

# Relationships of Muscle Function and Subjective Knee Function in Patients After ACL Reconstruction

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**Background:** After anterior cruciate ligament reconstruction (ACLR), relationships between objective measures of muscle function and patient-reported outcomes may change over time. Examining these measures at different time frames after surgery may help develop individualized approaches to improve post-ACLR analysis.

**Purpose:** To examine the associations between subjective knee function and lower-extremity muscle function in individual patients at various time points after ACLR.

**Study Design:** Descriptive laboratory study.

**Methods:** Fifty-one participants who underwent primary, unilateral ACLR (15 males, 36 females; mean age,  $22.9 \pm 4.5$  years; mean height,  $172.4 \pm 10.1$  cm; mean weight,  $68.7 \pm 13.1$  kg) were separated into 3 groups depending on time since surgery (early, <2 years; middle, 2-5 years; late, >5 years). Subjective knee function was quantified using the International Knee Documentation Committee (IKDC) subjective knee form and the Knee injury and Osteoarthritis Outcome Score (KOOS). Isometric knee extension and flexion strength were collected at 90 deg/s. Single-leg hop performance was measured using the single hop, triple hop, cross-over hop, and 6-m timed hop. Coefficient correlations were calculated between subjective knee function and objective measures of muscle function for each group.

**Results:** The early group demonstrated moderate correlations between the KOOS and unilateral measures of flexion peak torque ( $r = 0.514$ ,  $P = .035$ ) and flexion power ( $r = 0.54$ ,  $P = .027$ ). The middle group demonstrated the strongest correlations between the KOOS and symmetry measures of the single hop ( $r = 0.69$ ,  $P = .002$ ) and extension work ( $r = 0.71$ ,  $P = .002$ ) as well as unilateral measures of the triple hop ( $r = 0.52$ ,  $P = .034$ ) and extension work ( $r = 0.66$ ,  $P = .004$ ). The late group demonstrated strong correlations between the 6-m timed hop symmetry and the IKDC ( $r = 0.716$ ,  $P = .001$ ) and KOOS ( $r = 0.71$ ,  $P = .001$ ).

**Conclusion:** Patients with a post-ACLR status of less than 2 years exhibited stronger relationships with unilateral strength measures to subjective function; graft type was found to change these relationships. Patients at 2 to 5 years postsurgery demonstrated relationships with both unilateral and symmetry measures of muscle function to subjective function. Patients who were more than 5 years after ACLR exhibited strong associations between hopping symmetry and subjective function.

**Clinical Relevance:** Future clinical guidelines for patients after ACLR may need to consider time since surgery as a potential factor.

**Keywords:** IKDC; KOOS; hopping; quadriceps strength; hamstring strength

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Anterior cruciate ligament reconstruction (ACLR) surgery is common for physically active individuals who have sustained an ACL injury. Unfortunately, a large proportion of patients experience chronic knee symptoms that interfere with activities of daily living and impede on the ability to exercise. These patients may experience bouts of instability,<sup>28</sup> muscle weakness,<sup>13</sup> and joint pain<sup>26,38</sup> and may perceive a greater level of disability,<sup>8</sup> which collectively influences return to previous level of activity, potentially affecting the ability to maintain a healthy, physically active lifestyle.<sup>1</sup>

Skeletal muscle function plays a primary role in providing stability to the knee joint, maintaining postural control,

and absorbing forces acting on the knee. ACLR is accompanied by diminished muscle function<sup>13,14</sup> and abnormal functional movement patterns<sup>7,9</sup> that can persist long after the initial injury or surgical reconstruction.<sup>18</sup> Impaired muscle function after ACLR, represented by a decrease in quadriceps strength,<sup>20</sup> has been found to be a predictor of poor subjective knee function.<sup>14</sup> Current studies that aim to distinguish relationships of subjective function have primarily recruited large cohorts with a broad range of time from ACLR. These relationships may differ as patients progress further from surgery, as activity levels and physical demands may change.

Development of clinical guidelines for improving function in ACLR patients after release to unrestricted activity may be facilitated by a better understanding of the relationship between skeletal muscle dysfunction and subjective knee disability. Many current predictors of outcomes after ACLR are directed at preventing ACL reinjury and safely returning the patient to his or her previous level of activity.<sup>29</sup> Traditional clinical tests such as quadriceps and hamstring strength and symmetry<sup>2</sup> and single-leg hop performance and symmetry<sup>34</sup> are often administered to identify muscle impairment after ACLR to inform return-to-play decision making and to monitor joint health across the life span.

