# Effect of Increased Time to Surgery on the Ability of MRI to Rule Out Medial Meniscal Tears in Young Athletes With ACL Injury

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**Background:** The prevalence of meniscal tears in patients with anterior cruciate ligament (ACL) injury increases with extended time between injury and ACL reconstruction.

**Purpose/Hypothesis:** The purpose of this study was to determine if there is a relationship between time from magnetic resonance imaging (MRI) to ACL reconstruction and the predictive value of MRI to diagnose meniscal tears in the young active population. It was hypothesized that increased time between MRI and ACL reconstruction would lead to a decrease in the negative predictive value of MRI in diagnosing meniscal tears, as more injuries may accrue over time in the ACL-deficient knee.

**Study Design:** Case series; Level of evidence, 4.

**Methods:** Included were patients aged 13 to 25 years at the authors' institution who underwent primary ACL reconstruction from January 2017 to June 2020. Time from MRI to surgery as well as descriptions of medial and lateral meniscal tears on both MRI and operative reports were documented. Time from MRI to surgery was divided into 4 intervals: 0 to 6 weeks, >6 weeks to 3 months, >3 to 6 months, and beyond 6 months. Multivariable analysis was used to determine the positive and negative predictive values of MRI in diagnosing a meniscal tear as compared with arthroscopic findings.

**Results:** A total of 432 patients were included with a mean age of 17.9 ± 3.4 years. The mean time from MRI to surgery was 70.5 ± 98 days. There was a significant decrease in the negative predictive value of MRI to identify a medial meniscal tear in patients who underwent ACL reconstruction >6 months after imaging (odds ratio, 0.16 [95% CI, 0.05-0.53]; $P = .003$). This same relationship was not shown for lateral meniscal tears, nor was any other predictor significant.

**Conclusion:** The utility of MRI to rule out a medial meniscal tear significantly diminished in the young athletic population when >6 months passed between MRI and ACL reconstruction. These data suggest these tears occur between the time of the MRI and surgery and that the medial meniscus is more susceptible than the lateral meniscus to new injury once the ACL has torn.

**Keywords:** ACL tear; meniscal tear; MRI; adolescent athlete

Injuries to the anterior cruciate ligament (ACL) and meniscus are among the most common traumatic injuries to the knee in young active individuals, making up over half of all knee injuries.[16,20,23,25,29] Often, these injuries occur concomitantly, with 40% to 80% of patients with ACL tears also found to have a meniscal tear.[2,8,9,19] While meniscal damage often occurs at the initial time of ACL injury, further injury to the meniscus can occur over time in the ACL-deficient knee.[2,4,27,28] Untreated meniscal tears combined with ACL tears have been shown to lead to poorer outcomes in young patients because of clinical instability and progressive degeneration of cartilage.[6,18]

Given the potential for poor outcomes with nonoperative management of ACL and meniscal tears in young athletes, an accurate diagnosis of both is critical for guiding management and setting appropriate patient expectations of risks, benefits, rehabilitation, and outcomes of surgery. Magnetic resonance imaging (MRI) is often used to confirm ACL and meniscal injury.[5,7,17,21,22,30] MRI has excellent sensitivity, specificity, and predictive value in diagnosing knee pathology, specifically meniscal tears. Previous studies have reported the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of MRI in diagnosing meniscal tears to be 70% to 95%, 75% to 93%, 80% to 88%, and 90% to 91%, respectively.[5,31] Interestingly, in patients with ACL injuries, the ability of MRI to diagnose meniscal tears varies widely, with a reported sensitivity, specificity, PPV, and NPV of 62% to 90%, 68% to 95%, 58% to 88%, and 50% to 95%, respectively.[7,14,21,30]

Previous studies have shown that the prevalence of meniscal tears in patients with ACL injury increases with

