Epidemiology, Injury Patterns, and Treatment of Meniscal Tears in Pediatric Patients

A 16-Year Experience of a Single Center

Taylor Jackson,* MD, Peter D. Fabricant,* MD, MPH, Nicholas Beck,* MD, Eileen Storey,* BA, Neeraj M. Patel,* MD, MPH, MBS, and Theodore J. Ganley,*†‡§ MD

Investigation performed at the Department of Orthopaedics, The Children’s Hospital of Philadelphia, Philadelphia, Pennsylvania, USA

Background: Meniscal injuries in children continue to increase, which may be attributable to increasing levels of athletic participation and may be associated with additional injuries or need for additional surgeries.

Purpose: To better understand the patterns of pediatric meniscal injuries by analyzing tear location, morphologic features, and associated injury patterns over a 16-year period.

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

Methods: Pediatric patients were identified and were included in the study if age at the time of initial surgery for meniscal tear was between 5 and 14 years for female patients and 5 and 16 years for male patients. Patients were observed until age 18, and any subsequent surgeries were noted. Demographic factors, tear type and location, associated injuries, and treatment type were analyzed.

Results: Mean patient age at surgery was 13.3 years, and 37% of patients were female. A total of 1040 arthroscopic meniscal surgeries in 880 pediatric patients were evaluated. There were 160 reoperations in 138 patients, representing a reoperation rate of 15%. These included 98 reoperations on the ipsilateral knee in 88 patients and 62 operations for injuries to the contralateral knee in 50 patients; 53% of surgeries were meniscal repair, as opposed to partial meniscectomy, and the most common technique was an all-inside repair (91%). Significant differences were identified between male and female patients. Male patients were more likely to have lateral meniscus (74% vs 65%), posterior horn (71% vs 60%), peripheral (45% vs 30%), and vertical tears (31% vs 21%); concomitant ACL injury (50% vs 40%); and an associated osteochondritis dissecans lesion (7% vs 4%). Female patients were more likely to have medial meniscus (24% vs 17%), anterior horn (25% vs 15%), and degenerative tears (34% vs 26%); discoid meniscus (33% vs 24%); and isolated meniscal tears (47% vs 33%).

Conclusion: This evaluation of a large series of patients has helped characterize injury patterns associated with pediatric meniscal surgeries. Most meniscal tears were repaired (53%) and were associated with additional injuries (62%), especially anterior cruciate ligament injuries (48%). More than 25% of patients had a discoid meniscus. Injury patterns differed significantly between male and female patients.

Keywords: meniscal injury; pediatric; meniscectomy; meniscal repair; epidemiology

Historically, it has been reported that meniscal injuries are much less common in children than in adults.2,22 However, the reported incidence of meniscal tears in children has continued to rise.10,25 Likely due to more intense athletic activity, early sports specialization, year-round competition, and increasing awareness of and screening for these injuries.16,25

Meniscal injuries requiring surgery are treated with partial meniscectomy or meniscal repair.6 In children, a greater portion of the meniscus is vascularized, which makes it more amenable to repair, so repairs tend to have better outcomes than in adults.4 Current treatment goals focus on preservation of meniscus tissue whenever possible. Accordingly, in recent years, a trend has been seen toward repair over partial meniscectomy, especially in younger patients.18,25 The overall incidence of meniscal surgery has increased, and the incidence of meniscal repair has outpaced the rate of increase in meniscectomies (increase of 55% compared with 38%, respectively, between 2007 and 2011).25

Prior studies have reported several risk factors for meniscal injuries, including adolescent age, male sex, type
of sporting activity, higher body mass index (BMI), and
delayed repair of a concomitant anterior cruciate ligament
(ACL) injury.\textsuperscript{6,7,15,19,22,25,26} Because treatment decisions
may be based on injury patterns and associated injuries,
the purpose of this study was to investigate the epidemi-
ological patterns of surgically treated meniscal tears in pedi-
atric patients to better characterize tear location and
morphologic features as well as associated injuries.