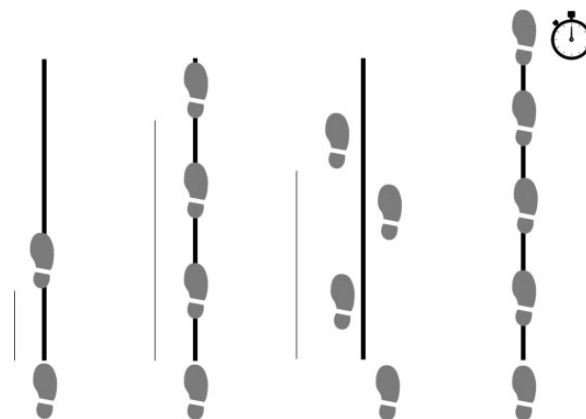
Within the ACLR population who have been released from postsurgical rehabilitation, clinical recommendations have been made for measures of muscle performance to improve perceived function.<sup>19,31</sup> A limitation within these studies is the examination of a broad patient population from the time after surgery. These relationships between muscle function and subjective function may not be consistent over such a large frame of time, where activity levels and the functional demands of the ACLR knee may change. It is important to establish these relationships to potentially provide individualized clinical recommendations dependent on time after ACLR. Therefore, the purpose of this study was to examine the associations between subjective knee function and lower-extremity muscle strength and hopping performance in ACLR patients at sequential postsurgery time frames.

## METHODS

This was a descriptive laboratory study, and all data were collected in a controlled laboratory environment. Participants were stratified into groups based on sequential time frames after ACLR surgery. Within each group, we examined the relationship between 2 measures of subjective knee function, the International Knee Documentation Committee (IKDC) subjective knee evaluation<sup>35</sup> and the Knee injury and Osteoarthritis Outcome Score (KOOS),<sup>33</sup> and lower-extremity functional measures of knee extension and flexion muscle strength as well as single-leg hop performance.

### Participants

A convenience sample of 51 individuals with a history of primary, unilateral ACLR with no concomitant ligament reconstruction were recruited to participate in this study. All participants were recreationally active, between 18 and



**Figure 1.** (Left to right) The single hop was performed by having the participant stand on the tested limb, hopping as far as possible, and landing on the same leg. The triple hop was performed by having the participant stand on the tested limb, followed by performing 3 consecutive single-leg hops as far as possible. For the crossover hop, the participant stood on the tested limb, then hopped as far as possible 3 consecutive times while crossing over a 15-cm line with each hop. The 6-m timed test was performed by having the participant stand on the tested limb and instructing the participant to hop on the tested leg as fast as he or she could to the end of the 6-m line.

35 years old, had no neurological conditions, and self-reported having returned to their desired level of physical activity after surgery. Meniscal repair or removal at the time of ACLR was not an exclusion criterion. Participants were stratified into 3 groups: “early” (9 months to 2 years after index ACLR), “middle” (2 to 5 years after index ACLR), and “late” (5 to 15 years after index ACLR). Two years postsurgery was viewed as the time of returning to sport where the individual is at a greater risk of reinjury, 2 to 5 years postsurgery being the likely duration of the individual’s sports career, and more than 5 years postsurgery for the individual’s transition to a decreased level of activity. The study was approved by our university’s institutional review board, and all participants provided written informed consent.

### Testing Procedures

After enrollment, participants completed patient-reported outcome measures evaluating subjective knee function (the IKDC and KOOS) and physical activity levels (the Tegner Activity Scale<sup>37</sup> [Tegner] and the Godin Leisure-Time Activity Scale<sup>10</sup> [Godin]).

**Knee Extension and Flexion Strength.** Isokinetic, concentric knee extension and flexion strength were measured bilaterally using a Biodex Systems III dynamometer (Biodex Medical Systems). The uninvolved limb was tested first for all participants. The participants then performed practice trials on each limb for warm-up and task familiarization. For testing, the participants exerted maximal effort during an isokinetic speed of 90 deg/s through their full knee flexion and extension range of motion for 8 repetitions.