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extended time between injury and ACL reconstruction. Explanations for this include the development of instability that is associated with injured athletes returning to sport and the associated torsional forces on the knee that come with it.[4,27,28,32] However, no study, to our knowledge, has examined the role of time on the predictive value of diagnostic MRI, specifically in the young active population. Particularly in this population, delayed ACL reconstruction may result in an accrual of new meniscal injury over time, especially in the medial meniscus, as it resists anterior translation (the tibia in the ACL-deficient knee).[1,15,24] As ACL reconstruction is an elective surgery, there is a wide range in time between diagnosis with MRI and treatment of ACL injury. The start of the coronavirus pandemic in January 2020 led to restrictions in elective surgeries and further increased this time difference.[10]

In the current study, we aimed to build on previous work examining the role that time plays on meniscal tears in ACL-deficient knees by studying the relationship between time from MRI to ACL reconstruction as well as the predictive value of MRI in diagnosing either medial or lateral meniscal tears in a young active population. We hypothesized that increased time between MRI and ACL reconstruction will lead to a decrease in the NPV of MRI in diagnosing meniscal tears, as more meniscal injuries may accrue over time in the ACL-deficient knee.

## METHODS

The protocol for this study was approved by our institutional review board. A retrospective chart review was performed on patients who underwent primary ACL reconstruction between January 1, 2017, and June 30, 2020, by 7 fellowship-trained orthopaedic surgeons at 1 of 2 affiliated institutions. Inclusion criteria were all patients aged 13 to 25 years at the time of surgery, with a radiologist-read MRI report and operative report available in the chart. Exclusion criteria were the lack of active participation in an athletic activity, prior surgery to the ipsilateral knee, or other ligament surgery at the time of ACL reconstruction. This age range was selected to minimize the chance of preexisting meniscal damage and also to include patients with the highest likelihood of participating in an athletic activity at the time of ACL tear. We defined "athletic activity" as participation in a sport within the past year.

The electronic medical records of all included patients were reviewed. Meniscal findings from both the MRI report and the operative report were charted, as was the time from MRI to surgery. We documented all meniscal tears found at the time of surgery regardless of treatment as a gold standard to compare against the MRI report. Secondary variables collected included age, sex, ethnicity, body mass index (BMI), primary sport, mechanism of injury, and time from injury to MRI. Data were then analyzed to examine the relationship between the time from MRI to surgery and MRI findings of meniscal tear confirmed on operative findings.

### Data Preparation

Time from MRI to surgery was divided into 4 clinically relevant follow-up intervals: 0 to 6 weeks (42 days), 6 weeks to 3 months (43-90 days), 3 to 6 months (91-180 days), and >6 months (>180 days). This was because exploratory data analysis indicated that the relationship between PPV and NPV of the MRI finding tended not to be linear in time. Primary sports were grouped into risk categories of "high" (soccer, lacrosse, basketball, football, gymnastics/cheer, rugby, volleyball, Ultimate Frisbee, and extreme sports) and "low" (softball, baseball, track and field, tennis, wrestling, martial arts, and other). Age and BMI were binned into 3 and 5 quantiles, respectively. For each multivariable statistical model, PPV and NPV were plotted against categorical age and BMI. If linearity seemed a plausible assumption, the continuous versions of these variables were used in multivariable modeling. Otherwise, the categorical versions were used. For univariable modeling, the PPV and NPV of MRI findings, with 95% CIs, were calculated and graphed independently for each time interval, for both lateral and medial meniscal tears.

### Multivariable Modeling

PPV, in the present context, is the probability of observing a (lateral/medial) meniscal tear at surgery, given a positive MRI finding for a (lateral/medial) tear. The PPV models included only those patients with a positive MRI finding for a (lateral/medial) meniscal tear. Logistic regression was used to test for significant differences in the likelihood of observing a tear between 43 and 90 days, between 91 and 180 days, and >180 days after MRI, compared with the likelihood of observing a tear upon surgery between 0 and 42 days after MRI. NPV is the probability of not observing a (lateral/medial) meniscal tear at surgery, given a negative MRI finding for a (lateral/medial) tear. The PPV models included only those patients with a negative MRI finding

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Ethical approval for this study was obtained from the University of Washington (reference No. 00009903) and Seattle Children's (reference No. 00001752).