METHODS

After gaining institutional review board approval, we per-
formed a retrospective chart review of all pediatric
patients treated surgically at our institution for a menis-
cal tear between January 1, 2000, and December 31, 2015.
Patients were included if their initial surgery occurred
between ages 5 and 14 years for female patients and ages
5 and 16 years for male patients. If a patient fit the age
range for the initial surgery, all subsequent surgeries that
the patient received at our institution before age 18 were
also included in our analysis. Patients who had undergone
trephination or who were originally treated at another
institution were excluded. All surgeries were performed
by 1 of 4 fellowship-trained orthopaedic surgeons, and the
postoperative weightbearing and return to activity proto-
cols were identical.

Age, sex, weight, BMI, discoid meniscus, and associated
injuries were recorded. Operative notes were reviewed to
determine the operative side and meniscus, vascular zone
of tear, tear location and morphologic features, and method
of surgical treatment. The vascular zone of tear was clas-
sified as red-red, red-white, or white-white. Tear location
was grouped into anterior horn, midbody, posterior horn,
intrasubstance delamination, or multiple locations. The
type of tear was classified as horizontal, vertical, bucket
handle, flap, parrot beak, radial, degenerative, oblique, or
complex.

Associated ACL tears, parameniscal cysts, medial colla-
lateral ligament (MCL) injuries, tibial spine fractures,
and osteochondritis dissecans (OCD) lesions were noted.
Surgeries were classified as either partial meniscectomy
or meniscal repair. Repairs were categorized as all-
inside, inside-out, outside-in, or a combination of
approaches. All-inside repairs were performed through
use of the Arthrex Meniscal Cinch Implant. Rasping was
performed at the tear margins. Concomitant ACL recon-
struction or prior surgery on the same knee was also
noted.

Statistical Analysis

Demographic characteristics were summarized by stan-
dard descriptive summaries (eg, means and standard
deviations for continuous variables such as age, percen-
tages for categorical variables such sex). For categorical
variables, a chi-square test was used. Statistical signifi-
cance was set at an alpha level of \( P = .05 \). Analyses were
performed by use of Stata Statistical Software release 14
(StataCorp LP).

RESULTS

Between January 2000 and December 2015, there were
1040 arthroscopic meniscal surgeries performed on 880
patients who met inclusion and exclusion criteria. The
average age of patients at the time of surgery was 13.4
years (range, 5.2-18.0 years), and the sample included
414 (39\%) female patients. A concomitant ACL repair or
reconstruction was performed in 477 surgeries (45\%). A
total of 160 subsequent surgeries were performed in 138
patients after their index operation, representing a reopera-
tion rate of 15\%. These surgeries included 98 reoperations
on the ipsilateral knee in 88 patients and 62 operations for
injuries to the contralateral knee in 50 patients (Table 1).

A summary of the tear characteristics, associated inju-
ries, and surgeries of the entire study group is shown in
Table 2.

Significant differences were identified between male and
female patients. Male patients were more likely to have
lateral meniscal tears (74\% vs 65\%; \( P = .002 \)), posterior
horn tears (71\% vs 60\%; \( P < .001 \)), peripheral tears (45\% vs
30\%; \( P = .001 \)), vertical tears (31\% vs 21\%; \( P = .003 \)),
concomitant ACL tear (50\% vs 40\%; \( P = .001 \)), and an asso-
ciated OCD lesion (7\% vs 4\%; \( P = .038 \)). Female patients
were more likely to have medial meniscal tears (24\% vs
17\%; \( P = .008 \)), anterior horn tears (25\% vs 15\%; \( P < .001 \)),
intrasubstance delamination (22\% vs 15\%; \( P = .014 \)),
degenerative tears (34\% vs 26\%; \( P = .012 \)), discoid meniscus
(33\% vs 24\%; \( P = .001 \)), and isolated meniscal tears (47\% vs
33\%; \( P < .001 \)). A full comparison of male and female
patients is detailed in Table 3.

