Original Article

Effect of Age and Sex on Anterior Cruciate Ligament Functional Tests Approximately 6 Months After Anterior Cruciate Ligament Reconstruction

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Purpose: To examine age- and sex-related differences in postoperative functional outcomes at approximately 6 months after anterior cruciate ligament reconstruction (ACLR). **Methods:** In this study, patients who underwent primary ACLR performed a series of return-to-sport functional tests at 5 to 8 months after surgery. Functional tests included strength tests (knee extensors, knee flexors, hip abductors, and hip extensors), a balance test (Y-balance composite score), and hop tests (single, triple, crossover, and 6-m timed hop tests). Limb symmetry was calculated to compare the reconstructed limb with the uninvolved limb. A 2-way multivariate analysis of covariance was used, and effect size was calculated for data analysis. **Results:** A total of 176 subjects were included in this study. There were no significant interaction between age and sex on return-to-sport functional tests after ACLR. Also, no main effects of age and sex on return-to-sport functional tests were found in our data. **Conclusions:** Age and sex do not significantly affect functional test performance after ACLR 6 months postoperatively. **Level of Evidence:** Level III, retrospective review of prospective cohort study.

Studies have reported an increase in anterior cruciate ligament (ACL) injuries in the youth population.[1-3] Although nonsurgical treatment has been reported,[4,5] ACL reconstruction (ACLR) is considered the current gold standard of treatment.[6] This is especially true for patients who want to return to competitive sport activities.[7,8] After ACLR surgery, postoperative rehabilitation is a necessary step for optimal recovery.[8,9] There are several different perspectives regarding the feasible timeline from initiation of ACLR surgery to safe return to sport (RTS).[10-12] Historically, surgeons in the 1980s believed that the appropriate time range to RTS was 6 to 12 months after ACLR.[13] Then, in the 1990s, Shelbourne and Nitz[14] introduced the concept of accelerated rehabilitation, which suggested a 4- to 6- month time frame from ACLR to RTS, and it is the genesis of the idea of “criterion-based” RTS rehabilitation. This method was later introduced as “milestone-based” rehabilitation[15] and has become a predominant approach in the modern-day rehabilitation of ACL injuries.[16-18] This method has been highlighted again for its increased patient safety and economic feasibility.[19]

Along with the development of the criteria- or milestone-based rehabilitation procedures, there have been several studies that have investigated the recovery of involved (surgical) limbs versus uninvolved (nonsurgical) limbs after ACLR.[10,20,21] These studies have shown asymmetries in landing mechanics and deficits in muscular strength in young athletes after ACLR surgery. However, studies regarding how age and sex influence the recovery process after ACLR surgery have been limited.[22-24] Understanding the potential effects of age and sex on postoperative recovery after

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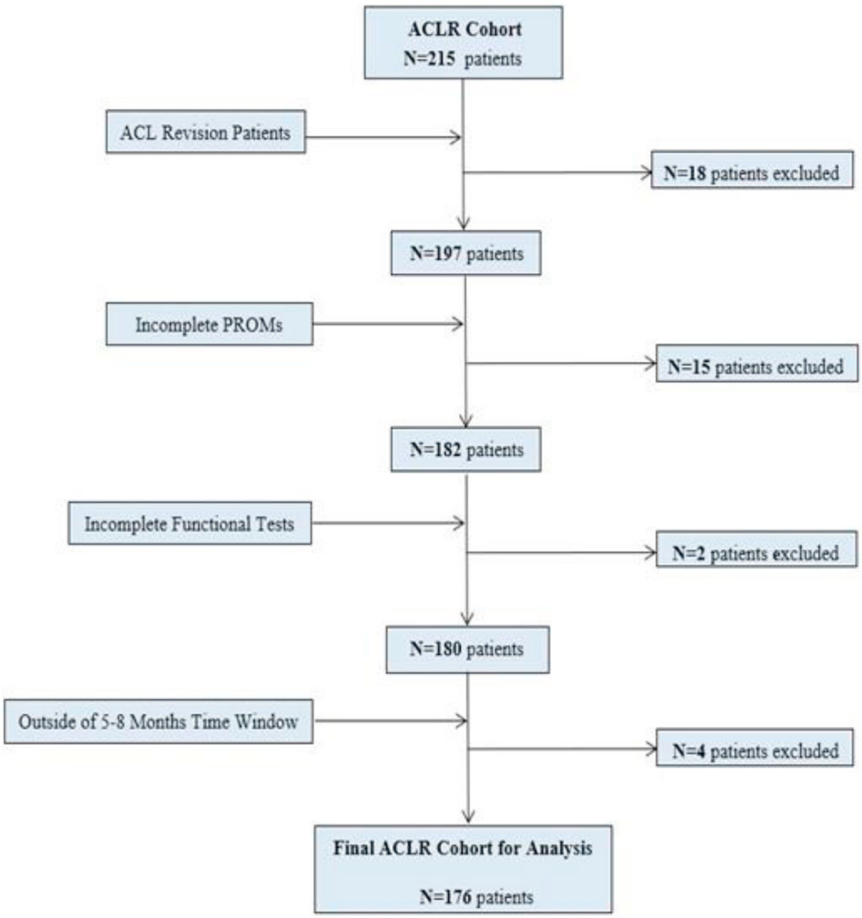