TABLE 1
Baseline Demographic Data of the Cohort (N = 432)[a]

| Category | Value | Category | Value |
|---|---|---|---|
| Age, y, mean ± SD | 17.9 ± 3.4 | Primary sport | |
| Sex | | American football | 61 (14) |
| Female | 235 (54) | Baseball | 2 (<1) |
| Male | 197 (46) | Basketball | 68 (16) |
| Race/ethnicity | | Extreme sports | 40 (9) |
| Black | 29 (7) | | 14 (3) |
| American Indian/Native Alaskan | 4 (<1) | Lacrosse | 7 (2) |
| Asian | 46 (11) | Martial arts | 4 (1) |
| White | 227 (53) | Rugby | 8 (2) |
| Hispanic | 33 (8) | Soccer | 129 (30) |
| Native Hawaiian, Pacific Islander | 5 (1) | Softball | 9 (2) |
| Other | 25 (6) | Tennis | 1 (<1) |
| None reported | 63 (15) | Track and field | 5 (1) |
| Body mass index | | Ultimate Frisbee | 12 (3) |
| <18.5 | 17 (4) | Volleyball | 23 (5) |
| 18.5-24.9 | 249 (58) | Wrestling | 6 (1) |
| 25-29.9 | 106 (25) | Other (includes skiing) | 43 (10) |
| ≥30 | 60 (14) | | |

[a]Data are reported as n (%) unless otherwise indicated.

for a (lateral/medial) meniscal tear. Logistic regression was used to test for significant differences in the likelihood of not observing a tear between 43 and 90 days, 91 and 180 days, and >180 days after MRI, compared with the likelihood of not observing a tear upon surgery between 0 and 42 days after MRI.

## Statistical Analysis

For multivariable models, the dependent variable was an indicator of whether a tear was observed at surgery. The independent variable of primary interest was the time period. Covariates included age, risk category of primary sport, BMI, sex, and physes. Variable selection followed the procedure described in Bursac et al.[3] The significance level for hypothesis tests was set at $P < .05$. Data analysis was carried out using Stata Version 16.1 (StataCorp).[26]

## RESULTS

The cohort included 432 patients with a mean age of 17.9 ± 3.4 years. There was no loss to follow-up, as we only included those patients who went on to undergo surgery. The mean time from MRI to surgery was 70.5 ± 98 days. The mean time from injury to MRI was 85.3 ± 255 days. The most common primary sport was soccer (129/432 patients; 30%). Additional baseline demographic data are displayed in Table 1. The number of patients included per time group are displayed in Table 2.

The overall percentages of medial and lateral meniscal tears in the cohort were 36.8% and 22.2%, respectively. The sensitivity of MRI in diagnosing medial meniscal tears in the cohort was 79.2%, and the specificity was 80.2%. The sensitivity and specificity in diagnosing lateral meniscal tears were 63.9% and 87.4%, respectively. Our univariable

TABLE 2
Number of Patients per Study Group[a]

| Group (based on time from MRI to surgery) | No. of Patients |
|---|---|
| 0-42 d (0-6 wk) | 203 |
| 43-90 d (6 wk-3 mo) | 156 |
| 91-180 d (3-6 mo) | 48 |
| >180 d (>6 mo) | 25 |

[a]MRI, magnetic resonance imaging.

analysis of MRI for medial and lateral meniscal tears is shown in Table 3. The greatest change in predictive value in our univariable analysis was observed with the NPV of a medial meniscal tear at >180 days, decreasing from 89 to 61 (28%). The NPVs of both medial and lateral meniscal tears are illustrated in Figure 1. Multivariable results are displayed in Table 4. Most notably, the odds ratio of the NPV of MRI to identify a medial meniscal tear after 180 days significantly declined to 0.16 (95% CI, 0.05-0.53; $P = 0.003$), whereas it was not significant at any other time point for the medial meniscus or at any time point for the lateral meniscus.

