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Original Research

Isokinetic Strength Profiles Among Youth after Medial Patellofemoral Ligament Reconstruction

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Background

Knee strength is a critical measure of successful rehabilitation following medial patellofemoral ligament reconstruction (MPFLR). Yet, strength outcomes of youth following MPFLR are not widely reported.

Hypothesis/Purpose

The primary purpose was to profile isokinetic strength outcomes by sex and age among youth following MPFLR. A secondary purpose was to determine the relationship between normalized isokinetic strength values and patient-reported outcome scores by age and sex. The hypotheses were that 1) males would demonstrate higher normalized strength, and that 2) a higher proportion of males would achieve ⩾90% limb symmetry when compared to females.

Study Design

Cross-sectional

Methods

At 6.9±2.1 months after MPFLR, 162 patients completed isokinetic assessment of knee extension (KE) and flexion (KF) strength at 180°/s and 300°/s on both limbs (uninvolved [UN], involved [INV]). Strength data and patient-reported outcome scores, including the International Knee Documentation Committee (IKDC) Subjective Knee Form and Pediatric Quality of Life Inventory (PedsQL) were extracted from electronic medical records. Descriptive statistics were used to categorize data by age (Pre-adolescent, Early Adolescent, Late Adolescent, Young Adult) and sex. Independent-samples t-tests and chi-square analyses were used to determine sex-based differences in strength. Multiple linear regression analyses were used to determine the relationship between strength and patient-reported function.

Results

Among Early Adolescents, males demonstrated higher normalized KE strength at 300°/s compared to females (UN: 1.27±0.3 vs. 1.07±0.3 [p=0.01]; INV: 1.07±0.2 vs. 0.92±0.3 [p=0.03]). Among Late Adolescents, males demonstrated higher INV limb strength for KE 180°/s (1.55±0.53 vs. 1.24±0.5; p=0.02), KE 300°/s (1.25±0.4 vs. 1.00±0.4; p=0.01), and KF 180°/s (0.98±0.4 vs. 0.82±0.3; p=0.05). A higher proportion of Late Adolescent and Young

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Adult males achieved ⩾90% LSI compared to females (p=<0.01-0.04). Regression models estimating IKDC and PedsQL scores were significant with INV KE strength as an independent variable (p=0.01-0.03).

Conclusions

Males demonstrated higher normalized strength and symmetry compared to females following MPFLR. Higher INV KE strength was associated with higher patient-reported function.

Level of Evidence

2b

INTRODUCTION

Patellar dislocations of the knee are a common injury among young active individuals, with an estimated incidence of primary patellar dislocation of 23-29 per 100,000 person-years in those between 10-17 years of age.[1,2] Conservative management of these injuries has been shown to be effective at addressing common impairments in strength, range of motion, and function.[3] Yet, 28.5% of all patients will continue to have instability and/or anterior knee pain after patellar dislocation.[4] For young patients, the surgical approach of medial patellofemoral ligament reconstruction (MPFLR) is the gold standard intervention for those with recurrent instability who intend to return to preinjury activity level.[5]

In the past decade, peer-reviewed literature on young individuals who undergo MPFLR has been mostly limited to studies of surgical management.[6-8] Yet recently, emerging evidence has provided insight on post-surgical outcomes in this population. In the two to three years following surgery, recurrent patellar dislocation rates are reported to be as low as 5% among young patients who undergo primary MPFLR, though up to 27% experience a reduction in physical activity participation level.[9,10] Additionally, self-reports of patellofemoral pain have been shown to improve following primary MPFLR.[10,11] Despite the recent uptick in MPFLR outcomes research, there continues to be a paucity of quality evidence on rehabilitation outcomes among youth who undergo primary MPFLR. Not surprisingly, there are no published clinical practice guidelines or return-to-activity criteria available to guide rehabilitation specialists who serve this patient population.