Fig 1. CONSORT (Consolidated Standards of Reporting Trials) diagram of enrolled patients. (ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; PROMs, patient-reported outcome measures.)

ACLR may have important clinical implications on rehabilitation progression and RTS timing.[25-28]

The purpose of this study was to examine age- and sex-related differences in postoperative functional outcomes at approximately 6 months after ACLR. We hypothesized that there would be age and sex differences on functional tests at approximately 6 months after ACLR.

Methods

Study Design

A cross section of data from an ongoing prospective longitudinal cohort study (ROAR [Readiness Outcomes Affecting Return-to-Sport]) was used.[29] This study was approved by our institutional review board prior to study commencement (No. IRB-P00013151), and the patients were consented for participation. This was a single-center study, performed in an orthopaedic and sports medicine tertiary care pediatric and adolescent center. ACLR was performed by 1 of 6 orthopaedic surgeons (M.D.M., M.S.K., D.E.K., L.J.M., Y-M.Y., and M.A.C.). All of the surgeons went through an orthopaedic fellowship training program.

Participants

Patients who underwent ACLR surgery between December 2018 and March 2020 were asked to participate in this study. The following inclusion criteria were used: (1) ACL tear confirmed by magnetic resonance imaging, (2) primary ACLR surgery performed by an orthopaedic sports medicine surgeon at our institution, (3) patient age between 8 and 30 years, and (4) completion of patient-reported outcome measures (PROMs) and functional performance testing at the 6-month postoperative visit (between 5 and 8 months postoperatively). Patients were excluded if they fell outside of the designated age range, underwent secondary or revision ACLR, had incomplete PROMs and functional tests, and/or underwent PROM and functional testing outside of a 5- to 8-month period. The 5- to 8-month period was selected because 5 to 8 months is the first functional test appointment window for all primary ACLR patients at the study host institution. For analysis purposes, patients were divided into 3 age categories: preadolescent (aged 8-14 years), adolescent (aged 15-18 years), and adult (aged 19-30 years). Patients were also classified as either male or female sex using their PROM responses.

Table 1. Demographic Characteristics of Enrolled Patients (N = 176)

Variable	Data, n (%)
Age group	
Preadolescent	29 (16.5)
Adolescent	105 (59.7)
Adult	42 (23.9)
Sex	
Female	107 (60.8)
Male	69 (39.2)
Graft type	
BPTB autograft	31 (17.6)
HS autograft	128 (72.7)
ITB	13 (7.4)
Quadriceps autograft	4 (2.3)
Meniscal pathology treatment	
Meniscal repair	59 (33.5)
Partial meniscectomy	33 (18.8)
None	84 (47.7)
Sports*	
Soccer	50 (28.4)
Basketball	32 (18.2)
Lacrosse	19 (10.8)
Football	13 (7.4)
Hockey or field hockey	11 (6.2)
Track or running	9 (5.1)
Baseball or softball	7 (4.0)
Skiing	7 (4.0)
Cheerleading	4 (2.3)
Dance	3 (1.7)
Gymnastics	3 (1.7)
Martial arts	3 (1.7)
Other	15 (8.5)

NOTE. The overall mean age, collected at the time of consent, was 17.1 ± 3.1 years. The mean ages of preadolescents, adolescents, and adults were 13.3 ± 1.2 years, 16.4 ± 1.0 years, and 21.4 ± 2.9 years, respectively. The mean ages of female and male patients were 16.8 ± 2.3 years and 17.5 ± 4.1 years, respectively.

BPTB, bone–patellar tendon–bone; HS, hamstring; ITB, iliotibial band.

*Event during which patient sustained anterior cruciate ligament injury.