## DISCUSSION

Through our multivariable analysis, we found that the NPV of MRI in detecting medial meniscal tears decreased significantly when time from MRI to surgery eclipsed 180 days. This supports previous studies that have demonstrated an increased incidence of medial meniscal tear in ACL-deficient knees with longer periods of time between injury and surgery.[4,27,28,32] We did not find a significant relationship with lateral meniscal tears, nor did we see this

TABLE 3
Diagnostic Accuracy of MRI for Medial and Lateral Meniscal Tears, Based on Surgical Finding[a]

| Time From MRI to Surgery | Sensitivity, % | Specificity, % | PPV, % | NPV, % |
|---|---|---|---|---|
| Medial meniscal tear | | | | |
| 0-42 d | 80.6 (69.1-89.2) | 77.2 (69.2-84.0) | 63.5 (52.4-73.7) | 89.0 (81.9-94.0) |
| 43-90 d | 83.3 (71.5-91.7) | 82.3 (73.2-89.3) | 74.6 (62.5-84.5) | 88.8 (80.3-94.5) |
| 91-180 d | 85.0 (62.1-96.8) | 85.7 (67.3-96.0) | 81.0 (58.1-94.6) | 88.9 (70.8-97.6) |
| >180 d | 41.7 (15.2-72.3) | 84.6 (54.6-98.1) | 71.4 (29.0-96.3) | 61.1 (35.7-82.7) |
| Overall | 79.2 (72.1-85.3) | 80.2 (75.0-84.3) | 70.0 (62.7-76.6) | 86.9 (82.1-90.8) |
| Lateral meniscal tear | | | | |
| 0-42 d | 66.7 (56.3-76.0) | 87.9 (80.1-93.4) | 83.1 (72.9-90.7) | 74.6 (66.1-81.9) |
| 43-90 d | 61.4 (49.0-72.8) | 86.0 (76.9-92.6) | 78.2 (65.0-88.2) | 73.3 (63.5-81.6) |
| 91-180 d | 52.5 (29.8-74.3) | 88.9 (70.8-97.6) | 78.6 (49.2-95.3) | 70.6 (52.5-84.9) |
| >180 d | 85.7 (42.1-99.6) | 88.9 (65.3-98.6) | 75.0 (34.9-96.8) | 94.1 (71.3-99.9) |
| Overall | 63.9 (56.7-70.7) | 87.4 (82.5-91.3) | 80.5 (73.4-86.5) | 74.8 (69.3-79.8) |

[a]Percentages are reported with 95% CI in parentheses. MRI, magnetic resonance imaging; NPV, negative predictive value; PPV, positive predictive value.