Quadriceps muscle dysfunction is the most common complication following MPFLR, with strength deficits reported to be as high as 20% at 12 months after surgery.[12-15] Furthermore, these deficits are known to persist for up to four years among adult patients after MPFLR.[16,17] In a study of 28 young patients aged 12-16 years who underwent primary MPFLR, significant isometric quadriceps strength deficits were noted at a mean of 7.5 months post-surgery.[13] With evidence showing that most patients are released to return to sport 6-7 months after MPFLR,[18] there is a high likelihood that many patients are returning to activity with unresolved significant quadriceps strength deficits. Restoration of quadriceps muscle function to at least 90% limb symmetry is widely accepted as sufficient criteria for sport readiness after knee ligament injury, particularly for youth who intend to return to recreational or competitive sport activities involving cutting, pivoting, and decelerating.[19-21] Following other orthopedic surgical procedures, such as anterior cruciate ligament reconstruction, between-limb strength asymmetries measured in youth have been linked to altered landing mechanics, lower functional performance, and lower patient-reported outcomes.[22-24] Understanding the timeframe and extent to which young patients are able to regain strength after MPFLR will inform the development of strengthening interventions and return to sport guidelines, in addition to advancing the current knowledge base of post-surgical outcomes for this population.

To the authors' knowledge, there have been no publications of isokinetic strength outcomes among youth following MPFLR. Furthermore, between-limb strength symmetry following knee surgery is known to differ across sexes and maturational levels among youth.[25] Therefore, the primary purpose of this study was to profile isokinetic strength outcomes by sex and age among youth following MPFLR. A secondary purpose of this study was to determine the relationship between normalized isokinetic strength values and patient-reported outcome scores by age and sex.

The hypotheses were that 1) males would demonstrate higher normalized isokinetic strength, and that 2) a higher proportion of males would achieve traditional criteria of ⩾90% limb symmetry when compared to females.

METHODS

PARTICIPANTS

This retrospective study used data collected from an ongoing, robust occupational therapy and physical therapy divisional registry of patients within a large, Midwest pediatric medical center. Chart review of electronic medical records was performed for all registry patients presenting for evaluation within the medical center's outpatient orthopedic physical therapy clinics following MPFL reconstruction between May 2018 and May 2023. Inclusion criteria required participants 1) to have undergone primary, unilateral MPFL reconstruction by one of two primary orthopedic surgeons at the medical center, 2) be ⩽21 years old at time of surgery, and 3) to have completed an isokinetic strength test during participation in post-surgical physical therapy at the medical center. Exclusion criteria included 1) history of concomitant trochleoplasty during MPFL reconstruction and 2)

history of concomitant patellar fracture during patellar dislocation injury. The medical center's Institutional Review Board approved this study.

DATA EXTRACTION

Demographic data (e.g. age, sex, anthropometrics) and isokinetic strength data were extracted from each participant's electronic medical record. All participants completed isokinetic assessment of knee extension (KE) and flexion (KF) strength as part of the rehabilitation plan designed by the respective primary treating physical therapist. An isokinetic dynamometer (Biodex Medical Systems Inc., Shirley, NY) was used to measure strength, quantified as peak torque output normalized to body weight (Newton-meters per kilogram, Nm/kg). According to the institution's standardized procedure, each participant was seated in the chair of the dynamometer with trunk fully supported. Trunk, pelvis and thigh of the limb being tested were stabilized with straps to avoid accessory or compensatory movement. The axis of the dynamometer was aligned with the knee joint line, and the distal shank is securely strapped to the resistance arm of the dynamometer (Figure 1). Testing was performed at 180°/s (10 repetitions) and 300°/s (15 repetitions) on both limbs (uninvolved [UN], involved [IN]). Limb symmetry index (LSI; [IN limb (Nm)/UN limb (Nm)] x 100%) was calculated for each test.

At time of isokinetic strength testing, patient-reported outcome measure scores were also extracted from each participant's record, including International Knee Documentation Committee Subjective Knee Form (IKDC) and Pediatric Quality of Life Inventory (PedsQL). The IKDC is a common measure of knee-related symptoms, function, and sport activity developed for patients with various knee conditions, including ligament injuries.[26] Among individuals aged 6-18 years with knee impairment, the IKDC is shown to be valid and reliable.[27] The PedsQL is a measure of pediatric health-related quality of life for healthy children and those with chronic disease.[28] Validity and reliability of the PedsQL have been shown to be high among a variety of pediatric populations.[29,30]

Neither rehabilitation plan of care nor timing of isokinetic strength testing was controlled for by the study team.