Testing

All ACLR patients were consented for participation at their 6-month follow-up visit (range, 5-8 months). ACLR patients at our institution routinely undergo functional testing consisting of strength, balance, and hop tests at this time point. Functional testing was performed at an injury prevention research and training center located adjacent to the host study site. All data were collected by certified athletic trainers and certified strength and conditioning specialists. Each of the functional tests was verbally explained to patients prior to their first attempt at the testing site. If patients did not understand the given instructions, the testers demonstrated with additional verbal instructions. During the functional tests, patients were also allowed to practice each of the functional tests until they felt comfortable. The practice was allowed mainly for safety reasons. The study host institution and institutional review board office recommended avoiding the risk of any graft rupture or any injury to the contralateral limb during the functional tests.

The isometric strength of each patient's knee extensors (quadriceps), knee flexors (hamstrings), hip abductors, and hip extensors was measured by a handheld dynamometer (microFET2; Hoggan Scientific, Salt Lake City, UT). For knee extensor (quadriceps) strength, participants were asked to sit down at the edge of the treatment table with 90° of knee flexion and cross the arms in front of the chest. A handheld dynamometer was applied to the anterior side of the distal tibia above the dome of the talus, and participants were asked to extend their knees with maximum effort against the standardized dynamometer for 3 seconds. For knee flexor (hamstring) strength, participants were asked to lie prone with 90° of knee flexion. A handheld dynamometer was applied on the posterior aspect of the distal calf just proximal to the Achilles tendon, and participants were asked to flex their knees with maximum effort against the dynamometer for 3 seconds. For hip abductor strength, participants were asked to take a side-lying position while maintaining a hip neutral position, and the tested leg was slightly pulled just posterior to the contralateral leg. A handheld dynamometer was applied just proximal to the lateral malleolus, and participants were asked to abduct the hip, keeping the leg straight, with maximum effort against the stabilized dynamometer for 3 seconds. For hip extensor strength, participants were asked to lie prone with 90° of knee flexion. A handheld dynamometer was applied at the middle one-third of the posterior thigh (hamstring side), and participants were asked to move the flexed leg toward the ceiling with maximum effort against the stabilized dynamometer for 3 seconds. The strength tests were performed 2 times per muscle group bilaterally, and the average of the 2 attempts for each leg was calculated for each muscle group for analysis. The intraclass and interclass correlation coefficients of the test variables were reported in previous studies.[6,30]

After strength testing, balance was quantified using a commercially available Y-balance assessment system (Functional Movement Systems, Chatham, VA). Participants were instructed to stand at the center and push a plastic piece in the anterior, posteromedial, and posterolateral directions while placing the hands on the waist. This test was performed 3 times in each direction bilaterally. The composite score was used for analysis and was calculated as the sum of the 3 directions (anterior reach, posteromedial reach, and posterolateral reach) divided by 3 times the limb length and multiplied by 100.

After the strength and balance tests, hop tests including single hop for distance, triple hop for

Table 2. Functional Test by Age Group

Functional Test	Preadolescent (n = 29)	Adolescent (n = 105)	Adult (n = 42)	*P* Value	Effect Size (η^2)
Knee extensor	+1.2 (−5.5, +7.9)	−2.6 (−6.3, +1.0)	−5.9 (−12.0, +0.2)	.308	0.026
Knee flexor	−27.6 (−36.0, −19.1)	−23.1 (−27.7, −18.5)	−16.1 (−23.8, −8.4)	.132	0.045
Hip abductor	+11.0 (+3.1, +18.9)	+2.1 (−2.2, +6.4)	+0.5 (−6.7, +7.7)	.108	0.049
Hip extensor	+3.8 (−1.6, +9.2)	+1.7 (−1.2, +4.7)	+4.8 (−0.1, +9.7)	.525	0.015
Y-balance composite score	+0.9 (−1.1, +3.0)	−0.9 (−2.0, +0.2)	+0.3 (−1.6, +2.2)	.238	0.032
Single hop	−4.8 (−10.5, +0.9)	−6.9 (−10.0, −3.8)	−9.0 (−14.1, −3.8)	.567	0.013
Triple hop	−2.6 (−7.9, +2.7)	−5.5 (−8.3, −2.6)	−9.1 (−13.9, −4.3)	.196	0.036
Crossover hop	+0.1 (−7.4, +7.6)	−0.2 (−4.3, +3.9)	−9.7 (−16.6, −2.9)	.052	0.065
6-m Timed hop	−1.2 (−7.6, +5.0)	−4.9 (−8.3, −1.4)	−11.4 (−17.1, −5.6)	.055	0.064