The average peak torque, average power, and total work during extension and flexion were exported from a multi-mode isokinetic dynamometer (Biodex System 3). Average peak torque was calculated using the average of the maximum torque produced in each of the 8 trials. Total work was calculated using the total force produced over the angular displacement measured for all 8 trials. Average power was calculated using the average work produced over the total time during each of the 8 trials.

**Single-Leg Hop.** Single-leg hop performance was measured bilaterally using 4 separate hop tasks: single hop for distance, triple hop for distance, crossover hop for distance, and 6-m timed hop (Figure 1), similar to previously recorded methods.<sup>12,24</sup> Each participant was given as many warm-up trials as needed until he or she felt comfortable completing the task. Testing always started with the uninvolved limb, and 3 trials were measured bilaterally for all 4 hopping tasks. For all hopping tasks, participants needed to maintain single-leg balance and “stick” landings for each hop. Any trials that resulted in a 2-footed landing, touching of the hands or contralateral foot to the ground, or double hops were considered a failed trial, and the trial was repeated. For the triple hop for distance tests, measures were taken from toe at start to heel at landing. For the 6-m timed hop, the instructor started the stopwatch at initial movement of the tested foot and stopped the time as soon as the tested foot crossed the 6-m line.

Data Processing

**Involved Limb and Limb Symmetry Calculations.** Unilateral involved limb calculations of strength and single-leg hop distance measures (single, triple, cross) were normalized by mass and height, respectively. The timed hop for the involved limb was not normalized. Limb symmetry calculations for both strength and hopping measures were calculated using the following formula<sup>21</sup>:

$$Limb\ symmetry = \frac{Involved\ limb}{Uninvolved\ limb}$$

Statistical Analysis

Demographics variables were compared between groups using 1-way analyses of variance (group: early, middle, late) with post hoc Tukey least significance difference for continuous data and chi-square tests for categorical data. Within each group, Pearson *r* correlation coefficients (2-tailed) were calculated between IKDC and KOOS scores and the involved limb and limb symmetry measures of knee extension and flexion strength and single-leg hop performance. These analyses were all also performed on a combined sample of all ACLR participants. Correlation coefficients were considered statistically significant if the associated *P* value was .05 or less. We classified correlation coefficients (*r*) of 0 to 0.39 as weak, 0.4 to 0.69 as moderate, and 0.7 to 1.0 as strong.