STATISTICAL ANALYSIS

Participants were categorized into four age groups: Pre-adolescent: <12.6 years old, Early Adolescent: 12.6-14.9 years old, Late Adolescent: 15-17.9 years old, and Young Adult: 18-21 years old. Descriptive statistics were used to categorize demographic and normalized strength data by age group and sex. Primary analyses included independent-samples t-tests used to determine sex-based differences in normalized strength within each age group. Effect sizes were calculated to determine magnitude of differences. Chi-square analyses were used to determine sex-based differences in the proportion of participants who met traditional criteria of ⩾90% LSI in each age group. Secondary analyses included multiple linear regression analyses used to determine the relationship between normalized strength and patient-reported outcome measure scores, while controlling for age and sex. All analyses were performed with SPSS 28 (SPSS Inc, Chicago, USA).

Figure 1. Isokinetic strength testing setup

RESULTS

Following completion of the chart review, 162 participants were included in the primary analyses for this study. Across age groups, the mean time between MPFL reconstruction and isokinetic test was 6.87 ± 2.08 months. Participant demographics are shown in Table 1.

ISOKINETIC STRENGTH RESULTS

The Pre-Adolescent group (<12.6 years old) consisted of 27 female participants. Normalized mean peak torque of KE and KF strength of INV and UNINV limbs is displayed in Table 2. Within this group, 48.1% and 33.3% of participants achieved ⩾90% LSI for KE strength at 180°/s and 300°/s, respectively. For KF strength, 81.5% and 63% of participants were able to achieve ⩾90% LSI at 180°/s and 300°/s, respectively.

In the Early Adolescent group (12.6-14.9 years old), male participants demonstrated significantly higher KE strength at 300°/s compared to female participants for both INV ($p=0.03$; $\diamond=0.63$) and UNINV limbs ($p=0.01$; $\diamond=0.70$) (Table 3). Achievement of ⩾90% LSI for KE and KF strength across isokinetic speeds ranged from 33.3-66.7% for females and from 26.1-73.9% for males (Table 3). No differences were found in the proportion of males and females who were able to achieve ⩾90% LSI for each test ($p=0.07$-0.95).

Analyses of the Late Adolescent group (15-17.9 years old) showed significant sex-based differences in both KE and KF strength. Compared to females, males demonstrated

Table 1. Participant Demographics by Age Group

		Entire cohort n=162	Pre-Adolescent (<12.5y) n=27	Early Adolescent (12.6-14.9y) n=55	Late Adolescent (15-17.9y) n=66	Young Adult (≥18y) n=14
Age (years)		14.90 ± 2.32	11.35 ± 0.85	13.88 ± 0.71	16.36 ± 0.85	18.92 ± 0.99
Sex	F	96	27	32	28	9
	M	66	0	23	38	5
Time between MPFLR and isokinetic test (months)		6.87 ± 2.08	7.05 ± 1.81	6.80 ± 2.19	6.69 ± 2.12	7.51 ± 1.80

MPFLR, medial patellofemoral ligament reconstruction; F, female; M, male; y, years

Table 2. Isokinetic Strength: Pre-Adolescent Group (<12.6 years old)

			Peak torque INV (ft-lb) (*mean ± SD*)	Peak torque UNINV (ft-lb) (*mean ± SD*)	Limb symmetry index (LSI) (*INV/UNINV*)	Achievement of 90% LSI (*n, %*)
Female (n=27)	KE	180°/s	1.12 ± 0.40	1.31 ± 0.48	0.88 ± 0.15	(13, 48.1%)
		300°/s	0.91 ± 0.29	1.06 ± 0.35	0.88 ± 0.16	(9, 33.3%)
	KF	180°/s	0.80 ± 0.33	0.79 ± 0.34	1.06 ± 0.21	(22, 81.5%)
		300°/s	0.70 ± 0.24	0.73 ± 0.26	0.99 ± 0.23	(17, 63.0%)

