Factors Associated With a Delay in Achieving Full Knee Extension Before Anterior Cruciate Ligament Reconstruction

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Background: Arthrofibrosis commonly occurs after an acute anterior cruciate ligament (ACL) injury and following ACL reconstruction and can lead to poor outcomes. Preoperative stiffness has been shown to be associated with postoperative stiffness; however, few studies have examined predictors of preoperative delay in obtaining full knee extension.

Purpose: To examine demographic and injury factors as predictors of time required to achieve full knee extension preoperatively in patients with an acute ACL injury.

Study Design: Case-control study; Level of evidence, 3.

Methods: A total of 172 patients with an acute ACL tear at presentation (defined as $\leq$3 weeks from injury) who underwent magnetic resonance imaging (MRI) within 6 weeks of the injury were included in this analysis. Preoperative data included date of injury, age at injury, sex, body mass index, mechanism of injury (noncontact/contact), time from injury to surgery (days), time to achieve full extension prior to surgery (weeks), and bone bruising on MRI. Time to achieve full extension was categorized as $<$3 or $\geq$3 weeks. Unadjusted and adjusted logistic regression was used to examine predictors of delayed time to achieve full extension ($\geq$3 vs $<$3 weeks). Odds ratios and 95% CIs were reported.

Results: Time to achieve full extension was early ($<$3 weeks) in 98 patients and delayed ($\geq$3 weeks) in 74 patients. The average time to achieve full extension was 7 days in the early group and 32.5 days in the delayed group. Delayed time to achieve full extension was associated with increased lateral femoral condyle (LFC) bruising compared with early time to achieve extension (82.8% vs 66.7%, respectively; $P = .03$). No other statistically significant predictors were found after adjustment for age, sex, body mass index, and mechanism of injury.

Conclusion: Acute ACL injuries associated with LFC bone bruising seen on MRI are more likely to result in reduced extension prior to ACL reconstruction. These injuries should be identified and addressed by an appropriate preoperative rehabilitation program, and surgery should be delayed to avoid risking arthrofibrosis postoperatively by reconstructing a knee with less than full extension.

Keywords: anterior cruciate ligament; reconstruction; range of motion; delayed extension; bone bruise

Range of motion (ROM) may be reduced after knee injury or surgery, and arthrofibrosis is defined by the presence of scar tissue in at least 1 compartment of the knee joint, which has been observed during revision surgery for arthrofibrosis.[14] The incidence of arthrofibrosis following anterior cruciate ligament (ACL) reconstruction has been found to be as high as 26%; however, more recent advances in surgical techniques and rehabilitation protocols have reduced the incidence to approximately 5%.[2,14]

Arthrofibrosis can lead to decreased subjective outcomes, especially functional disability, and increased osteoarthritic changes on radiographs after ACL reconstruction.[19] Previously identified predictors of postoperative arthrofibrosis include reduced preoperative ROM, early surgical intervention, female sex, increased preoperative pain, lack of psychological preparedness for surgery, lateral bone bruise injury, poor postoperative rehabilitation program, and an "irritated knee" (swelling, effusion, and hyperthermia).[8,14,16,20,21] In many cases of arthrofibrosis, more aggressive means are necessary to improve ROM postoperatively, including manipulation under anesthesia and arthroscopic or open lysis of adhesions.[21] No consensus has been reached regarding the optimal timing of surgery to minimize the risk of arthrofibrosis; however, symmetrical full ROM can usually be achieved preoperatively and has been shown to reduce the risk of arthrofibrosis and improve outcomes postoperatively.[5,10,15,20]

Several studies have found preoperative ROM to be a predictor of reduced postoperative ROM; however, only 1 previous study has examined predictors of reduced

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preoperative ROM.[13] The purpose of this study was to examine demographic factors and knee injury factors as predictors of time required to achieve full knee extension in patients with an acute ACL injury. Our hypothesis was that among the factors studied, 1 or more would predict a delay in gaining extension after ACL injury.