TABLE 1  
Patient Demographics by Time Group<sup>a</sup>

	Early (n = 17)	Middle (n = 17)	Late (n = 17)
Age, y	21.8 ± 4.2	20.1 ± 1.5	26.7 ± 4.5 <sup>b</sup>
Sex, n			
Male	6	3	6
Female	11	14	11
Mass, kg	68.6 ± 16.0	68.0 ± 10.2	69.6 ± 13.1
Height, cm	171.2 ± 12.3	172.4 ± 8.0	173.6 ± 9.9
Time postsurgery, mo	17.1 ± 5.5 <sup>c</sup>	40.7 ± 7.1 <sup>c</sup>	103.1 ± 34.0 <sup>c</sup>
Graft type, %			
PT	41	59	59
HS	53	24	29
Allograft	6	17	12
Tegner	7.4 ± 1.5	6.4 ± 1.3	6.5 ± 1.3
Godin	73.9 ± 15.6	66.4 ± 20.7	68.1 ± 18.1
IKDC	86.0 ± 9.1	87.4 ± 6.5	89.3 ± 10.2
KOOS Symptoms	83.4 ± 11.8	86.34 ± 9.2	87.4 ± 10.2
KOOS Pain	90.7 ± 7.5	93.0 ± 4.1	92.5 ± 10.1
KOOS ADL	97.8 ± 2.9	98.6 ± 1.5	97.7 ± 4.3
KOOS Sport	77.6 ± 13.6	88.8 ± 5.5	85.9 ± 13.9
KOOS QoL	73.2 ± 16.5	78.7 ± 16.7	81.6 ± 16.0
Normalized			
Ext peak torque	1.70 ± 0.41	1.73 ± 0.35	1.73 ± 0.34
Ext power	1.77 ± 0.52	1.82 ± 0.40	1.86 ± 0.40
Ext work	15.82 ± 3.07	16.74 ± 3.41	17.52 ± 4.1
Flex peak torque	0.83 ± 0.26	0.85 ± 0.23	0.88 ± 0.23
Flex power	0.89 ± 0.29	0.89 ± 0.26	0.94 ± 0.24
Flex work	8.18 ± 1.86	8.52 ± 2.14	9.29 ± 2.68
Single hop	0.65 ± 0.21	0.64 ± 0.15	0.64 ± 0.12
Triple hop	2.30 ± 0.59	2.13 ± 0.46	2.25 ± 0.38
Crossover hop	2.07 ± 0.58	2.05 ± 0.45	2.05 ± 0.49
6-m timed hop	2.20 ± 0.49	2.34 ± 0.42	2.28 ± 0.32
Symmetry			
Ext peak torque	0.84 ± 0.10 <sup>d,e</sup>	0.92 ± 0.12	0.95 ± 0.12
Ext power	0.86 ± 0.10 <sup>e</sup>	0.93 ± 0.11	0.98 ± 0.23
Ext work	0.85 ± 0.10 <sup>d,e</sup>	0.93 ± 0.11	0.96 ± 0.11
Flex peak torque	0.94 ± 0.16	0.98 ± 0.15	1.01 ± 0.12
Flex power	0.94 ± 0.18	1.00 ± 0.17	0.98 ± 0.12
Flex work	0.92 ± 0.19	0.99 ± 0.15	0.99 ± 0.13
Single hop	0.92 ± 0.21	0.98 ± 0.15	0.97 ± 0.15
Triple hop	0.98 ± 0.06 <sup>e</sup>	0.99 ± 0.04 <sup>f</sup>	1.02 ± 0.05
Crossover hop	0.97 ± 0.06	0.99 ± 0.05	1.01 ± 0.07
6-m timed hop	0.97 ± 0.06	1.01 ± 0.06	0.97 ± 0.075

<sup>a</sup>Data are presented as mean ± SD unless indicated otherwise. ADL, activities of daily living; Ext, extension; Flex, flexion; HS, hamstring graft; IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; PT, patellar tendon graft; QoL, quality of life.

<sup>b</sup>Late group significantly older than the early and middle group (*P* < .05).

<sup>c</sup>All groups significantly different (*P* < .05).

<sup>d</sup>Early group significantly different from middle group (*P* < .05).

<sup>e</sup>Early group significantly different from late group (*P* < .05).

<sup>f</sup>Middle group significantly different than late group (*P* < .05).

As an investigatory analysis, Pearson *r* correlations coefficients (2-tailed) were calculated between patient-reported outcomes and objective measures of muscle function for the early group, stratified by graft type.

TABLE 2  
Correlation Coefficients Between Subjective Function and Objective Measures of Muscle Function in All ACLR Participants<sup>a,b</sup>

	IKDC	KOOS Symptoms	KOOS Pain	KOOS ADL	KOOS Sport	KOOS QoL
Normalized						
Ext peak torque	0.21	0.21	0.12	0.27	0.28 <sup>c</sup>	0.23
Ext power	0.18	0.22	0.10	0.23	0.25	0.23
Ext work	0.13	0.19	0.08	0.23	0.20	0.22
Flex peak torque	0.15	0.27	0.07	0.19	0.26	0.32 <sup>c</sup>
Flex power	0.20	0.27	0.11	0.22	0.26	0.36 <sup>c</sup>
Flex work	0.15	0.27	0.07	0.19	0.21	0.34 <sup>c</sup>
Single hop	0.17	0.18	0.12	0.18	0.22	0.19
Triple hop	0.17	0.17	0.12	0.16	0.18	0.10
Crossover hop	0.21	0.27	0.18	0.26	0.28 <sup>c</sup>	0.29 <sup>c</sup>
6-m timed hop	-0.10	-0.20	-0.10	-0.17	-0.22	-0.25
Symmetry						
Ext peak torque	0.25	0.21	0.21	0.28 <sup>c</sup>	0.29 <sup>c</sup>	0.25
Ext power	0.10	0.13	0.04	0.23	0.10	0.18
Ext work	0.26	0.19	0.18	0.25	0.279 <sup>c</sup>	0.27
Flex peak torque	0.18	0.34 <sup>c</sup>	0.20	0.18	0.16	0.24
Flex power	0.27	0.38 <sup>c</sup>	0.28 <sup>c</sup>	0.27	0.297 <sup>c</sup>	0.38 <sup>c</sup>
Flex work	0.20	0.32 <sup>c</sup>	0.22	0.21	0.21	0.30 <sup>c</sup>
Single hop	0.18	0.16	0.09	0.16	0.15	0.16
Triple hop	0.18	0.06	0.06	0.02	0.27	0.19
Crossover hop	0.13	0.26	0.03	0.05	0.24	0.16
6-m timed hop	0.32 <sup>c</sup>	0.33 <sup>c</sup>	0.38 <sup>c</sup>	0.38 <sup>c</sup>	0.33 <sup>c</sup>	0.38 <sup>c</sup>