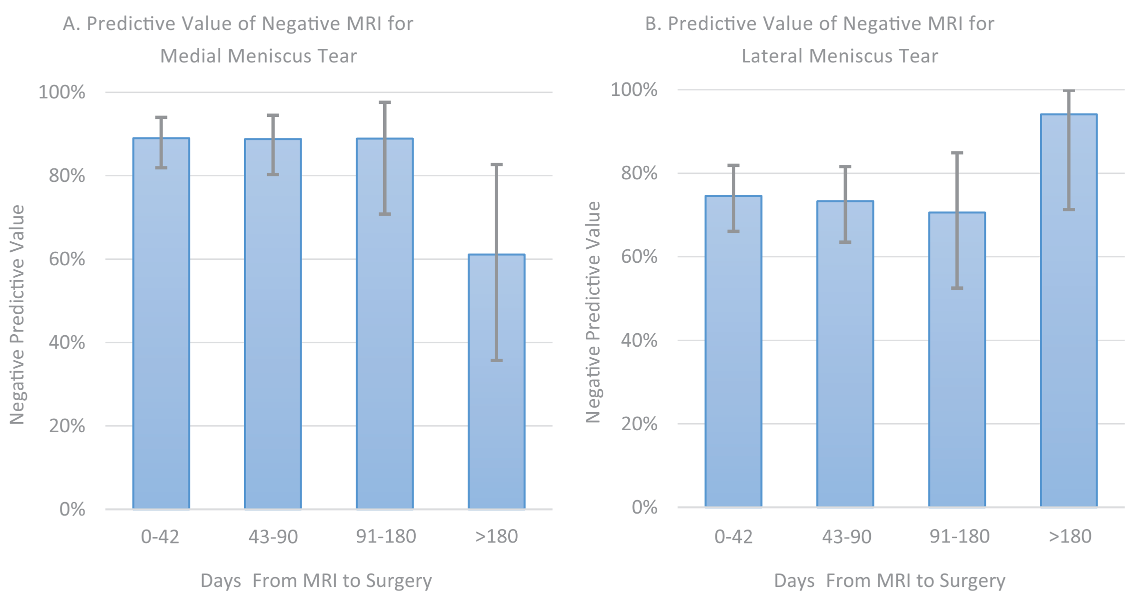


**Figure 1.** Negative predictive values (NPVs) of magnetic resonance imaging (MRI) for (A) medial and (B) lateral meniscal tears in patients aged 13 to 25 years undergoing anterior cruciate ligament reconstruction, stratified by time from MRI to surgery. Error bars represent 95% CIs. For the medial meniscus, the NPV stayed relatively consistent during the first 3 intervals and then dropped precipitously when surgery was performed >180 days after imaging. For the lateral meniscus, the NPV of MRI remained unchanged.

at earlier time intervals. The PPV, sensitivity, and specificity did not differ significantly with time.

Our findings are consistent with previous studies that have demonstrated increased numbers of meniscal tears found during ACL reconstruction when time to surgery is increased.[4,27,28,32] Yoo et al[32] noted that the medial meniscus was found to be injured more often than the lateral one in ACL-deficient knees. Given that the ACL is the primary stabilizer of anterior tibial translation at the knee, when the ACL is injured, the role of anterior translation falls on secondary stabilizers, such as the posterior horn of the medial meniscus. As a result, previous hypotheses that the medial meniscus would sustain more wear and tear in ACL-deficient knees were shown to be accurate.[4,27,28,32]

Our study corroborates these findings. Given the high sensitivity and specificity of MRI in diagnosing meniscal tears, our data support the idea that these tears occur after the initial injury in the time period between the injury and surgery. In addition, they demonstrate that there is a higher incidence of medial meniscal tears compared with lateral ones when the tears occur after the initial injury. However, our study differs from previous ones in 2 main aspects. First, we look directly at the predictive value of MRI in ruling out meniscal tears, and we demonstrate that

TABLE 4
Multivariable Analysis of the Predictive Value of MRI in Diagnosing Meniscal Tears Over Time, Based on Surgical Findings[a]

| Time From MRI to Surgery | OR (95% CI) | *P* |
|---|---|---|
| Medial meniscal tear | | |
| Positive predictive value | | |
| 0-42 d (reference) | — | — |
| 43-90 d | 1.81 (0.88-3.7) | .11 |
| 91-180 d | 2.31 (0.7-7.59) | .17 |
| >180 d | 1.32 (0.23-7.47) | .76 |
| Negative predictive value | | |
| 0-42 d (reference) | — | — |
| 43-90 d | 1.01 (0.44-2.59) | .89 |
| 91-180 d | 1.02 (0.26-4.04) | .98 |
| >180 d | 0.16 (0.05-0.53) | **.003** |
| Lateral meniscal tear | | |
| Positive predictive value | | |
| 0-42 d (reference) | — | — |
| 43-90 d | 0.77 (0.31-1.87) | .56 |
| 91-180 d | 0.66 (0.16-2.79) | .58 |
| >180 d | 0.62 (0.11-3.49) | .58 |
| Negative predictive value | | |
| 0-42 d (reference) | — | — |
| 43-90 d | 0.98 (0.53-1.78) | .94 |
| 91-180 d | 0.8 (0.34-1.9) | .62 |
| >180 d | 4.59 (0.57-36.58) | .15 |