METHODS

Sample Selection

Patients were selected from a prospective registry of 987 ACL reconstructions performed by 2 sports medicine fellowship–trained orthopaedic surgeons (L.J.B., J.M.M.) between January 2005 and April 2016 at a single institution. Patients with acute ACL injuries, defined as initial presentation ≤3 weeks from injury, were included in this institutional review board–approved study. Exclusion criteria (not mutually exclusive) were patients with chronic injuries (>3 weeks from injury to initial presentation, n = 53), prior history of knee surgery (n = 125), surgery more than 6 months from the date of injury (n = 177), magnetic resonance imaging (MRI) performed more than 6 weeks from the date of injury (n = 157), and missing data (n = 425). A total of 172 patients met the study criteria and were included in this analysis.

Data Collection

Demographics, injury characteristics, preoperative MRI findings, and arthroscopic findings were documented by the patient's surgeon using standard data collection forms. Preoperative data included date of injury, age at injury, sex, body mass index (BMI), mechanism of injury (noncontact/contact), time from injury to surgery (days), and time to achieve full extension prior to surgery (weeks). Extension was measured by visual passive ROM examination and was considered full if it matched the degree of extension of the contralateral knee. If a patient presented with full extension, the day of initial examination was listed as the date of achieving full extension. Patients were evaluated in-office on a weekly basis, and surgery was delayed until full extension was confirmed by visualization and examination, and at this time the surgery was scheduled. If a patient achieved full extension between visits, then the patient's verbal response or the physical therapy report was used as the date of achieving full extension. Age was categorized as ≤17, 18-28, and ≥29 years. BMI was categorized as normal (≤24.99 kg/m^2), overweight (25-29.99 kg/m^2), and obese (≥30 kg/m^2). Time to achieve full extension was categorized as early (<3 weeks) or delayed (≥3 weeks).

MRIs were performed preoperatively within 6 weeks of injury at various locations and were read by the study surgeons. The presence of medial collateral ligament (MCL) and lateral collateral ligament injuries seen on MRI was documented. Also, the presence of bone bruising on sagittal and coronal MRI images was evaluated and documented for each of the following anatomic sites: medial tibial plateau, lateral tibial plateau, medial femoral condyle, and lateral femoral condyle (LFC). The presence of lateral meniscal tears, medial meniscal tears, and chondral lesions observed during arthroscopy was also documented.

Statistical Analysis

Descriptive statistics were calculated for age, sex, BMI, mechanism of injury, time from injury to surgery, MRI findings, and arthroscopic findings stratified by the time to achieve full extension (<3 and ≥3 weeks). Group comparisons were made by use of chi-square or Fisher exact test. Unadjusted and adjusted logistic regression was used to examine predictors of delayed time to achieve full extension (≥3 vs <3 weeks). Predictors included age, sex, BMI, mechanism of injury, time from injury to surgery, MRI findings, and arthroscopic findings. Analyses were adjusted for age, sex, BMI, and mechanism of injury. Unadjusted and adjusted odds ratios (ORs) and 95% CIs are reported. Statistical significance was considered $P < .05$ or when the null value (1.00) was absent from the CI. Statistical analyses were performed with SAS 9.4 (SAS Institute Inc).

RESULTS

The average time to achieve full extension was 18 days overall. Time to achieve full extension was early (<3 weeks) in 57% (n = 98) and delayed (≥3 weeks) in 43% (n = 74) of patients. The average time to achieve full extension was 7 days in the early group and 32.5 days in the delayed group. Delayed time to achieve full extension (≥3 weeks) was associated with increased LFC bone bruising compared with early time to achieve extension (<3 weeks) (82.8% vs 66.7%, $P = .03$). Patients who were delayed in achieving full extension were more likely to have an MCL injury compared with those who achieved full extension early, although this finding was not statistically significant (35.2% vs 20.6%; $P = .08$). No other statistically significant group differences were found in demographics, MRI findings, or arthroscopic findings (Table 1). In the unadjusted and adjusted predictor models shown in Table 2, LFC bone

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Ethical approval for this study was obtained from the SUNY University at Buffalo Institutional Review Board.