<sup>a</sup>ACLR, anterior cruciate ligament reconstruction; ADL, activities of daily living; Ext, extension; Flex, flexion; IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; QoL, quality of life.

<sup>b</sup>Correlations between subjective function and unilateral normalized and symmetry measures of both strength and hopping performance were weak ( $r = 0.0-0.39$ ).

<sup>c</sup>Correlation is significant at the .05 level (2-tailed).

## RESULTS

Demographic variable means and standard deviations for each study group and results of post hoc group comparison are presented in Table 1. There were no significant between-group differences in sex, mass, height, activity level, or subjective knee function as quantified by the IKDC and KOOS subscales. The late group was significantly older than the early and middle groups, and time postsurgery was significantly different between all 3 groups. Significant differences were found between groups for measures of extension peak torque symmetry, extension work symmetry, extension power symmetry, and triple hop symmetry.

Correlation coefficients are presented by groups in Tables 2 and 3. In all ACLR participants, we observed weak correlations between unilateral and symmetry measures of strength and hopping performance to subjective function (Table 2). In the early group, we observed moderate correlations between unilateral normalized measures of knee flexion strength and the KOOS Sport subscale ( $r = 0.535$ ,  $P = .027$ ). In the middle group, we observed moderate to strong correlations with both unilateral normalized values and symmetry measures of strength and hopping, with the highest correlation coefficient between the extension work symmetry variable and the KOOS Symptoms subscale ( $r = 0.704$ ,  $P = .002$ ). In the late group, we observed moderate to strong correlations between measures of strength and hopping symmetry, with the highest correlation coefficient

presenting between the 6-m timed hop symmetry variable and the IKDC ( $r = 0.721$ ,  $P < .001$ ).

In members of the early group with a patellar tendon graft, we observed strong correlations with unilateral measures of the single hop ( $r = 0.863$ ,  $P = .012$ ), triple hop ( $r = 0.787$ ,  $P = .036$ ), crossover hop ( $r = 0.855$ ,  $P = .014$ ), and 6-m timed hop ( $r = -0.755$ ,  $P = .05$ ) to the KOOS ADL (activities of daily living) subscale and between normalized extension work and the KOOS Sport subscale ( $r = 0.754$ ,  $P = .05$ ). In members of the early group with a hamstring graft, we observed strong correlations with unilateral measures of knee flexion power to the KOOS Sport subscale ( $r = 0.790$ ,  $P = .011$ ) and the IKDC ( $r = 0.704$ ,  $P = .017$ ), unilateral knee flexion peak torque to the KOOS Sport subscale ( $r = 0.788$ ,  $P = .012$ ), and unilateral knee flexion work to the KOOS QoL (quality of life) subscale ( $r = 0.717$ ,  $P = .03$ ). Patients in the early group with a hamstring graft demonstrated stronger relationships to knee flexion measures, compared with patients with a patellar tendon graft, who demonstrated stronger relationships to single-leg hop and knee extension measures.