KE, knee extension; KF, knee flexion; INV, involved limb; ft-lb, foot-pounds; SD, standard deviation; UNINV, uninvolved limb; LSI, limb symmetry index

Table 3. Isokinetic Strength: Early Adolescent Group (12.6-14.9 years old)

			Peak torque INV (ft-lb) (*mean ± SD*)	Peak torque UNINV (ft-lb) (*mean ± SD*)	Limb symmetry index (LSI) (INV/UNINV)	Achievement of 90% LSI (n, %)
Female (n=32)	KE	180°/s	1.19 ± 0.30	1.42 ± 0.31	0.85 ± 0.17	(11, 33.3%)
		300°/s	**0.92 ± 0.25***	**1.07 ± 0.27***	0.87 ± 0.14	(16, 48.5%)
	KF	180°/s	0.82 ± 0.24	0.83 ± 0.20	0.99 ± 0.19	(21, 63.6%)
		300°/s	0.71 ± 0.22	0.72 ± 0.22	1.01 ± 0.24	(22, 66.7%)
Male (n=23)	KE	180°/s	1.34 ± 0.29	1.55 ± 0.36	0.89 ± 0.21	(10, 43.5%)
		300°/s	**1.07 ± 0.23***	**1.27 ± 0.30***	0.87 ± 0.20	(6, 26.1%)
	KF	180°/s	0.92 ± 0.25	0.93 ± 0.31	1.01 ± 0.15	(17, 73.9%)
		300°/s	0.78 ± 0.24	0.80 ± 0.29	1.01 ± 0.18	(16, 69.6%)

*bolded values indicate statistically significant differences (p<0.05); KE, knee extension; KF, knee flexion; INV, involved limb; ft-lb, foot-pounds; SD, standard deviation; UNINV, uninvolved limb; LSI, limb symmetry index

higher KE strength for INV limb at 180°/s (p=0.02, ◇=0.61) and 300°/s (p=0.01, ◇=0.66), and for UNINV limb at 180°/s (p=0.05, ◇=0.49). Males also demonstrated higher KF strength of the INV limb at 180°/s (p=0.05, ◇=0.51) (Table 4). Achievement of ⩾90% LSI for KE and KF strength across isokinetic speeds ranged from 29.6-70.4% for females and from 56.4-69.2% for males (Table 4). A higher proportion of males were able to achieve ⩾90% LSI for KE strength at 300°/s compared to females (X^2[1]=7.72, p<0.01).

Normalized strength results for the Young Adult group (⩾18 years old) are presented in Table 5. Within this group, males demonstrated significantly higher KE strength of the UNINV limb at 300°/s when compared to females (p=0.05, ◇=1.02). In this group, 44.4% of females were able to achieve ⩾90% LSI for KE and KF strength across isokinetic speeds, while between 20-100% of males achieved ⩾90% LSI across all tests. A higher proportion of males were able to achieve ⩾90% LSI for KF strength at 180°/s compared to females (X^2[1]=4.32, p=0.03).

ASSOCIATION BETWEEN STRENGTH AND PATIENT-REPORTED FUNCTION

Of the 162 participants included in this study, 137 (84.6%) had patient-reported outcome data available at time of isokinetic testing and were included in the secondary analysis. Demographic data for this subset of participants, in addition to patient-reported outcome scores, are shown in

Table 4. Isokinetic Strength: Late Adolescent Group (15-17.9 years old)

			Peak torque INV (ft-lb) (*mean ± SD*)	Peak torque UNINV (ft-lb) (*mean ± SD*)	Limb symmetry index (LSI) (*INV/UNINV*)	Achievement of 90% LSI (*n, %*)
Female (n=28)	KE	180°/s	**1.24 ± 0.47***	**1.50 ± 0.47***	0.82 ± 0.16	(9, 33.3%)
		300°/s	**1.00 ± 0.38***	1.19 ± 0.35	0.84 ± 0.19	**(8, 29.6%)***
	KF	180°/s	**0.82 ± 0.26***	0.86 ± 0.26	0.97 ± 0.16	(19, 70.4%)
		300°/s	0.74 ± 0.21	0.77 ± 0.21	0.97 ± 0.18	(19, 70.4%)
Male (n=38)	KE	180°/s	**1.55 ± 0.53***	**1.77 ± 0.58***	0.89 ± 0.15	(22, 56.4%)
		300°/s	**1.25 ± 0.39***	1.37 ± 0.41	0.93 ± 0.15	**(25, 64.1%)***
	KF	180°/s	**0.98 ± 0.34***	1.01 ± 0.37	0.10 ± 0.20	(25, 64.1%)
		300°/s	0.82 ± 0.28	0.83 ± 0.26	1.01 ± 0.22	(27, 69.2%)