Patients who had a discoid meniscus were compared with
patients who did not have a discoid meniscus. Patients with
a discoid meniscus had increased rates of anterior horn
tears (25\% vs 16\%; \( P = .004 \)), intrasubstance delamination
(60\% vs 2\%; \( P < .001 \)), horizontal tears (21\% vs 11\%;
\( P < .001 \)), degenerative tears (47\% vs 22\%; \( P < .001 \)),
isolated tears (81\% vs 22\%; \( P < .001 \)), parameniscal cysts

\textsuperscript{6}Address correspondence to Theodore J. Ganley, MD, The Children’s Hospital of Philadelphia, Department of Orthopaedic Surgery, 3401 Civic Center
Boulevard, Wood Building, 2nd Floor, Philadelphia, PA 19104, USA (email: ganley@email.chop.edu).

\textsuperscript{7}Department of Orthopaedics, The Children’s Hospital of Philadelphia, Philadelphia, Pennsylvania, USA.

\textsuperscript{8}Sports Medicine and Performance Center, The Children’s Hospital of Philadelphia, Philadelphia, Pennsylvania, USA.

\textsuperscript{9}Hospital of the University of Pennsylvania, Philadelphia, Pennsylvania, USA.

One or more of the authors declared the following potential conflict of interest or source of funding: P.D.F. has received educational support from Smith &
Nephew and hospitality payments from Medical Device Business Systems. N.M.P. has received educational support from Liberty Surgical. T.J.G. has
received educational support from Arthrex and Liberty Surgical and is a paid associate editor for \textit{The American Journal of Sports Medicine}. AOSSM checks
author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any
liability or responsibility relating thereto.

Ethical approval for this study was obtained from The Children’s Hospital of Philadelphia Institutional Review Board (protocol 15-012614).
TABLE 1
Patient Demographics and Surgical Information

| Value                                      |
|--------------------------------------------|
| Age, y, mean (range)                        | 13.3 (5.2-18.0) |
| Female sex, n (%)                          | 391 (37)        |
| Body mass index, mean (range)              | 22.4 (12.8-60.4) |
| Knee, right/left, n (%)                    | 519/521 (50/50) |
| Total procedures, knees/patients, n        | 1040/880        |
| Total subsequent surgeries, knees/patients, n | 160/138         |
| Ipsilateral surgery                        | 98/88           |
| Contralateral injuries                     | 62/50           |
| Meniscectomy, n (%)                        | 489 (47)        |
| Meniscal repair, n (%)                     | 551 (53)        |
| All inside                                 | 498 (91)        |
| Outside in                                 | 45 (8)          |
| Concomitant anterior cruciate ligament     | 465 (45)        |
| reconstruction, n (%)                      |                 |

TABLE 2
Overall Tear Patterns and Associated Injuries

| Overall Proportion | Reinjury Rate |
|--------------------|---------------|
| Meniscus           |               |
| Medial meniscus    | 20            | 17 |
| Lateral meniscus   | 71            | 7  |
| Both menisci       | 9             | 12 |
| Tear location      |               |
| Anterior horn      | 19            | 13 |
| Midbody            | 30            | 10 |
| Posterior horn     | 67            | 9  |
| Intrasubstance     | 18            | 3  |
| delamination       |               |
| Multiple locations | 27            | 9  |
| Zone               |               |
| Red-red zone       | 40            | 5  |
| Red-white zone     | 54            | 12 |
| White-white zone   | 43            | 13 |
| Tear type          |               |
| Bucket handle      | 24            | 13 |
| Horizontal tear    | 13            | 13 |
| Vertical tear      | 27            | 4  |
| Flap               | 8             | 8  |
| Radial             | 8             | 9  |
| Degenerative       | 29            | 12 |
| Complex            | 8             | 10 |
| Oblique            | 3             | 20 |
| Associated lesion  |               |
| Discoid meniscus   | 27            | 8  |
| Isolated meniscal tear | 38           | 11 |
| Anterior cruciate ligament tear | 46 | 5 |
| Parameniscal cyst  | 2             | 26 |
| Medial collateral ligament injury          | 3             | 10 |
| Tibial spine fracture | 3            | 0  |
| Osteochondritis dissecans lesion           | 6             | 13 |

aValues are expressed as percentages. The percentages may total more than 100% because patients may have met criteria for multiple categories. Bolded P values indicate statistically significant differences between female and male patients (P ≤ .05).

bValues are expressed as proportion (ie, percentage) of patients with repeat surgery on the ipsilateral knee.