## DISCUSSION

The primary objective of our study was to examine the associations between subjective knee function and lower-extremity muscle strength and hopping performance in

TABLE 3  
Correlation Coefficients Between Subjective Function and Objective Measures of Muscle Function in ACLR Participants by Time Cohort<sup>a,b</sup>

	Early					Middle					Late							
	IKDC	KOOS Symptoms	KOOS Pain	KOOS ADL	KOOS Sport	KOOS QoL	IKDC	KOOS Symptoms	KOOS Pain	KOOS ADL	KOOS Sport	KOOS QoL	IKDC	KOOS Symptoms	KOOS Pain	KOOS ADL	KOOS Sport	KOOS QoL
Normalized																		
Ext peak torque	0.36	0.03	0.22	0.42	0.46	0.12	0.20	0.489 <sup>c</sup>	0.21	0.29	0.45	0.45	0.01	0.24	-0.01	0.19	0.03	0.14
Ext power	0.38	0.06	0.25	0.42	0.47	0.17	0.16	0.491 <sup>c</sup>	0.20	0.21	0.43	0.45	-0.06	0.19	-0.08	0.12	-0.06	0.07
Ext work	0.31	-0.08	0.21	0.35	0.40	0.16	0.19	0.663 <sup>c</sup>	0.09	0.10	0.43	0.28	-0.07	0.04	-0.03	0.24	-0.05	0.14
Flex peak torque	0.39	0.24	0.26	0.43	0.51 <sup>c</sup>	0.34	-0.05	0.34	0.03	0.18	0.21	0.48	0.02	0.24	-0.08	0.06	0.07	0.13
Flex power	0.46	0.28	0.30	0.43	0.54 <sup>c</sup>	0.41	-0.01	0.32	0.05	0.18	0.23	0.510 <sup>c</sup>	0.06	0.22	-0.01	0.12	0.06	0.15
Flex work	0.38	0.24	0.24	0.36	0.44	0.42	-0.02	0.50 <sup>c</sup>	-0.08	0.08	0.23	0.40	0.03	0.11	0.01	0.18	0.03	0.17
Single hop	0.24	0.01	0.20	0.44	0.36	0.10	0.27	0.40	0.38	-0.02	0.33	0.42	0.03	0.31	-0.02	0.05	0.15	0.14
Triple hop	0.18	-0.07	0.15	0.38	0.32	0.07	0.26	0.52 <sup>c</sup>	0.26	-0.17	0.38	0.21	0.14	0.29	0.10	0.18	0.17	0.12
Crossover hop	0.29	0.09	0.31	0.47	0.47	0.29	0.21	0.450 <sup>c</sup>	0.27	0.01	0.33	0.46	0.16	0.37	0.08	0.23	0.20	0.17
6-m timed hop	-0.12	-0.10	-0.23	-0.47	-0.35	-0.27	-0.18	-0.35	-0.24	0.10	-0.31	-0.35	-0.07	-0.29	0.02	-0.11	-0.30	-0.20
Symmetry																		
Ext peak torque	0.10	-0.29	-0.12	0.07	0.29	-0.16	0.06	0.56 <sup>c</sup>	0.09	0.24	0.33	0.32	0.39	0.23	0.42	0.48 <sup>c</sup>	0.08	0.31
Ext power	0.34	-0.11	0.07	0.23	0.36	-0.05	-0.01	0.45	0.04	0.13	0.19	0.36	-0.04	0.03	-0.03	0.26	-0.16	0.06
Ext work	0.10	-0.45	-0.25	0.00	0.22	-0.20	0.12	0.71 <sup>c</sup>	0.05	-0.01	0.33	0.42	0.37	0.26	0.47	0.55 <sup>c</sup>	0.09	0.37
Flex peak torque	0.17	0.39	0.11	0.29	0.14	0.16	-0.11	0.28	0.02	-0.07	0.08	0.27	0.36	0.26	0.38	0.25	0.12	0.19
Flex power	0.37	0.46	0.25	0.38	0.33	0.33	-0.23	0.28	-0.05	-0.17	0.02	0.33	0.62 <sup>c</sup>	0.37	0.556	0.47	0.39	0.48
Flex work	0.25	0.30	0.10	0.27	0.22	0.22	-0.11	0.50 <sup>c</sup>	-0.04	-0.20	0.13	0.39	0.32	0.10	0.46	0.36	0.05	0.21
Single hop	0.20	0.05	0.15	0.34	-0.10	-0.15	0.49 <sup>c</sup>	0.26	0.69 <sup>c</sup>	0.36	0.62 <sup>c</sup>	0.58 <sup>c</sup>	-0.09	0.15	-0.26	-0.07	0.15	0.06
Triple hop	0.10	-0.22	-0.13	-0.07	0.12	-0.19	-0.32	-0.02	-0.08	-0.10	-0.24	0.26	0.38	0.34	0.23	0.17	0.54 <sup>c</sup>	0.44
Crossover hop	0.30	0.07	0.07	0.05	0.24	-0.03	-0.51 <sup>c</sup>	0.12	-0.43	-0.31	-0.56 <sup>c</sup>	-0.12	0.24	0.46	0.09	0.15	0.39	0.42
6-m timed hop	-0.11	-0.18	-0.19	-0.02	-0.07	0.03	0.20	0.61 <sup>c</sup>	0.44	0.16	0.37	0.55 <sup>c</sup>	0.72 <sup>c</sup>	0.61 <sup>c</sup>	0.71 <sup>c</sup>	0.66 <sup>c</sup>	0.56 <sup>c</sup>	0.57 <sup>c</sup>