TABLE 1
Comparison of Demographic Factors by Time to Achieve Full Extension in Patients Undergoing Anterior Cruciate Ligament Reconstruction[a]

	Time to Full Extension		
	<3 Weeks (n = 98)	≥3 Weeks (n = 74)	*P*
Age group, y			.80
≤17	35 (35.7)	30 (40.5)	
18-28	34 (34.7)	23 (31.1)	
≥29	29 (28.4)	21 (28.4)	
Age at injury, y	24.7 ± 11	24.2 ± 11.4	.78
Sex			.29
Male	49 (50)	43 (58.1)	
Female	49 (50)	31 (41.9)	
Time from injury to first evaluation, d	7.2 ± 5.5	8.7 ± 5.9	.17
Mechanism of injury			.16
Noncontact	73 (80.2)	48 (70.6)	
Contact	18 (19.8)	20 (29.4)	
BMI group, kg/m^2			.20
≤24.99	56 (59)	41 (60.3)	
25-29.99	31 (32.6)	16 (23.5)	
≥30	8 (8.4)	11 (16.2)	
BMI, kg/m^2	24.3 ± 3.7	25.6 ± 5.2	.08
MRI findings			
MCL injury	13 (20.6)	19 (35.2)	.08
LCL injury	2 (3.8)	4 (9.1)	.41
MTP bone bruising	30 (33.3)	25 (39.1)	.46
LTP bone bruising	76 (84.4)	58 (90.6)	.26
MFC bone bruising	7 (7.8)	9 (14.1)	.21
LFC bone bruising	60 (66.7)	53 (82.8)	.03
Arthroscopic findings			
Lateral meniscal tear	43 (44.8)	35 (48.6)	.62
Medial meniscal tear	29 (29.6)	21 (28.4)	.86
Chondral injury	5 (8.2)	4 (8.9)	≤.999

[a]Data are reported as n (%) or mean ± SD. BMI, body mass index; LCL, lateral collateral ligament; LFC, lateral femoral condyle; LTP, lateral tibial plateau; MCL, medial collateral ligament; MFC, medial femoral condyle; MRI, magnetic resonance imaging; MTP, medial tibial plateau.

bruising was the only statistically significant predictor of delayed time to extension. No other statistically significant predictors were found after adjustment for age, sex, BMI, and mechanism of injury.

DISCUSSION

Our study found that the only predictor of delayed time to achieve full extension preoperatively was LFC bone bruising on MRI. These findings are in agreement with those by Johnson et al,[13] who studied the effects of bone bruising on preoperative knee physiological status and homeostatic condition. Their study found that lateral bone bruising on

TABLE 2
Predictors of Delayed Time to Achieve Full Extension in Patients Undergoing Anterior Cruciate Ligament Reconstruction[a]