*bolded values indicate statistically significant differences (p<0.05); KE, knee extension; KF, knee flexion; INV, involved limb; ft-lb, foot-pounds; SD, standard deviation; UNINV, uninvolved limb; LSI, limb symmetry index

Table 5. Isokinetic Strength: Young Adult Group (⩾18 years old)

			Peak torque INV (ft-lb) (*mean ± SD*)	Peak torque UNINV (ft-lb) (*mean ± SD*)	Limb symmetry index (LSI) (*INV/UNINV*)	Achievement of 90% LSI (*n, %*)
Female (n=9)	KE	180°/s	1.18 ± 0.44	1.40 ± 0.41	0.84 ± 0.12	(4, 44.4%)
		300°/s	0.92 ± 0.30	**1.06 ± 0.27***	0.86 ± 0.09	(4, 44.4%)
	KF	180°/s	0.80 ± 0.20	0.86 ± 0.15	0.92 ± 0.15	**(4, 44.4%)***
		300°/s	0.72 ± 0.18	0.77 ± 0.14	0.93 ± 0.09	(4, 44.4%)
Male (n=5)	KE	180°/s	1.32 ± 0.48	1.84 ± 0.37	0.70 ± 0.16	(1, 20.0%)
		300°/s	1.12 ± 0.33	**1.34 ± 0.29***	0.84 ± 0.13	(1, 20.0%)
	KF	180°/s	0.85 ± 0.16	0.84 ± 0.18	1.01 ± 0.07	**(5, 100%)***
		300°/s	0.65 ± 0.18	0.65 ± 0.17	1.02 ± 0.14	(3, 60.0%)

*bolded values indicate statistically significant differences (p<0.05); KE, knee extension; KF, knee flexion; INV, involved limb; ft-lb, foot-pounds; SD, standard deviation; UNINV, uninvolved limb; LSI, limb symmetry index

Table 6. Multiple regression models estimating IKDC score were statistically significant when INV limb KE strength was used as an independent variable, while controlling for age group and sex (180°/s: $F(3,133) = 2.98$, p=0.03, adj. $R^2 = 0.04$; 300°/s: $F(3,133) = 3.21$, p=0.03, adj. $R^2 = 0.05$) (Tables 7-8). Similarly, regression models estimating PedsQL score were statistically significant when INV limb KE was used as an independent variable, while controlling for age group and sex (180°/s: $F(3,133) = 4.16$, p<0.01, adj. $R^2 = 0.07$; 300°/s: $F(3,133) = 4.13$, p<0.01, adj. $R^2 = 0.07$) (Tables 7-8). Regression models estimating IKDC and PedsQL scores were not statistically significant when KF strength was used as the independent strength variable, after adjusting for age group and sex.

DISCUSSION

The purpose of this study was to profile isokinetic quadriceps and hamstrings strength outcomes by sex and age among youth following MPFLR, and to investigate the relationship between strength and patient-reported function. In accordance with the first hypothesis, at a mean of 6.9 months post-MPFLR, significant sex-based differences in strength were found in the Early-Adolescent, Late Adolescent, and Young Adult groups, with males in all age groups demonstrating higher normalized strength compared to females. In partial accordance with our second hypothesis, a higher proportion of males were able to achieve traditional criteria of ⩾90% limb symmetry index (LSI) for select quadriceps and hamstrings strength tests. Across groups, between 26-64% of youth are able to achieve ⩾90% LSI for isokinetic quadriceps strength, while 44-100% of youth demonstrate ⩾90% LSI for isokinetic hamstrings strength. Lastly, in a secondary analysis of a subset of participants, IKDC and PedsQL scores were found to be significantly positively associated with normalized quadriceps strength of the involved limb, after adjusting for age and sex. To the authors' knowledge, this study represents the first successful report of sex- and age-based isokinetic strength data for youth following MPFLR. As such, these findings serve as an important first step towards the development of age-relevant rehabilitation interventions and return to activity criteria for youth who undergo primary MPFLR.