<sup>a</sup>ACLR, anterior cruciate ligament reconstruction; ADL, activities of daily living; Ext, extension; Flex, flexion; IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; QoL, quality of life.

<sup>b</sup>Correlation coefficient heat map:

Weak:	Moderate:	Strong:
0.0-0.39	0.40-0.69	0.70-1.0

<sup>c</sup>Correlation is significant at the .05 level (2-tailed).

ACLR patients at sequential postsurgery time frames. Within all ACLR participants, we found weak associations for both symmetry and unilateral measures to subjective function. After separating the participants into cohorts depending on the time since surgery, these associations strengthened. ACLR participants less than 2 years postsurgery possessed relationships with unilateral strength and subjective function. Participants from 2 to 5 years postsurgery exhibited relationships with both normalized unilateral and symmetry measures to strength and hopping performance. Participants later than 5 years postsurgery demonstrated relationships with both strength and single-leg hop symmetry to subjective function.

For all ACLR patients, the 6-m timed hop symmetry was shown to be the best predictor of subjective function; however, these correlations were weak (Table 2). These correlation trends may be overgeneralized due to the patient population within the study. ACLR patients have been found to experience poor function throughout many stages after reconstruction, expressing the need to determine these relationships and different time frames.<sup>25</sup>

For the early group, we found the strongest relationship to subjective function to be knee flexion power at 90 deg/s normalized to body weight. Previous literature has reported knee flexion torque to be associated with poor subjective function in patients that had obtained a semitendinosus tendon graft.<sup>5,22</sup> In this study, the early group was mostly composed of patients that had obtained a hamstring

graft, whereas the middle and late groups were mostly composed of patients that obtained a patellar tendon graft. Once the time groups were stratified by graft type, relationships existed with knee extension strength and single-leg hopping performance to subjective function with early patients with a patellar tendon graft. Patients with a hamstring graft in the early group demonstrated relationships of subjective function to knee flexion strength. Results from the early group stratified by graft type may indicate the importance of strengthening muscle groups dependent on graft type less than 2 years after ACLR. The authors acknowledge low sample sizes once separating groups by graft type; however, results in the early group support previous literature that places emphasis on knee extension or flexion strengthening dependent on graft type.<sup>40</sup> The associations found in the early group (Tables 2 and 3) show the importance of increasing unilateral strength. A previous study<sup>19</sup> reported normalized knee extension maximum voluntary isometric contraction torque of 3.00 N·m/kg to be a strong indicator of subjective function in 22 ACLR patients approximately 31 months after surgery. These results may suggest strengthening ACLR patients within 2 years from surgery to unilateral normalized measures for greater outcomes,

The middle group, tested 2 to 5 years after ACLR, had the greatest associations between extension work symmetry and 6-m timed hop symmetry to the KOOS Symptoms subscale. This time period is seen as a transition from the

patient's returning to sport to the duration of his or her competitive careers.<sup>6,17,27</sup> These moderate to strong correlations expressed for the middle group also show that the objective and subjective measures of knee function are describing different aspects in the ACLR patient, thus expressing the importance of both in a comprehensive evaluation of the patient. Previous literature looking at ACLR patients within this time frame found similarly low correlations between subjective function and single-leg hopping symmetry.<sup>32,36</sup> From the results of this study, symmetry of both quadriceps strength and function are best associated with subjective outcomes.

