Effect of Delayed Primary Anterior Cruciate Ligament Reconstruction on Medial Compartment Cartilage and Meniscal Health

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Background: The time required to develop a secondary cartilage or meniscal injury in the medial compartment after anterior cruciate ligament (ACL) injury is not well understood.

Purpose: To determine the association between time delay until ACL reconstruction and the presence of medial compartment Outerbridge grade 3 or 4 chondral injury or medial meniscal tear requiring treatment.

Study Design: Cohort study; Level of evidence, 3.

Methods: A total of 609 patients underwent primary ACL reconstruction at a single institution at a median 46 days between injury and surgery (61.4% male; mean age, 26.5 years [SD, 11.1]). Chondral status was graded according to Outerbridge criteria at the time of surgery. Multivariate regression analysis was used to assess the relationship between time delay until surgery and medial compartment chondral injury or meniscal injury requiring treatment. Adjustment was performed as needed for patient demographics, sporting activity, and prior knee injuries. Time until surgery had a nonlinear association with medial compartment health and was more effectively described in discrete intervals rather than as a continuous variable. The optimal time intervals to predict medial compartment health were determined by comparison of Bayes information criterion values between fully adjusted regression models.

Results: After controlling for relevant confounders, delay of surgery >8 weeks had an increased likelihood of a medial meniscal tear requiring partial meniscectomy (adjusted odds ratio [aOR], 2.30; 95% CI, 1.04-5.12; P = .04) and a decreased likelihood of a meniscal tear requiring repair (aOR, 0.50; 95% CI, 0.32-0.76; P = .001). Delay of surgery >5 months had an increased likelihood of a medial Outerbridge grade ≥3 chondral defect (aOR, 3.11; 95% CI, 1.64-5.87; P = .001) or a grade 4 defect (aOR, 3.84; 95% CI, 1.75-8.45; P = .001).

Conclusion: From the time of ACL injury, risk of an irreparable medial meniscal tear found at the time of ACL reconstruction is significantly increased by 8 weeks, and risk of high-grade medial chondral damage is increased by 5 months.

Keywords: anterior cruciate ligament; delayed ligament reconstruction; medial compartment injury; chondral damage; meniscal tear

Injury of the anterior cruciate ligament (ACL) of the knee is relatively common, and the frequency of surgical ACL reconstruction (ACLR) has been increasing.[21] There are often concurrent injuries associated with ACL rupture that are similarly debilitating as, if not more than, the ACL injury itself. With possible injury of other ligaments of the knee, patients frequently have significant injury to the meniscus or the chondral surfaces of the knee. In a study by Kluczynski et al[17] of patients with ACL injuries, incidence of lateral meniscal injury was 39%, medial meniscal injury was 36.4%, and chondral injury was 15%.

For ACLR, the current standard is to delay operative care until the patient has regained full range of motion and the swelling of the knee has subsided. Delaying operative treatment allows patients to regain range of motion, improve leg strength, and limit preoperative stiffness before undergoing surgery.[11] There is some evidence that nonoperative treatment is effective for return to sport, particularly for those patients who do not report instability ("copers")[9,10,13,16,22]; however, there is also significant evidence that, for most patients, surgical intervention is necessary for return to sport.[2,15] Delay of surgery is often

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indicated to allow (1) surgical patients to participate in preoperative therapy and (2) providers to determine patients' "coping" ability for possible nonoperative care. Although delay of ACLR can be beneficial, the ideal time frame to incur the benefits of presurgical therapy or possible nonoperative treatment while minimizing the risk of instability-related secondary medial compartment injury is not well understood.

For pediatric patients, delaying surgery was found to increase the risk of secondary meniscal and chondral lesions in the medial and lateral compartments of the knee.[1,8,18] These findings were echoed for adults by Brambilla et al,[3] although the authors looked only at ACLRs before or after 12 months after injury. Other studies emphasized that lateral compartment injuries occur more commonly with acute injury, whereas medial compartment injuries are caused by chronic stresses in an ACL-deficient knee.[12,17] Still others suggested that increasing time to surgery may negatively affect cartilage and meniscal health.[7]

While chronic ACL deficiency has been associated with medial compartment injury,[12] it is unclear what specific time frame is associated with increased injury risk. The objective of this study is to determine the association between delay in ACLR and the presence of medial compartment pathology at the time of primary ACLR. Specifically, we seek to determine the association between delay in primary ACLR and (1) Outerbridge grade 2, 3, and 4 medial compartment chondral defect formation; (2) medial meniscal tear requiring repair; and (3) medial meniscal tear requiring meniscectomy.

