treatment program, our results indicate that time since surgery may carry little association with determining PROs long after ACLR.

Kinesiophobia consistently added a significant level of variance to each multivariate linear regression model. To the best of our knowledge, this is the first evidence demonstrating an independent relationship between the TSK-17 and long-term PROs with physical performance testing included in the final model. This adds to the growing body of literature supporting the important role psychological factors carry with patient outcomes and their negative association with function.[8] Much of the ACL research to date associates kinesiophobia primarily with return to sport,[3] and our data suggest that fear continues to play a role in recovery years after surgery. While the level of

Table 2. Mean scores for physical performance testing and self-reported outcomes

Variable	Mean (SD)	Median	Range
Performance testing on injured limb			
Isometric quadriceps strength (N·m/kg)	2.46 (0.50)	2.56	1.02-3.47
Step downs in 60 s (No. of reps)	31.7 (13.17)	33.0	0-62
Single hop (cm)	125.6 (32.85)	127.8	44.67-204.6
Triple hop (cm)	349.5 (84.42)	353.0	138.0-572.3
Performance testing on uninjured limb			
Isometric quadriceps strength (N·m/kg)	2.53 (0.58)	2.53	1.14-4.01
Step downs in 60 s (No. of reps)	33.26 (12.78)	34.0	5-57
Single hop (cm)	129.07 (32.73)	130.3	61.67-201.0
Triple hop (cm)	358.75 (87.69)	362.7	164.67-594.33
Self-reported outcome			
TSK-17	29.8 (5.6)	30.5	19-39
KOOS Sport	79.3 (21.5)	85.0	25-100
KOOS QoL	73.6 (21.3)	78.1	25-100
IKDC	82.0 (16.2)	86.8	34.5-100
LEFS	74.6 (6.8)	76.5	49-80

IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; LEFS, Lower Extremity Functional Scale; QoL, Quality of Life; TSK-17, Tampa Scale of Kinesiophobia.

kinesiophobia in this study was relatively low, the fact that it was associated with PROs seems to indicate that any level of kinesiophobia is important to consider when developing a rehabilitation strategy.

Patients with a body weight–normalized maximal quadriceps strength value between 2.18 and 2.62 N·m/kg tended to exceed the PASS scores for each PRO. Pietrosimone et al[30] reported that the optimal cutoff score for maximal isometric quadriceps strength normalized to body weight in patients greater than 6 months post-ACLR is 3.10 N·m/kg[30] while Lepley et al[20] reported a cutoff of 2.67 N·m/kg. These past studies were conducted in younger patients who were still undergoing or recently finished rehabilitation, which may contribute to the higher cutoff scores compared with those of this study. This may indicate that clinicians should strive to help patients who are in the chronic stages of recovery for ACLR achieve a peak quadriceps strength of 2.62 N·m/kg or greater in order to improve patient-perceived function. In the event that exceeding this threshold is not possible, rehabilitative techniques with even slight improvements in quadriceps strength should increase the odds of exceeding PASS threshold standards (Table 4).

Limitations

The results of this study should be understood in light of the limitations present. First, this study was cross-sectional in nature. Therefore, it is not possible to draw causal associations between maximal isometric quadriceps strength and PROs, as all data collections were completed at a single time point. Additionally, the sample size was relatively small (N = 40) and only contained 11 male patients. Future larger scale, prospective studies evaluating the relationship between early quadriceps strength and long-term outcomes are indicated. An important consideration that was not accounted for was the quantity and quality of activity the patients performed to maintain knee health at the time of the study, which may affect the patient's self-perceived function. Similarly, we did not account for the patient's level of activity in the regression models. This is an important consideration for future, larger scale studies. Additionally, kinesiophobia is only 1 component of an individual's psychosocial profile. Controlling for other important psychological variables such as knee self-efficacy is indicated for future studies. There may also be other factors related to the surgical procedure that may influence PROs and/or the results of

Table 3. Multiple linear regression results demonstrate isometric quadriceps strength as the sole functional test independently associated with patient-reported outcomes

Outcome Variables	Predictor Variables	Final β Coefficient	Adjusted R^2	*P*
KOOS Sport	Time since surgery	–0.28	<0.01	0.68
	Age	–0.31	<0.01	0.28
	TSK-17	–1.64	0.16	0.003
	Isometric quadriceps strength	16.95	0.30	0.006
KOOS QoL	Time since surgery	–0.43	0.02	0.44
	Age	–0.28	0.01	0.22
	TSK-17	–2.37	0.39	<0.001
	Isometric quadriceps strength	17.06	0.54	0.001
IKDC	Time since surgery	–0.72	0.07	0.09
	Age	–0.18	0.07	0.31
	TSK-17	–1.31	0.25	<0.001
	Isometric quadriceps strength	17.60	0.55	<0.001
LEFS	Time since surgery	–0.06	0.02	0.76
	Age	–0.20	0.11	0.02
	TSK-17	–0.39	0.19	0.01
	Isometric quadriceps strength	6.81	0.44	<0.001

IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; LEFS, Lower Extremity Functional Scale; QoL, Quality of Life; TSK-17, Tampa Scale of Kinesiophobia.

Table 4. Results of ROC curve comparing dichotomized patient-reported outcomes with maximal quadriceps strength output

Outcome	Isometric Quadriceps Strength Odds Ratio	Odds Ratio, 95% CI	AUC	AUC, 95% CI	Sensitivity	Specificity	Biodex Cutoff, N·m/kg
IKDC	26.4	1.83 to 379.61	0.73	0.57-0.90	0.89	0.50	2.18
LEFS	29.4	2.25 to 385.76	0.79	0.59-0.99	0.90	0.67	2.18
KOOS QoL	20.7	1.98 to 217.12	0.77	0.60-0.95	0.83	0.64	2.35
KOOS Sport	6.0	1.03 to 34.69	0.66	0.49-0.85	0.44	0.80	2.62

AUC, area under the curve; IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; LEFS, Lower Extremity Functional Scale; QoL, Quality of Life; ROC, receiver operating characteristic.

the physical performance tests. For example, during the time period that the surgical procedures were performed, clinical practice transitioned from more frequent use of transtibial femoral tunnel drilling to the use of an accessory anteromedial portal. These details were not collected as part of the current study and future studies should assess the potential role of surgical

technique. Finally, there were a number of other physical performance tests that were not collected in this study, such as hip strength, balance, and neuromuscular control. It is possible that these variables may explain additional variance in PROs and should be evaluated in future, larger scale studies.

CONCLUSION

This study adds to the growing body of literature suggesting that maximal isometric quadriceps strength and kinesiophobia each carry important implications for PROs after ACLR. Rehabilitative efforts focused on maintaining maximal isometric quadriceps strength and reducing kinesiophobia may improve long-term patient-perceived recovery.

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