	Unadjusted OR (95% CI)	Adjusted OR (95% CI)[b]
Age group, y		
≤17	1.00 (ref)	1.00 (ref)
18-28	0.79 (0.38-1.62)	0.73 (0.33-1.66)
≥29	0.85 (0.40-1.78)	0.83 (0.36-1.94)
Sex		
Female	1.00 (ref)	1.00 (ref)
Male	1.39 (0.76-2.55)	1.45 (0.69-3.04)
BMI group, kg/m^2		
≤24.99	1.00 (ref)	1.00 (ref)
25-29.99	0.71 (0.34-1.46)	0.67 (0.29-1.56)
≥30	1.88 (0.69-5.08)	1.53 (0.48-4.86)
Mechanism of injury		
Noncontact	1.00 (ref)	1.00 (ref)
Contact	0.59 (0.28-1.23)	0.74 (0.34-12.22)
Time from injury to first evaluation, d	0.99 (0.99-1.00)	0.99 (0.98-1.00)
MRI findings		
MCL injury		
Absent	1.00 (ref)	1.00 (ref)
Present	2.09 (0.91-4.78)	2.38 (0.91-6.27)
LCL injury		
Absent	1.00 (ref)	1.00 (ref)
Present	2.55 (0.44-14.63)	4.73 (0.69-32.31)
MTP bone bruising		
Absent	1.00 (ref)	1.00 (ref)
Present	1.28 (0.66-2.50)	1.23 (0.58-2.59)
LTP bone bruising		
Absent	1.00 (ref)	1.00 (ref)
Present	1.78 (0.65-4.92)	2.11 (0.63-7.00)
MFC bone bruising		
Absent	1.00 (ref)	1.00 (ref)
Present	1.94 (0.68-5.52)	1.85 (0.60-5.71)
LFC bone bruising		
Absent	1.00 (ref)	1.00 (ref)
Present	2.41 (1.10-5.27)	3.11 (1.21-7.95)
Arthroscopic findings		
Lateral meniscal tear		
Absent	1.00 (ref)	1.00 (ref)
Present	1.17 (0.63-2.15)	1.19 (0.60-2.38)
Medial meniscal tear		
Absent	1.00 (ref)	1.00 (ref)
Present	0.94 (0.48-1.84)	1.04 (0.50-2.17)
Chondral injury		
Absent	1.00 (ref)	1.00 (ref)
Present	1.09 (0.28-4.32)	1.24 (0.19-8.21)

[a]Delayed time to achieve full extension (≥3 weeks) was compared with early time to achieve extension (<3 weeks). BMI, body mass index; LCL, lateral collateral ligament; LFC, lateral femoral condyle; LTP, lateral tibial plateau; MCL, medial collateral ligament; MFC, medial femoral condyle; MRI, magnetic resonance imaging; MTP, medial tibial plateau; OR, odds ratio; ref, reference variable.

[b]Odds ratios were adjusted for demographic factors, including age, sex, body mass index, and mechanism of injury.

MRI was associated with a statistically significant increase in time to achieve return of full symmetrical ROM of the injured knee compared with the contralateral knee in 40 patients. We also found that MCL injuries may be predictive of delayed time to achieve full extension preoperatively, although this finding was not statistically significant. This is consistent with previous research that has found MCL repair to be associated with postoperative loss of ROM.[9]

Postoperative ROM deficits have been reported to occur in up to 26% of patients who undergo an ACL reconstruction.[14,17] Quelard et al[16] found an increase in postoperative arthrofibrosis requiring postoperative lysis of adhesions in patients with limited preoperative ROM, lateral compartment bone bruising, and female sex, and when surgery was performed fewer than 45 days from injury. Many other factors have been reported in the literature to contribute to arthrofibrosis postoperatively, including decreased preoperative ROM, increased preoperative pain, psychological unreadiness for surgery, and poor postoperative rehabilitation programs.[8,14,16,20,21] It seems clear that preoperative ROM deficits are a risk factor for postoperative arthrofibrosis.[3] We aimed to focus on which preoperative factors would predict a delay in time to achieve full knee extension after an acute ACL injury. During the period of data collection, we treated 172 patients who presented at an average of 7.8 days after acute ACL injury, and time to achieve full extension was early ($<$3 weeks) in 98 patients and delayed ($\geq$3 weeks) in 74 patients.

Preoperative rehabilitation can improve knee function and strength before the patient undergoes ACL reconstruction.[8,14] Multiple studies have found that so-called "prehabilitation" can improve postoperative outcomes.[4,7,8] Heijne et al[11] found that the absence of ROM deficits was the most important preoperative predictor of a good outcome following ACL reconstruction. Grindem et al[8] reported improved preoperative patient-reported knee function in a group of patients who underwent a progressive prehabilitation program in preparation for ACL surgery. Shaarani et al[18] showed that a 6-week prehabilitation protocol led to improved outcomes 12 weeks after surgery. Conversely, Frobell et al[6] assessed prehabilitation with ACL reconstruction within 10 weeks of injury compared with prehabilitation for 2 years with the option of ACL reconstruction within 5 years. Those investigators found no statistically significant differences in patient-reported outcomes or meniscal damage and no statistically significant differences between the group with early ACL reconstruction, those with delayed ACL reconstruction, and those in the delayed group who decided not to have surgery at 5 years.[6]