METHODS

Following approval from the biomedical institutional research board of The Ohio State University, all patients (N = 609) assessed at a single academic medical center from 2008 to 2016 were retrospectively reviewed. There is no preestablished clinical time interval for delay of ACLR and medial compartment health; in our opinion, a difference of ≥2 weeks would be clinically meaningful. An a priori power analysis determined that the sample was adequate to detect a mean 14-day difference in time to surgery between patients with (n = 74) and without (n = 535) Outerbridge grade 3 or 4 medial compartment cartilage injury and between patients who did (n = 72) and did not (n = 537) require a partial medial meniscectomy, at 96% power and an alpha of .05. All patients underwent primary ACLR by 1 of 2 sports medicine fellowship–trained surgeons (C.C.K., D.C.F.) between 2006 and 2017. Recommendations to proceed with ACLR were based on patient age, desire to return to cutting or pivoting activities, or symptomatic instability during sporting activities or activities of daily living. A total of 709 ACLRs in the period were screened, 100 of which did not meet study inclusion criteria: patients who presented for revision ACLR (n = 52) and patients requiring multiligament knee reconstructions (n = 48). No other cases were excluded from the series. Patients with prior knee surgery other than ACLR were included. A total of 78 (12.8%) patients had prior non-ACL surgery (in descending order): partial lateral meniscectomy (n = 38, 49%), partial medial meniscectomy (n = 21, 27%), arthroscopic debridement/chondroplasty (n = 8, 10%), medial meniscal repair (n = 7, 9%), lateral meniscal repair (n = 2, 3%), and extensor mechanism repair (n = 2, 3%). Sport participation data as well as date of injury were obtained. All cartilage and meniscal assessments were based on direct arthroscopic visualization during the initial diagnostic arthroscopy before ACLR. Cartilage lesions within each knee compartment were graded according to the Outerbridge classification (Table 1).[4] The decision to perform a meniscal repair versus a partial meniscectomy was made at the time of surgery.

TABLE 1
Outerbridge Classification for Joint Cartilage Defects[4]

Grade	Definition
0	Normal
1	Cartilage with softening and swelling
2	A partial-thickness defect with fissures on the surface that do not reach subchondral bone or exceed 1.5 cm in diameter
3	Fissuring to the level of subchondral bone in an area with a diameter >1.5 cm
4	Exposed subchondral bone

Statistical Analysis

All analyses were performed with a standard statistical software package (STATA, v 13.0). Descriptive statistics were first generated for the entire sample population. The crude association between delay of surgery and risk of medial or lateral compartment pathology was

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determined by logistic regression. Time was initially treated as a continuous variable and found to have a nonlinear association with the primary outcomes; therefore, time was assessed as described in discrete intervals in 2-week increments up to 1 year. Logistic regression models were created with time described in 2-level (eg, ≤8 or >8 weeks) or 3-level (eg, ≤8, 8-20, or >20 weeks) intervals with either categorical or continuous data or a combination thereof (eg, ≤8 weeks as a categorical variable and time >8 weeks as a continuous variable). The optimal time intervals were selected that achieved the lowest Bayes information criterion, a common method for selecting among a finite set of models.

To determine the independent association between delay in surgery and medial compartment health, multivariate logistic regression models were created with adjustment as needed for patient demographics, sporting activity, and prior injury. A backward selection method was utilized with an exit criterion of likelihood ratio $P < .05$. If there was evidence of significant confounding, as defined by a change in estimate >15% of the dependent variable of interest, the confounding variable was kept in the model regardless of P value. Separate multivariate models for the medial and lateral compartments were created for the following: the presence of a grade 2, 3, or 4 cartilage defect; the presence of meniscal tear requiring repair; and the presence of a meniscal tear requiring meniscectomy. Interaction terms between age or prior surgery and time delay were assessed in all models. No significant interactions were identified ($P > .20$, each model), indicating that the relationship between medial or lateral compartment health and time to surgery was unaffected by patient age or prior surgery; the interaction terms were therefore excluded from the final models.

TABLE 2
Summary Statistics[a]

	Mean (SD) or %
Age, y	26.5 (11.1)
Sex	
Male	61.4
Female	38.6
Body mass index	27.2 (5.4)
Athlete	
Yes	79.3
No	20.7
Prior knee surgery other than ACLR[b]	12.8
Time until primary ACLR, d[c]	
All patients	46 (29, 100)
Partial medial meniscectomy required	82 (35, 192)[d]
No partial medial meniscectomy required	39 (26, 71)
Grade 3 or 4 medial cartilage defect present	126 (44, 276)[e]
No grade 3 or 4 medial cartilage defect present	44 (27, 91)
Sporting activity at time of ACL injury	
Soccer	24.6
Basketball	23.0
Football	16.7
Volleyball	6.4
Ski/snowboarding	4.9
Baseball/softball	3.1
Rugby	2.5
Martial arts	2.0
Other sport (<2% participation per sport)	16.8
Highest-grade medial compartment chondral injury	
0 or 1	64.0
2	23.3
3	6.9
4	5.3
Highest-grade cartilage defect location	
Tibia	15.9
Femur	84.1
Grade 4 defect size (when present), cm^2	2.6 (2.2)
Partial medial meniscectomy	11.8
Medial meniscal repair	43.9

[a]ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction.