Table 6. Demographics for Participants Included in Secondary Analysis: Association between Strength and Patient-Reported Function

		Entire Cohort n=137	Pre-Adolescent (<12.5y) n=20	Early Adolescent (12.6-14.9y) n=45	Late Adolescent (15-17.9y) n=60	Young Adult (≥18y) n=12
Age (years)		15.04 ± 2.24	11.34 ± 0.83	13.93 ± 0.71	16.36 ± 0.85	18.74 ± 0.78
Sex	F	80	20	27	26	7
	M	57	0	18	34	5
Time between MPFLR and isokinetic test (months)		6.87 ± 2.08	7.01 ± 1.82	6.70 ± 2.17	6.61 ± 2.17	7.51 ± 1.80
PedsQL score		79.97 ± 15.85	81.56 ± 12.74	80.28 ± 16.11	79.27 ± 16.86	79.69 ± 15.96
IKDC score		76.95 ± 12.94	76.76 ± 11.97	77.77 ± 11.59	77.22 ± 13.72	72.87 ± 15.99

MPFLR, medial patellofemoral ligament reconstruction; PedsQL, Pediatric Quality of Life Inventory; IKDC, International Knee Documentation Committee Subjective Knee Form; y, years

Table 7. Multiple Regression Results for Involved Limb Knee Extension Strength at 180°/s

			Age	Sex	180°/s KE INV
	Adj. R^2	p-value of model	*B* (95% CI)	*B* (95% CI)	*B* (95% CI)
IKDC score	0.042	0.034	-0.574 (-1.591,0.443)	-1.256 (-6.073,3.562)	**6.664* (1.564,11.764)**
PedsQL score	0.065	0.008	-0.604 (-1.834,0.627)	-1.584 (-7.412,4.245)	**9.816* (3.646,15.985)**

*bolded values indicate statistically significant differences (p<0.05); Model = "Enter" method in SPSS Statistics; IKDC, International Knee Documentation Committee Subjective Knee Form; PedsQL, Pediatric Quality of Life Inventory; *B,* unstandardized regression coefficient; CI, confidence interval; Adj. R^2, adjusted R^2.

Table 8. Multiple Regression Results for Involved Limb Knee Extension Strength at 300°/s

			Age	Sex	300°/s KE INV
	Adj. R^2	p-value of model	*B* (95% CI)	*B* (95% CI)	*B* (95% CI)
IKDC score	0.047	0.025	-0.591 (-1.606,0.424)	-0.828 (-5.713,4.057)	**9.085 (2.459,15.711)**
PedsQL score	0.065	0.008	-0.626 (-1.857,0.604)	-1.115 (-7.041,4.810)	**12.737 (4.700,20.774)**

*bolded values indicate statistical significance (p<0.05); Model = "Enter" method in SPSS Statistics; IKDC, International Knee Documentation Committee Subjective Knee Form; PedsQL, Pediatric Quality of Life Inventory; *B,* unstandardized regression coefficient; CI, confidence interval; Adj. R^2, adjusted R^2.

STRENGTH DEFICITS AFTER MPFL RECONSTRUCTION

Limited literature on return to sport timelines following MPFLR indicates that clinicians are releasing young patients back to their respective sports between 5-10 months after surgery.[12,13,18] In the current study, strength data was collected from participants at 6.9 ± 2.1 months, a timeframe consistent with published return to sport timelines. Our findings reveal that less than 65% of young patients are achieving quadriceps strength LSI of ⩾90% at this time. While timing of return to sport clearance was not measured nor controlled for in this study, it should be noted that a high proportion of youth across age groups demonstrate between-limb quadriceps strength deficits even beyond the 6-month timepoint after MPFLR. This finding, from a larger sample of participants, supports results published in the few existing studies of strength outcomes among small samples that include youth after MPFLR.[12,13] Krych et al. noted mean knee extension strength deficits up to 21.4% at 6 months after MPFLR, a timeframe similar to that of the current study.[12] Furthermore, by time of return to sport, Saper et al. reported that only 44% of young patients achieved quadriceps strength LSI ⩾90%.[13]