Within the late cohort of ACLR patients, the 6-m timed hop symmetry had the best association with subjective function. The 6-m timed hop is a functional task demanding muscular strength, coordination, and speed.<sup>15,37</sup> The results show the patients within the late group with better symmetry within functional tasks have higher subjective scores. Due to the natural attrition of activity levels throughout life,<sup>3,16</sup> the daily functional demand may not be the same in patients in the late group than the patients in the early group. For the patients in the late group, the uninvolved limb may be acclimated to the muscular demands of the patient's desired function. Therefore, limb symmetry of a functional task, such as the 6-m timed hop, may be the best indicator of perceived outcome for this population.

Symmetry measures have become a commonly used guideline when evaluating outcomes after ACLR.<sup>11,25</sup> The relationship between limb symmetry and subjective function is not well understood. A limb symmetry index (LSI) of 80%, which is often a sought goal of ACLR patients returning to play, has been used to establish predictors of subjective knee function for the ACLR patient.<sup>25</sup> However, an LSI less than 88% for the single-leg crossover hop have been associated to lower IKDC scores in the ACLR population.<sup>24</sup> Other studies have refuted symmetry measures and found that unilateral normalized values are a better predictor of subjective function within the chronic ACLR population.<sup>19,31</sup> Symmetry may have a varying degree of value depending on the time after surgery. Results from this study (Table 3) find that symmetry measures are best associated with subjective outcomes in patients greater than 5 years from ACLR. These results may support the use of unilateral normalized measures to improve subjective function after ACLR.<sup>19,30</sup> Contralateral weakness may also increase symmetry values but may be a false representation of the strength of the involved limb, potentially resulting in a decrease in subjective function. Our study, which took 3 separate cohorts after ACLR, found that symmetry or normalized unilateral values may be used dependent on the time since reconstruction.

The results of the current study indicate that the relationships between muscle function and subjective function are not uniform over time after ACL surgery. ACLR is most common in younger individuals with an active lifestyle.<sup>4,23</sup> Other factors, such as desired activity level, may also be related to subjective outcomes; therefore, a clinician's evaluation may be altered to help restore maximum function

dependent on the patient's physical demands. This study finding that unilateral measures are related in some groups but symmetry in others may indicate that values to improve subjective function may change as the patient progresses from ACLR. Patients 2 years or less from ACLR should focus on unilateral normalized strength to improve subjective function. As the patient progresses away from highly competitive sport, their uninvolved limb may be an optimal measure of strength and function to their desired activity level. Clinicians should consider using limb symmetry of strength and functional tasks for patients beyond 2 years from ACLR, as symmetry measures were shown to have a stronger relationship to subjective outcomes in the middle and late groups.

Stratification of our ACLR cohort into early, middle, and late groups decreased the number of patients in each group. A greater number of patients within each group may have strengthened our findings. The time frames created were also not based on previous literature. We selected less than 2 years for the early group, as these are the patients returning to sport and are also at a high risk for reinjury.<sup>39</sup> The middle group was made 2 to 5 years postsurgery based on the estimated span of these patients' careers, and this time frame may be a stage of transition to a decrease in competitive activity level. The late group was then created 5 years or later. Within this late group, a broad range of patients were collected from 5.2 to 14.2 years after surgery. A smaller time range for this cohort would provide results better representing this group. Age differences between groups may also limit the findings resulting from solely time since surgery. Future literature consisting of age-matched groups may draw stronger conclusions for the relationships between groups. All these patients were also collected by a sample of convenience and were not seeking clinical care. Patients who perceive disability may want to seek routine evaluations after ACLR to help promote treatment decision making. The mean Tegner score for all ACLR patients was 6.75, indicating that patients in this study were high functioning. Results from an ACLR population seeking clinical care would provide better clinical recommendations.

## CONCLUSION

Relationships of muscle function and subjective knee function differ between separate cohorts of ACLR patients dependent on time postsurgery. ACLR patients less than 2 years after surgery exhibited stronger relationships with involved limb strength measures and subjective function, where graft type was found to change these relationships. ACLR patients 2 to 5 years after surgery demonstrated moderate relationships with unilateral normalized and symmetry measures of both strength and hopping performance to subjective function. ACLR patients greater than 5 years after surgery exhibited stronger associations between hopping task symmetry and subjective function. Future clinical guidelines for ACLR patients may need to consider time since surgery as a potential factor.

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