[b]In descending order: partial lateral meniscectomy (n = 38, 49%), partial medial meniscectomy (n = 21, 27%), arthroscopic debridement/chondroplasty (n = 8, 10%), medial meniscal repair (n = 7, 9%), lateral meniscal repair (n = 2, 3%), and extensor mechanism repair (n = 2, 3%).

[c]Median (25th percentile, 75th percentile).

[d]$P < .001$ (Wilcoxon rank sum): time to primary ACLR between patients with and without partial meniscectomy.

[e]$P < .001$ (Wilcoxon rank sum): time to primary ACLR between patients with and without high-grade cartilage defects.

RESULTS

Summary Statistics and Unadjusted Risk Factors for Chondral Injury

A total of 609 patients were included in the study (mean age, 26.5 years; SD, 11.1), most of whom regularly participated in athletic activities at the time of ACL injury (79.3%) (Table 2). The most common sporting activities at the time of ACL injury were soccer (24.7%), followed by basketball (22.9%) and football (16.7%). A total of 12.8% of patients had a history of ipsilateral knee surgery other than ACLR. The highest-grade chondral injury seen in the medial compartment at the time of ACLR was grade 0 or 1 in 64.0% of cases (Table 2). The area of most significant cartilage damage was the femoral condyle in 84.0% of cases. When present, grade 4 medial compartment defects were a mean 2.6 cm^2 (SD, 2.2). At the time of ACLR, medial meniscal injuries amenable to repair were seen in 43.9% of cases, and meniscal injuries requiring meniscectomy were seen in 11.8%.

The median time from injury to surgery for patients who required partial medial meniscectomy was 82 days versus 39 days among patients who did not ($P < .001$, Wilcoxon rank sum) (Table 2). The median time from injury to surgery for patients who had a grade 3 or 4 medial compartment chondral defect was 126 days versus 44 days among patients who did not ($P < .001$, Wilcoxon rank sum).

At baseline, without adjustment for confounders, grade 3 or 4 medial compartment chondral injuries were more commonly seen among patients who were male ($P = .03$)

TABLE 3
Unadjusted Association Between Baseline Variables and Risk of Medial Compartment Injury[a]

	Grade 3 or 4 Chondral Injury		Meniscal Tear Requiring Repair or Meniscectomy	
	OR (95% CI)	*P* Value	OR (95% CI)	*P* Value
Male sex	1.78 (1.04-3.07)	.03	1.62 (1.10-2.39)	.02
Age[b]	1.07 (1.05-1.10)	<.001	1.03 (1.01-1.06)	.02
Body mass index[c]	1.08 (1.03-1.13)	.001	1.03 (0.99-1.08)	.13
Athlete	0.17 (0.10-0.29)	<.001	0.92 (0.52-1.59)	.77
Prior knee surgery	3.49 (1.83-6.63)	<.001	1.10 (0.42-2.79)	.84

[a]OR, odds ratio.
[b]Per year increase.
[c]Per 1.0 increase.

TABLE 4
Independent Relationship Between Time to ACLR and Lateral Chondral Injury or Meniscal Tear[a]

	aOR (95% CI)	*P* Value
Lateral grade 3 or 4 chondral injury		
Time to surgery: continuous[b]	1.00 (0.99-1.01)	.57
Time to surgery >5 mo, yes[c]	0.94 (0.43-2.00)	.91
Age[d]	1.03 (1.01-1.05)	.02
Athlete, yes	0.44 (0.21-0.94)	.03
Lateral meniscal tear treated with partial meniscectomy		
Time to surgery: continuous[b]	1.00 (0.99-1.01)	.24
Time to surgery >8 wk, yes[c]	0.77 (0.21-1.45)	.26
Age[d]	0.99 (0.07-1.01)	.31
Prior knee surgery, yes	0.62 (0.22-1.59)	.33
Lateral meniscal tear treated with repair		
Time to surgery: continuous[b]	1.00 (0.99-1.01)	.76
Time to surgery >8 wk, yes[c]	0.67 (0.38-1.15)	.15
Age[d]	0.97 (0.94-1.00)	.09
Prior knee surgery, yes	0.74 (0.16-2.48)	.65

[a]ACLR, anterior cruciate ligament reconstruction; aOR, adjusted odds ratio.
[b]Per week.
[c]All other cut points for time until ACLR were nonsignificant predictors of lateral compartment chondral injury or meniscal status.
[d]Per year.

or older ($P < .001$) or who had a higher body mass index ($P = .001$) or prior knee surgery ($P < .001$) (Table 3). Athletes were less likely than nonathletes to have grade 3 or 4 cartilage damage ($P < .001$). Male patients and older patients were more likely to have a meniscal tear requiring treatment (repair or meniscectomy) ($P = .02$, both variables).