NOTE. Data are presented as mean (95% confidence interval). The graft types by group were as follows: hamstring autograft (HS) in 15 patients, iliotibial band (ITB) in 13, and quadriceps autograft in 1 in the preadolescent group; bone−patellar tendon−bone autograft (BPTB) in 19 patients, HS in 83, and QT in 3 in the adolescent group; and BPTB in 12 patients and HS in 30 in the adult group. The meniscal pathology data by group were as follows: meniscal repair in 9 patients, partial meniscectomy in 4, and none in 16 in the preadolescent group; meniscal repair in 34 patients, partial meniscectomy in 20, and none in 51 in the adolescent group; and meniscal repair in 16 patients, partial meniscectomy in 9, and none in 17 in the adult group. The unit is % based on LSI.

distance, crossover hop for distance, and 6-m timed hop were performed. For the single-hop test, participants stood on 1 limb, hopped as far as possible, and landed on the same limb. For the triple-hop test, participants stood on 1 leg, performed 3 consecutive hops as far as possible, and landed on the same leg. The crossover hop test was performed on a course consisting of a 15-cm marking strip on the floor; participants hopped 3 consecutive times on 1 foot, crossing over the center strip on each hop. For the 6-m timed hop test, a distance of 6 m was calculated, and participants were encouraged to use forceful 1-legged hopping motions to perform a series of hops over the total distance. The time needed to complete the hopping in 6 m was recorded. All hop tests were performed twice using each leg, and the mean value was calculated for analysis.

Data Analysis

To evaluate the recovery of the reconstructed limb, the limb symmetry index (LSI) was calculated for each of the strength, balance, and hop tests. The LSI is commonly used to assess the function of the reconstructed limb compared with the uninvolved limb.[6,31-33] The following equation was used to calculate the LSI: (ACLR-limb test results/Uninvolved-limb test results) − 1.[30] The LSI is represented as a percentage and is measured as the deficit of the reconstructed limb compared with the uninvolved limb.

Statistical Analysis

Descriptive statistics were used to analyze the demographic characteristics of the enrolled patients including physical characteristics, graft type used in ACLR, and time from ACLR to PROM and functional

Table 3. Functional Test by Sex

Functional Test	Female Patients (n = 107)	Male Patients (n = 69)	*P* Value	Effect Size (η^2)
Knee extensor	−5.7 (−10.1, −1.4)	+0.8 (−4.2, +5.8)	.059	0.040
Knee flexor	−21.2 (−26.7, −15.7)	−23.3 (−29.5, −17.0)	.638	0.003
Hip abductor	+5.9 (+0.7, +11.0)	+3.2 (−2.7, +9.1)	.501	0.005
Hip extensor	+5.0 (+1.5, +8.5)	+1.9 (−2.1, +6.0)	.276	0.013
Y-balance composite score	+0.1 (−1.2, +1.5)	+0.1 (−1.4, +1.6)	.976	0.001
Single hop	−5.7 (−9.4, −2.0)	−8.0 (−12.3, −3.8)	.421	0.007
Triple hop	−4.4 (−7.8, −1.0)	−7.0 (−11.0, −3.1)	.330	0.011
Crossover hop	−1.7 (−6.6, +3.2)	−4.8 (−10.4, +0.8)	.421	0.007
6-m Timed hop	−5.4 (−9.5, −1.4)	−6.3 (−11.0, −1.6)	.799	0.001

NOTE. Data are presented as mean (95% confidence interval). The graft types by group were as follows: bone−patellar tendon−bone autograft (BPTB) in 17 patients, hamstring autograft (HS) in 85, iliotibial band (ITB) in 1, and quadriceps autograft in 4 in the female group and BPTB in 14 patients, HS in 43, and ITB in 12 in the male group. The meniscal pathology data by group were as follows: meniscal repair in 34 patients, partial meniscectomy in 21, and none in 52 in the female group and meniscal repair in 25 patients, partial meniscectomy in 12, and none in 32 in the male group. The unit is % based on LSI.

tests. The dependent variables were the LSI strength, balance, and hop values, and the 2 independent variables were age and sex. Thus, a 2-way multivariate analysis of covariance (MANCOVA) was used. Past studies indicated that the graft type used in ACLR altered the outcomes of postoperative functions[6,30,34]; therefore, graft type was treated as a covariate. Interaction (age $\times$ sex) and main effect (age, sex) were examined. All tests were 2-sided, and the a priori level of statistical significance of $P < .05$ was used. Effect size was measured by using partial η^2 values for main effect ($\leq$0.010, small; 0.011-0.059, small to medium; 0.060-0.138, medium to large; and $\geq$0.139, large).[35,36] IBM SPSS statistical software (version 26; Armonk, NY) was used for all analyses. When statistically significant differences were found, pair-wise comparisons were performed using the Bonferroni post hoc correction method.