Graft choice for the MPFLR procedures was based on surgeon preference, with most MPFL grafts involving gracilis and/or semitendinosis tendons. Interestingly, across age groups, a higher proportion of our participants were able to achieve hamstrings strength LSI ⩾90%, which is also consistent with previously reported findings.[12,13] These findings may indicate that MPFLR is considerably more disruptive to the quadriceps, resulting in greater deficits in knee extension strength compared to knee flexion strength. Likewise, evidence of strength outcomes among youth after anterior cruciate ligament reconstruction (ACLR) indicates that less than 45% of youth achieve quadriceps strength LSI ⩾90% at time of return to sport, while over 60% of youth are able to meet the same criteria for hamstrings strength.[31] The inability to achieve limb symmetry of muscle function after knee ligament reconstruction is known to result in lower functional performance and patient-reported function.[22-24] Collectively, these studies indicate that many young patients are not achieving full restoration of muscle strength in expected timeframes following MPFLR, which may ultimately hinder return to prior level of function.

SEX-BASED DIFFERENCES IN STRENGTH

In addition to the identification of quadriceps and hamstrings strength deficits among youth, this study found that males in all age groups demonstrated higher normalized strength compared to females. Additionally, a higher proportion of males were able to achieve traditional criteria of ⩾90% LSI for select quadriceps and hamstrings strength tests. Previous work has shown a consistent difference in lower extremity strength between sexes, with healthy young males outperforming healthy young females across age groups.[32-34] Following anterior cruciate ligament reconstruction, current evidence also indicates that normalized quadriceps and hamstrings strength is greater among young males compared to young females.[35,36] Interestingly, Sugimoto et al. recently reported no significant interactions between age and sex on knee strength tests among youth 5-8 months after ACLR.[37] However, this research group relied on the use of LSI to make comparisons between sexes and age groups, which may overestimate absolute strength differences. Using similar methods, limited evidence in a population of youth after MPFLR indicates that males may demonstrate a higher between-limb difference in quadriceps strength LSI at six months after surgery when compared to females.[12] Clinical use of LSI for strength outcomes may be helpful when a patient-specific benchmark is needed. However, use of normalized strength outcomes allows for a more uniform comparison between sexes and age groups, as seen in the current study. Identification of sex-based differences in strength outcomes after MPFLR is important for future development of intervention design and return to activity guidelines for youth.

ASSOCIATION BETWEEN STRENGTH AND PATIENT-REPORTED FUNCTION

Patient-reported outcome data was available for 84.6% of study participants at the time of isokinetic strength testing. Our investigation of the relationship between strength and patient-reported outcome scores revealed that higher normalized quadriceps strength was significantly associated with higher self-perceived function and quality of life, while adjusting for age and sex. Previous studies have examined changes in patient-reported function among youth after MPFLR, reporting significant improvements in Kujala Anterior Knee Pain Scale, International Knee Documentation Committee, and Lysholm Knee Scoring Scale scores.[9,10,18,38] Less is known about changes in self-reported quality of life among youth following MPFLR, though Hao et al. has reported significant improvements in EQ-5D-5L score from preoperative testing to postoperative testing among young adults.[39] To the authors' knowledge, the current study provides novel insight on the relationship between these clinical outcomes. For every 1 Nm/kg increase in isokinetic quadriceps strength output at 180°/s, the mean estimated increase in IKDC and PedsQL scores was 6.7 points and 9.8 points, respectively. Similarly, for every 1 Nm/kg increase at 300°/s, the mean estimated increase in scores was 9.1 points on the IKDC and 12.7 points on the PedsQL. This association between strength and patient-reported function helps to amplify the importance of restoring quadriceps strength after ligament reconstruction, particularly since youth following MPFLR are known to self-report lower knee-related function compared to their healthy peers.[40] Future research is warranted to investigate the influence of strength on other clinical outcomes, such as pain, functional performance, and return to activity rates.