Independent Risk Factors of Chondral Injury at Time of ACLR

After adjustment for relevant confounders, time to surgery ≤20 or >20 weeks (time as a categorical variable) more effectively described risk of chondral injury than treating time as a continuous variable (Table 4, Figure 1). Significant confounders of risk of chondral injury included patient age and athletic status. In general, increased age was associated with higher odds of medial chondral injury, and athletes were at lower risk for chondral injury at the time of ACLR than were sedentary patients (Table 5). Delay in surgery >20 weeks independently increased risk of grade 2, 3, or 4 chondral injury (adjusted odds ratio [aOR], 1.73; $P = .02$), grade 3 or 4 chondral injury (aOR, 3.11; $P = .001$), or grade 4 chondral injury (aOR, 3.84; $P = .001$) (Table 6). However, time to ACLR did not affect lateral compartment chondral or meniscal injuries (Table 4).

Independent Risk Factors of Meniscal Injury Requiring Repair or Meniscectomy at the Time of ACLR

After adjustment for relevant confounders, time to surgery ≤8 weeks or >8 weeks (time as a categorical variable) more effectively described risk of medial meniscal injury requiring treatment than did treating time as a continuous variable (Table 5, Figure 1). Time until surgery was predictive

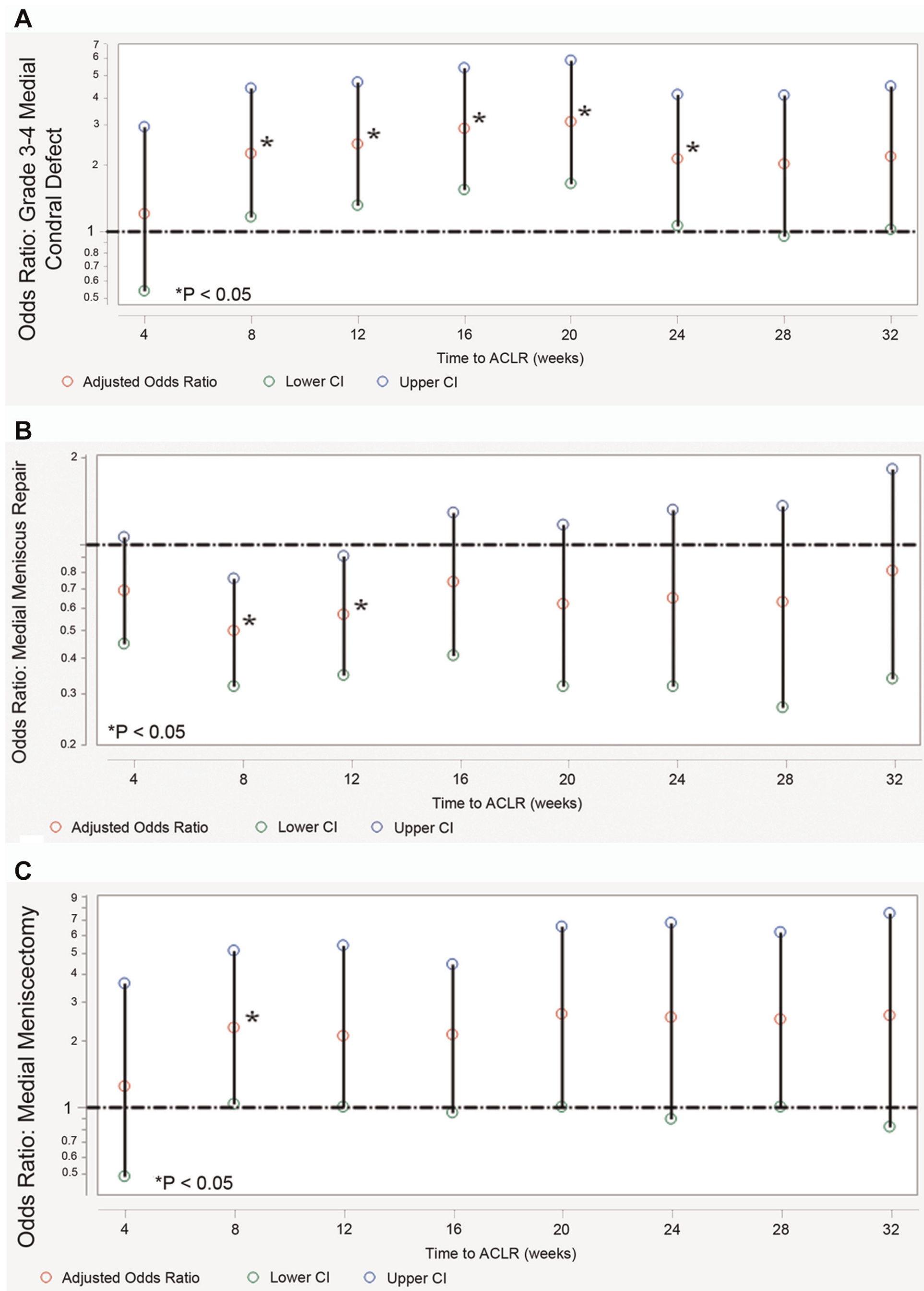

Figure 1. Adjusted odds of medial compartment pathology according to time delay from anterior cruciate ligament injury to anterior cruciate ligament reconstruction (ACLR). The adjusted odds ratios (aORs) and 95% CIs represent comparison of patients with time to surgery less than or equal to versus more than the indicated time in weeks; adjustment for confounders (Tables 5 and 7) was performed at each time point. (A) Adjusted odds of high-grade (Outerbridge grade 3 or 4) medial compartment chondral defect at varying time cutoffs. Odds of high-grade defect was most elevated at time >20 weeks (aOR, 3.11; 95% CI, 1.64-5.87; *P* = .001) versus ≤20 weeks, although was significantly elevated (*P* < .05) at weeks 8 to 24. (B) Adjusted odds of medial meniscal tear that underwent repair. Odds of repair was most decreased at time >8 weeks versus ≤8 weeks (aOR, 0.50; 95% CI, 0.32-0.76; *P* = .001) but was significantly diminished (*P* < .05) at weeks 8 to 12. (C) Adjusted odds of medial meniscal tear that underwent partial meniscectomy. Odds of meniscectomy were only significantly (*P* < .05) elevated at time >8 weeks versus ≤8 weeks (aOR, 2.30; 95% CI, 1.04-5.12; *P* = .04).

TABLE 5
Adjusted Association Between Time to Surgery and Medial Chondral Injury After ACL Injury[a]

Time to Surgery	Grade 2-4 Defect BIC	Grade 2-4 Defect *P* Value	Grade 3 or 4 Defect BIC	Grade 3 or 4 Defect *P* Value	Grade 4 Defect BIC	Grade 4 Defect *P* Value
Continuous	665.5	.32	322.2	.12	240.6	.08
Continuous, >1.0 y recoded as 1.0 y	661.4	.03	316.5	.02	237.1	.01