Results

A CONSORT (Consolidated Standards of Reporting Trials) diagram of patient recruitment can be seen in Figure 1. Patient demographic characteristics are displayed in Table 1. There were no significant interaction effects between age and sex on functional test performance.

Regarding the main effect of age, there were no significant differences in age comparisons although comparisons in crossover hops and 6-m timed hop tests approached just under the a priori significance level (Table 2). Similarly, analysis of the main effect of sex showed no statistically significant differences between female and male patients; however, comparison of knee extensors approached under the critical statistical value (Table 3).

Discussion

In this study, there were no functional recovery differences by age and sex after ACLR. Thus, our hypothesis was not supported. Hop and strength test results were not statistically significant. Hop tests are some of the most commonly used RTS variables after ACLR surgery among physical therapists.[37] Yet, studies have posed a few diverging clinical perspectives. Sousa et al.[38] questioned whether post-ACL surgery RTS tests could help predict mid-term functional recovery. Moreover, it was reported that an extremely low proportion of athletes pass current RTS testing at 7 months after ACLR.[10] Welling et al.[39] reported that their RTS tests, which consisted of jump-landing pattern, hamstring strength, and hop tests, assisted athletes in the RTS; however, they concluded that these tests do not help identify the risk of a future ACL retear. Conversely, a systematic review suggested that including isokinetic strength and hop tests in RTS testing can help reduce the future risk of ACL reinjury or retear.[40] In short, the functional tests were developed to determine whether patients could perform certain sporting activities at the required level both sufficiently and safely.

The inconsistency in previous functional test–related studies may be due to the psychological status of ACLR patients. A study suggested that scores assessing psychological readiness to RTS were better in ACLR patients with high hamstring strength than in those with low hamstring strength.[41] Moreover, Paterno et al.[42] reported that ACLR patients who expressed greater self-reported fear showed lower quadriceps strength and hop test performance. Additionally, a systematic review concluded that ACLR patients with fear of physical movement and feelings of vulnerability owing to painful injury or reinjury, so-called kinesiophobia,[43] performed worse on hop testing than ACLR patients with less kinesiophobia.[44] The fact that our study found similar functional muscle recovery across ages and between sexes suggests that perhaps other factors, such as psychological factors, may be more strongly contributing to return-to-play outcomes. The relation between psychological factors and functional outcomes, as well as RTS, deserves further in-depth study.

Limitations

This study has several limitations. First, the study protocol was designed to include a larger sample size; however, enrollment was stopped because of the COVID-19 (coronavirus disease 2019) pandemic (March 2020). This may cause our study to be underpowered when determining whether age or sex had a significant effect. A power analysis was performed after the current study to examine the minimal sample size, which suggested a sample size of 192 (with $\alpha = .05$ and $\beta = .80$). Thus, the results of this study might have been different with a larger sample size. Second, the study population contained patients with different graft types and surgical techniques. Previous studies have reported potential influences of graft type on functional tests[6,30,34]; therefore, variations in graft type and surgical technique might have resulted in differences in RTS testing for ACLR patients. To reduce the potential influence of graft type and surgical technique, we used a multivariate analysis of covariance (MANCOVA) model. Third, although we verified that all patients underwent at least 20 rehabilitation sessions prior to the RTS tests, it was not possible to track the exact number of rehabilitation sessions each patient underwent after the ACLR procedure. Finally, the current data were collected at a single institution. To enhance generalizability, a multicenter approach that includes various geographic regions may be needed for future studies.

Conclusions

Age and sex do not significantly affect functional test performance after ACLR 6 months postoperatively.

Disclosures

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: M.D.M. receives editorial royalties from Elsevier. D.E.K. receives consulting fees (<$5,000) from Miach and receives educational support from Arthrex. Y-M.Y. is on the editorial board of *American Journal of Sports Medicine* and is a consultant for Smith & Nephew and Orthopediatrics. All other authors (D.S., K.A.W., R.P.C., K.D.N., M.S.K., L.J.M., M.A.C.) declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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