CLINICAL APPLICATION OF STUDY FINDINGS

The findings of this study provide new and important insight for rehabilitation specialists who design treatment plans for youth after MPFLR. The majority of young participants in this study did not achieve a widely-accepted level of between-limb symmetry for quadriceps strength at ~six months after MPFLR, indicating a critical need for targeted strengthening interventions during this time. Restoration of muscle function is imperative for safe return to the demands of sport and recreational play.[41,42] As such, proper loading of the quadriceps and hamstrings should be ensured in order to increase muscle strength.[43] Clinicians should strive for the achievement of between-limb symmetry and sufficiency with their patients, as criteria based solely on LSI has been shown to overestimate knee function after knee ligament reconstruction.[44,45] The data reported in this study may serve as helpful age- and sex-relevant benchmarks for muscle sufficiency among youth who are >6 months post-MPFLR. A recommendation for future research includes the development of a normative database of strength outcomes from healthy youth in order to further enhance decision-making on the restoration of muscle function.

In addition to targeted strengthening interventions and routine strength testing, educational interventions on realistic timelines for return to sport following MPFLR are needed. Reported return to activity timelines vary widely, from as early as 3 months to as long as 48 months post-surgery,[42,46] with 6-8 months post-surgery as the most

common timeframe for youth to be released to sport.[9,18] This findings of this study indicate that many youth may not be physically ready to return to sport by 6-8 months after MPFLR, and may benefit from further intervention in order to fully restore muscle function and prevent subsequent injury upon return to activity. If physical readiness to return to sport is not achieved at time of discharge, it is possible that other markers of readiness, such as psychological status and neuromuscular function, have also not been fully restored. As such, it is recommended that clinicians discuss the importance of both time- and criteria-based return to sport expectations with young patients.

Lastly, alongside physical performance testing, clinicians should consider administering patient-reported outcome measures following MPFLR in order to gain a more comprehensive understanding of a patient's recovery. In the current study, patient-reported scores on measures of knee function and quality of life were found to be significantly associated with normalized quadriceps strength. This finding solidifies the notion that physical recovery may be linked to one's health-related quality of life. While there are currently no standardized guidelines for assessment of patient-reported outcomes among the population of youth after MPFLR, most experts recommend the inclusion of at least one subjective patient-centric criteria after MPFLR.[47,48]

LIMITATIONS

A careful consideration of the inherent limitations of this research study is important when interpreting the presented findings. The use of a retrospective design for this study provided an important lens for examining patient outcomes as a product of the current care model for youth after MPFLR. As such, the findings of this study are most likely generalizable to many youth who undergo primary MPFLR. Yet, due to the retrospective nature of the study, no information about rehabilitation, or return to sport rates and timelines is available. Overall, there is a lack of standardization of variables within this study, which could be better controlled with a prospective study design. Future investigation of related variables, such as hip strength and functional performance, may capture a more comprehensive view of the physical outcomes specific to youth who undergo MPFLR. Isokinetic strength testing of knee extension and flexion represents only one facet of return to sport readiness for this population.

Furthermore, all participants in this study received standard of care at a single institution, yet the current standard of care continues to be limited for this population. Aside from expert opinion, there are no existing criteria or guidelines for returning to sport after MPFLR.[41,42] Additionally, without a control group, no comparisons can be made regarding strength or patient-reported outcome scores. Future work is warranted for the comparison of strength and self-reported function outcomes between healthy youth and those after primary MPFLR. A better understanding of this population's impairments and limitations may serve to inform the future development of meaningful rehabilitation interventions and return to activity criteria.

CONCLUSION

The findings from this study provide important insight on quadriceps and hamstrings strength outcomes among youth at a mean of ~ seven months following MPFLR. In accordance with the hypotheses, young males of all age groups demonstrated higher normalized strength and limb symmetry compared to females. Furthermore, among all participants, higher quadriceps strength of the involved limb was associated with more positive patient-reported function. These results serve as an important step towards the development of age- and sex-relevant rehabilitation interventions and return to activity criteria for youth who undergo primary MPFLR.

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