Categorical, ≤20 and >20 wk[b]	661.2	.02	313.1	.001	232.7	.001

[a]For each *P* value, adjustment was performed for relevant confounders. The row with the lowest BIC represents the statistically optimal method of describing time within the statistical models for chondral injury after ACL injury. ACL, anterior cruciate ligament; BIC, Bayes information criterion.

[b]This represents the optimal interval for describing time as a categorical variable in this context. Cut points were individually assessed in 2-week increments up to 1 year.

TABLE 6
Independent Association Between Time Until ACLR and Risk of Medial Chondral Injury[a]

Chondral Injury	aOR (95% CI)	*P* Value
Grade 2-4		
Time to surgery ≤20 wk	1.0 (referent)	
Time to surgery >20 wk	1.73 (1.08-2.76)	.02
Age[b]	1.04 (1.02-1.06)	<.001
Athlete, yes	0.80 (0.46-1.37)	.41
Grade 3 or 4		
Time to surgery ≤20 wk	1.0 (referent)	
Time to surgery >20 wk	3.11 (1.64-5.87)	.001
Age[b]	1.05 (1.03-1.08)	<.001
Athlete, yes	0.43 (0.22-0.86)	.01
Grade 4		
Time to surgery ≤20 wk	1.0 (referent)	
Time to surgery >20 wk	3.84 (1.75-8.45)	.001
Age[b]	0.99 (0.96-1.03)	.73
Athlete, yes	0.32 (0.14-0.70)	.005

[a]ACLR, anterior cruciate ligament reconstruction; aOR, adjusted odds ratio.

[b]Per year.

TABLE 7
Independent Association Between Time Until ACL Reconstruction and Medial Meniscectomy or Repair[a]

Time	Meniscectomy or Repair BIC	Meniscectomy or Repair *P* Value	Meniscectomy BIC	Meniscectomy *P* Value	Meniscal Repair BIC	Meniscal Repair *P* Value
Continuous	475.5	.99	209.5	.24	600.8	.04
Continuous: >1.0 y recoded as 1.0 y	475.5	.98	207.7	.07	601.5	.08
Categorical: ≤8 and >8 wk[b]	473.7	.19	206.6	.04	594.3	.001

[a]For each *P* value, adjustment was performed for relevant confounders. The row with the lowest BIC represents the optimal method of describing time within the statistical models for medial meniscal pathology after ACL injury. ACL, anterior cruciate ligament; BIC, Bayes information criterion.

[b]This represents the optimal interval for describing time as a categorical variable in this context. Cut points were individually assessed in 2-week increments up to 1 year.

of meniscal injury requiring treatment only when meniscal repairs were differentiated from partial meniscectomies (Table 7). Increased patient age was an independent predictor of a degenerative tear's requiring meniscectomy ($P < .001$) (Table 8). Delay of surgery >8 weeks significantly increased the odds of a tear's requiring meniscectomy (aOR, 2.30; $P = .04$) and significantly decreased the odds of a tear's requiring repair (aOR, 0.50; $P = .001$). Similarly, a history of knee surgery independently increased the odds of a tear's requiring meniscectomy (aOR, 7.78; $P = .003$) and had a trend toward decreased odds of a tear's requiring repair (aOR, 0.32; $P = .05$). Time to injury did not affect odds of requiring a lateral meniscectomy or lateral meniscal repair ($P > .05$) (Table 8).