The current literature provides no consensus on operative timing from injury date in acute ACL tears.[1,5,9,20] Shelbourne et al[20] recommended against early operative intervention, showing that performing ACL reconstruction too early after injury may lead to complications such as arthrofibrosis. Those investigators found a statistically significant increase in the risk of arthrofibrosis in patients undergoing surgery within 3 weeks of the initial ACL injury and recommended waiting at least 3 weeks to reconstruct the ACL.[20] Harner et al[9] also found a significant risk of arthrofibrosis after ACL reconstruction in patients undergoing surgery less than 1 month from injury. Huleatt et al[12] confirmed this timing in a retrospective chart review of 2424 ACL reconstructions, reporting a statistically significant increase in postoperative arthrofibrosis for ACL surgery performed within 28 days of injury. Other risk factors for postoperative loss of ROM included infection, hematoma requiring evacuation, meniscal repair, use of a quadriceps tendon autograft, age younger than 18 years, multiple concomitant procedures, contact injury, and female sex.

In a study of acute ACL injury, Bottoni et al[1] randomized 70 consecutive patients to an early surgery group (within 21 days) or a delayed surgery group (beyond 6 weeks) without accounting for any patient clinical criteria, including preoperative ROM. The investigators found no statistically significant differences at 1 year between the early and delayed operative groups in terms of extension and flexion deficits. In a more recent study, Eriksson et al[5] randomized a group of 70 patients with acute ACL tears to undergo ACL reconstruction within 8 days of injury versus $\geq$6 weeks after injury. At 6-month follow-up, the investigators found no difference in flexion or extension loss between the acute versus delayed groups. They also found the early intervention group to have more muscle mass and improved single-legged hop performance at 6 months postoperatively. No significant differences between the 2 groups were found in most of the subjective outcome scores measured at the 6-month follow-up.

With differing conclusions on generalized time periods between injury and surgery, more attention may be needed on patient-specific factors to allow for return of ROM, soft tissue healing, and improved strength. An important indicator of patient preparedness for surgery is the achievement of full symmetrical ROM prior to undergoing ACL reconstruction, and our study suggests that LFC bone bruising predicts a delay in gaining full extension.

Strengths of this study include its prospective design and large sample size. A recognized limitation of this study is that we included no clinical outcomes to determine whether a delay in achieving full ROM preoperatively ultimately affected the clinical outcome. Notably, postoperative ROM was not evaluated. Another difficulty was that our survey relied on self-assessment of full extension for some of the patients, and they were asked to recall when full extension was achieved. If full extension was achieved prior to the initial evaluation or between subsequent appointments, there may have been some inaccuracy in determining the exact date when full extension was achieved. Regarding data on ROM obtained from physical therapy reports, we do not know specifically how each physical therapist determined full extension. In addition, the results of this study may not be generalizable to patients with chronic ACL tears, as we limited our analysis to patients with acute ACL tears ($\leq$3 weeks from injury to initial evaluation).

CONCLUSION

Our study suggests that ACL injuries associated with LFC bone bruising on MRI are more prone to loss of extension prior to ACL reconstruction. Reduced extension preoperatively can in turn increase the risk of reduced ROM postoperatively. Our standard recommendation is to delay surgery until full passive extension in the injured knee is equal to that of the opposite knee. The study data showed that the average time to achieve extension after an acute ACL injury is 18 days, which might suggest a similar waiting period before surgery, but we identified a group that took longer to achieve full extension, where the average was 32.5 days. In any given patient, bone bruising associated with ACL injury should be identified and preoperative rehabilitation should continue until full extension is achieved to avoid the development of arthrofibrosis postoperatively.

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