[a]Boldface *P* value indicates statistical significance. Dashes indicate areas not applicable. Nonsignificant factors (not shown) included age, sex, body mass index, mechanism of injury, primary sport, and ethnicity. MRI, magnetic resonance imaging.

the NPV of MRI in excluding a medial meniscal tear is significantly lower at >6 months between MRI and surgery. This is significant because of the crucial role that MRI plays in helping the surgeon plan his or her preoperative strategy. In addition, it allows the surgeon to counsel the patient on knowledge of the athlete's injury, expectations regarding surgery, recovery, and return to sport. The patient can be made aware that when there is a delay >6 months between imaging and surgery, the surgeon may find undiagnosed meniscal injury at the time of ACL reconstruction. Likewise, the surgeon should be prepared to treat medial meniscal injury at the time of ACL surgery in patients with >6 months from MRI to surgery and can decide whether updated preoperative imaging would be cost-effective.

Second, we specifically evaluated the young active population, one of interest regarding ACL and meniscal injuries. Young athletes who sustain ACL and meniscal tears are more likely to undergo surgery than older patients who are less active.[11-13] This study informs us that in this active population, additional medial meniscal tears may occur with increased time from injury to surgery. It may be difficult to restrict these active patients postinjury, and thus they may be more likely to participate in pivoting activities before surgery and sustain further damage to their menisci. Thus, it may be beneficial for surgeons to advocate for their young patients to receive ACL surgery within 6 months of diagnostic imaging to reduce the incidence of further knee injury.

## Strengths and Limitations

The present study has several strengths. These include the size and makeup of our population. Our study examined a large cohort of young athletic individuals with ACL tears. To our knowledge, no study has looked at such a large cohort of individuals in this specific active population. In addition, our population is one of special interest for acute knee injuries, as these patients may be at high risk for subsequent injury after ACL tear. Furthermore, the use of both univariable and multivariable analysis allows us to demonstrate the relationship between our primary variable and outcome, both with and without the influence of secondary variables. When controlling for other factors such as sex, race, and BMI, we can demonstrate a significant relationship between time from imaging to surgery and the NPV of MRI with regard to medial meniscal tears. Last, no study, to our knowledge, has asked this question, that is, one of the predictive value of MRI and the influence of time on its utility.

There are important limitations to consider with this study. First, this was a retrospective study; thus, data were collected on patients who had already received imaging and surgery. However, of the 435 patients in our initial cohort, only 3 were not included secondary to insufficient MRI or operative data. Second, we included a heterogeneous collection of MRI reports, not necessarily all from musculoskeletal-trained radiologists. Given that there were an unknown number of radiologists performing the reads, our results may be influenced by inconsistencies in their reporting and, in particular, our concluding remark that these medial meniscal injuries accrue over time. The heterogeneity also precluded our ability to perform inter- and intrarater reliability. Similarly, the operative reports were collected from a variety of attending surgeons in our institution, which may allow for inconsistent reporting. However, all surgeons included in the study were fellowship trained in sports medicine, with presumably enough experience to indicate the presence or absence of meniscal pathology, although it is possible that ramp tears may have been missed if specific intraoperative techniques to assess for these tears were not used. Another limitation is that we are unable to comment on any activity restrictions that may have been placed on patients after their MRI, or on reasons for delay from MRI to surgery, as many of the patients received their imaging at outside institutions and were later referred to our center. The inclusion of heterogeneous imaging, operative reports, and initial postinjury care may have a positive benefit in increasing the generalizability of this study for the practicing orthopaedic surgeon.

# CONCLUSION

Our analysis demonstrated that beyond 6 months after an MRI for ACL tear, the utility of MRI to rule out a medial meniscal tear significantly diminishes in the young athletic population. These data suggest that such tears occur between the time of the MRI and surgery and that the medial meniscus is more susceptible to new injury than the lateral meniscus once the ACL has torn. The study findings can help the practicing surgeon counsel patients preoperatively about the increased possibility of an undiagnosed medial meniscal tear being found at the time of surgery if >6 months has passed from MRI to surgery.

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