Meniscal Tear Injury Characteristics

There were 310 partial lateral meniscectomies and 152 lateral meniscal repairs performed. In addition, there were 72 partial medial meniscectomies performed and 267 medial meniscal repairs performed. The majority of lateral (85%) and medial (89%) meniscal tears that were repaired were described as vertical-longitudinal (Table 9). Tear vascularity at the time of ALCR significantly differed when time to surgery was ≤8 weeks versus >8 weeks ($P < .001$, Cochran-Armitage trend test) (Figure 2).

DISCUSSION

Patients and surgeons may choose to delay ACLR after acute injury for a variety of reasons, although the time needed to develop significant medial compartment damage in the setting of ACL deficiency is unclear. The current study results indicate that delay of surgery beyond 8 weeks after injury may affect medial meniscal health and that delay beyond 5 months may increase the risk of high-grade chondral defect formation. Older patients and patients

TABLE 8
Independent Association Between Time and Risk of Medial Meniscal Injury Requiring Treatment[a]

	aOR (95% CI)	*P* Value
Meniscectomy		
Time to surgery ≤8 wk	1.0 (referent)	
Time to surgery >8 wk	2.30 (1.04-5.12)	.04
Age[b]	1.10 (1.06-1.15)	<.001
Prior knee surgery, yes	7.78 (2.09-28.6)	.003
Meniscal repair		
Time to surgery ≤8 wk	1.0 (referent)	
Time to surgery >8 wk	0.50 (0.32-0.76)	.001
Age[b]	0.99 (0.96-1.20)	.44
Prior knee surgery, yes	0.32 (0.07-1.02)	.05

[a]ACLR, anterior cruciate ligament reconstruction; aOR, adjusted odds ratio.
[b]Per year.

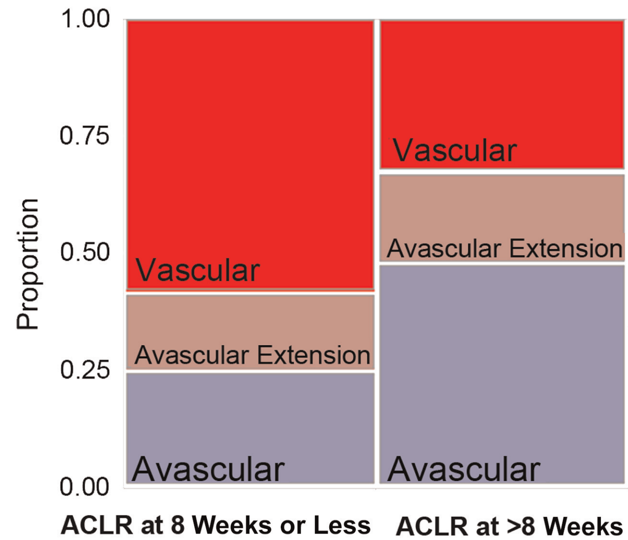

Figure 2. Proportion of medial meniscal tears according to vascular status with ACLR performed at ≤8 weeks since anterior cruciate ligament injury versus >8 weeks after injury. Vascular tears were defined as tears confined to the periphery or red-red zone. Tears with avascular extension were defined as tears involving the periphery and extending centrally into the red-white or white-white zone. Avascular tears were defined as central white-white tears without peripheral involvement. Tear vascularity at the time of ACLR significantly differed when time to surgery was ≤8 weeks (58% vascular, 17% with avascular extension, 25% avascular) versus >8 weeks (33% vascular, 13% avascular extension, 48% avascular) ($P < .001$, Cochran-Armitage trend test). ACLR, anterior cruciate ligament reconstruction.

with a surgical history have more cartilage and meniscal pathology at the time of primary ACLR, although delay of surgery has a uniformly negative effect on medial compartment health regardless of age or surgical history.

While it remains unclear to what degree they should be interpreted clinically, knowledge of generalized time intervals may help guide treatment decisions regarding timing of surgery, planned preoperative rehabilitation, and length of a planned trial of nonoperative treatment. Furthermore, these specific time intervals—8-week delay and meniscal health and 5-month delay and chondral health— should be implemented cautiously, as they represent the practice and outcomes of 1 institution and 2 surgeons. Nevertheless, the 8-week window between ACL injury and reconstruction may be a safe period for patients to work with therapists to improve strength and flexibility before surgery, which can have a beneficial effect on functional outcomes up to 2 years after ACLR.[11] Similarly, it appears that there is a safe initial window to attempt nonoperative treatment with physiotherapy and to determine whether a patient is a functional coper or noncoper without undue risk of developing significant medial compartment damage.

Other studies found that medial meniscal injury occurs more frequently with chronic ACL deficiency, but they failed to identify the time frame in which these injuries occur.[3,8] Importantly, it is possible that time to surgery is less of an important factor and that, rather, any giving-way episodes or instability results in direct medial compartment defects, regardless of time. Furthermore, medial compartment pathology is mostly due to the increased motion and laxity that accompany ACL deficiency, whether it is secondary to baseline ACL laxity or an ACL tear.[12,20] We also found that delaying surgery did not significantly affect the lateral compartment of the knee, which is consistent with the consensus that lateral meniscal injury is more often due to acute injury than chronic ACL deficiency. Ghodadra et al[12] also previously found that medial compartment chondral pathology was significantly affected by a >8-week history of a chronic ACL tear. However, that study utilized a predetermined cutoff to define a chronic injury, whereas the current study performed a robust analysis to determine the specific time range that best determines medial compartment injury risk.

One significant area of ACL injury management that requires further evaluation is the effect of full return to activities on medial compartment health in the setting of ACL deficiency but without functional instability. All of the patients in the current study had symptomatic instability after ACL injury and ultimately ended up with reconstruction. It is unclear whether patients who successfully rehabilitate an ACL-injured knee and return to desired activities without functional instability have the same time-dependent risk of medial compartment damage as patients with symptomatic instability. Conversely, if patients do want to return to sports before undergoing ACLR and "play through" the injury despite episodic instability episodes, their time frame to develop medial compartment damage may be shorter than the ranges described in the current study. There are instances in which athletes may choose to finish a season despite episodic instability, such as high-level athletes with a financial incentive to finish a season. Further research regarding the effect of playing through instability on medial compartment health may help sports medicine providers more accurately describe the magnitude of risk to athletes who desire this treatment approach.

TABLE 9
Treated Lateral and Medial Meniscal Tear Characteristics[a]

	Lateral		Medial	
	Partial Meniscectomy (n = 310, 51%)	Meniscal Repair (n = 152, 25%)	Partial Meniscectomy (n = 72, 12%)	Meniscal Repair (n = 267, 44%)
Time from injury to ACLR, d[b]	46 (28, 100)	41 (27, 64)	84 (35, 183)	38 (26, 65)
Shape				
Vertical-longitudinal	5	85	14	89
Radial	13	9	15	9
Horizontal	12	3	11	1
Root	0	3	0	1
Complex (multiplanar and bird beak)	80	0	60	0
Location[c]				
Posterior horn/body	88	95	90	98
Anterior horn/body	17	7	14	4
Root	2	3	0	1
Vascularity				
Vascular (peripheral)[d]	1	34	0	73
Avascular extension[e]	13	66	19	27
Avascular (central)[f]	86	0	82	0

[a]Values are presented as percentages. ACLR, anterior cruciate ligament reconstruction.
[b]Median (25th percentile, 75th percentile).
[c]Totals for tear location equal >100% owing to some extensive tears involving both the anterior and the posterior meniscus.
[d]Tears confined to the periphery or red-red zone.
[e]Tears involving the periphery and extending centrally into the red-white or white-white zone.
[f]Tears defined as central white-white tears without peripheral involvement.

There were several study limitations. We were unable to delineate which medial compartment chondral lesions were present at the time of injury, as knee magnetic resonance imaging (MRI) is not typically obtained on the day of injury. Additionally, accurate comparisons cannot be made between cartilage defects noted at the time of knee MRI and arthroscopic assessment at time of ACLR: MRI tends to underestimate defect size, and comparison of an initial MRI assessment with later arthroscopic assessment would exaggerate the effect of time to surgery on cartilage lesion propagation.[5,14]

We could not fully control for injury mechanism, and acute chondral injury could be higher in high-energy injuries. The time intervals identified in the current study for increased risk of medial compartment damage may vary according to postinjury activity level with an ACL-deficient knee, and it is unclear whether patients with ACL deficiency without functional instability have the same medial compartment injury risk as the current study population. Meniscal tears requiring repair were less frequently encountered >8 weeks after injury, which may in some cases represent spontaneous healing of the tear rather than progression to an irreparable repair. This is particularly true regarding meniscal ramp lesions, which are small vertical tears of the posterior horn of the medial meniscus that are commonly associated with ACL tear.[6,19] Shelbourne and Rask[23] showed that, when left alone, stable medial vertical meniscal tears have satisfactory outcomes.

After ACL injury, risk of an irreparable medial meniscal tear at time of ACLR in this study was significantly increased at 8 weeks after injury, and risk of high-grade medial chondral damage was increased at 5 months after injury.

REFERENCES

1. Anderson AF, Anderson CN. Correlation of meniscal and articular cartilage injuries in children and adolescents with timing of anterior cruciate ligament reconstruction. *Am J Sports Med*. 2014;43(2):275-281.
2. Barrack RL, Bruckner JD, Kneisl J, Inman WS, Alexander AH. The outcome of nonoperatively treated complete tears of the anterior cruciate ligament in active young adults. *Clin Orthop Relat Res*. 1990;259:192-199.
3. Brambilla L, Pulici L, Carimati G, et al. Prevalence of associated lesions in anterior cruciate ligament reconstruction: correlation with surgical timing and with patient age, sex, and body mass index. *Am J Sports Med*. 2015;43(12):2966-2973.
4. Cameron ML, Briggs KK, Steadman JR. Reproducibility and reliability of the outerbridge classification for grading chondral lesions of the knee arthroscopically. *Am J Sports Med*. 2003;31(1):83-86.
5. Campbell AB, Knopp MV, Kolovich GP, et al. Preoperative MRI underestimates articular cartilage defect size compared with findings at arthroscopic knee surgery. *Am J Sports Med*. 2013;41(3):590-595.
6. Chahla J, Dean CS, Moatshe G, et al. Meniscal ramp lesions: anatomy, incidence, diagnosis, and treatment. *Orthop J Sports Med*. 2016;4(7):2325967116657815.
7. Chhadia AM, Inacio MC, Maletis GB, Csintalan RP, Davis BR, Funahashi TT. Are meniscus and cartilage injuries related to time to anterior cruciate ligament reconstruction? *Am J Sports Med*. 2011;39(9):1894-1899.
8. Crawford EA, Young LJ, Bedi A, Wojtys EM. The effects of delays in diagnosis and surgical reconstruction of ACL tears in skeletally

immature individuals on subsequent meniscal and chondral injury. *J Pediatr Orthop*. 2019;39(2):55-58.
9. Daniel DM, Stone ML, Dobson BE, Fithian DC, Rossman DJ, Kaufman KR. Fate of the ACL-injured patient: a prospective outcome study. *Am J Sports Med*. 1994;22(5):632-644.
10. Eastlack ME, Axe MJ, Snyder-Mackler L. Laxity, instability, and functional outcome after ACL injury: copers versus noncopers. *Med Sci Sports Exerc*. 1999;31(2):210-215.
11. Failla MJ, Logerstedt DS, Grindem H, et al. Does extended preoperative rehabilitation influence outcomes 2 years after ACL reconstruction? A comparative effectiveness study between the MOON and Delaware-Oslo ACL Cohorts. *Am J Sports Med*. 2016;44(10):2608-2614.
12. Ghodadra N, Mall NA, Karas V, et al. Articular and meniscal pathology associated with primary anterior cruciate ligament reconstruction. *J Knee Surg*. 2013;26(3):185-193.
13. Giove TP, Miller SJ 3rd, Kent BE, Sanford TL, Garrick JG. Non-operative treatment of the torn anterior cruciate ligament. *J Bone Joint Surg Am*. 1983;65(2):184-192.
14. Gomoll AH, Yoshioka H, Watanabe A, Dunn JC, Minas T. Preoperative measurement of cartilage defects by MRI underestimates lesion size. *Cartilage*. 2011;2(4):389-393.
15. Hawkins RJ, Misamore GW, Merritt TR. Followup of the acute nonoperated isolated anterior cruciate ligament tear. *Am J Sports Med*. 1986;14(3):205-210.
16. Hurd WJ, Axe MJ, Snyder-Mackler L. A 10-year prospective trial of a patient management algorithm and screening examination for highly active individuals with anterior cruciate ligament injury: part 1, outcomes. *Am J Sports Med*. 2008;36(1):40-47.
17. Kluczynski MA, Marzo JM, Bisson LJ. Factors associated with meniscal tears and chondral lesions in patients undergoing anterior cruciate ligament reconstruction: a prospective study. *Am J Sports Med*. 2013;41(12):2759-2765.
18. Lawrence JT, Argawal N, Ganley TJ. Degeneration of the knee joint in skeletally immature patients with a diagnosis of an anterior cruciate ligament tear: is there harm in delay of treatment? *Am J Sports Med*. 2011;39(12):2582-2587.
19. Liu X, Feng H, Zhang H, Hong L, Wang XS, Zhang J. Arthroscopic prevalence of ramp lesion in 868 patients with anterior cruciate ligament injury. *Am J Sports Med*. 2011;39(4):832-837.
20. McDonald LS, van der List JP, Jones KJ, et al. Passive anterior tibial subluxation in the setting of anterior cruciate ligament injuries: a comparative analysis of ligament-deficient states. *Am J Sports Med*. 2017;45(7):1537-1546.
21. Sanders TL, Kremers HM, Bryan AJ, et al. Incidence of anterior cruciate ligament tears and reconstruction: a 21-year population-based study. *Am J Sports Med*. 2016;44(6):1502-1507.
22. Secrist ES, Frederick RW, Tjoumakaris FP, Stache SA, Hammoud S, Freedman KB. A comparison of operative and nonoperative treatment of anterior cruciate ligament injuries. *JBJS Rev*. 2016;4(11):01874474-201611000.
23. Shelbourne KD, Rask BP. The sequelae of salvaged nondegenerative peripheral vertical medial meniscus tears with anterior cruciate ligament reconstruction. *Arthroscopy*. 2001;17(3):270-274.