DISCUSSION

Although much has been written about meniscal injuries in adults, less is known about injury patterns in pediatric meniscal tears. The purpose of this study was to evaluate a large series of patients to better illustrate trends in pediatric meniscal injury, such as patterns in tear type,
location, and associated injuries, which potentially affect treatment approaches and outcomes. Risk factors for treatment failure include complex and bucket-handle tears, medial meniscal tears, and skeletal immaturity. In our study, an overall reoperation rate of approximately 15% was found, including contralateral meniscal injury. Repeat ipsilateral injury was 11% in female patients compared with 8% in male patients (P = .127) and 10% in patients without a discoid meniscus versus 7% in patients with a discoid meniscus (P = .288). Differences in injury pattern may have affected the rates of treatment failure; however, stricter follow-up criteria are necessary to fully assess treatment failures and outcomes of treatment approaches for specific injuries.

Previous authors have reported a trend toward meniscal repair in younger patients because of a higher success rate compared with adults and the desire to reduce the risk of subsequent osteoarthritis. Despite this, not all tear types are amenable to repair. Tear type may affect treatment success, with greater outcomes for simple tears compared with bucket-handle or complex tears. In our series, male patients had more vertical tears (31% vs 21%; P = .003). Female patients, in contrast, had a higher rate of degenerative tears (34% vs 26%; P = .012), which can be more difficult to repair and have a higher failure rate.

Tear location may also influence treatment decisions. For instance, the most common repair type in our study was an all-inside approach. However, all-inside repairs may be more difficult to perform in anterior horn tears, which were found more often in female patients in our study, and these tears may be more readily treated by an outside-in approach. Additionally, it is not entirely clear whether the healing potential in the medial and lateral menisci differs. Male patients were found to have more posterior horn tears (71% vs 60%; P < .001), which have been reported to have inferior healing potential compared with lesions extending into the middle segments. The vascular zone of meniscal tears has also been shown to be an important factor in healing. Tears of the peripheral third of the meniscus, which were found in a higher proportion of male patients (45% vs 30%; P = .001), have demonstrated greater healing potential than more central tears. However, the healing rate may not differ significantly between tears in the red-red zone compared with those in the red-white zone.

Prior studies have noted a high proportion of isolated injuries in children (71%-100%). However, in our series, associated lesions were observed in the majority of patients, with only 38% of meniscal tears occurring in isolation. The reason for this discrepancy is unclear, although it may be related to the population base or referral pattern at our institution. ACL ruptures were seen in approximately 46% of patients, although more commonly in male patients (50% vs 40%; P = .001). Of note, meniscal repairs during ACL reconstruction have a higher success rate compared with isolated meniscal injuries, perhaps because of increased perfusion in response to ACL rupture or because of altered mechanics of the knee to protect the repair from the conditions that may have led to meniscal injury in the first place. This difference in ACL tears may also help to explain some of the other differences in injury patterns. For instance, ACL injury is more commonly associated with acute lateral meniscal tears, as seen in the male patients in our study.

This study constitutes the largest series of meniscal tears in pediatric patients and provides a comprehensive summary of the meniscal injuries seen at a large, urban, tertiary referral center for sports injuries in children. The large catchment area affords a variety of patient populations, including urban, suburban, and rural. Our patients were consecutive and were not screened in any way other than age.

There are several limitations to this study. The majority of the data were abstracted from medical records and operative notes, and thus we were not able confirm other factors that may have been significant for healing potential. In addition, our follow-up lacked patient-reported outcomes. Because outcome data were limited to the patients who required subsequent surgery at our institution, we were not able to confirm other factors that may have been significant for healing potential. In addition, our follow-up lacked patient-reported outcomes. Because outcome data were limited to the patients who required subsequent surgery at our institution, we were not able to confirm other factors that may have been significant for healing potential.

### TABLE 4
Comparison of Characteristics, Tear Patterns, and Associated Injuries in Patients With or Without Discoid Meniscus

|                        | Discoid Meniscus | No Discoid Meniscus | P     |
|------------------------|------------------|---------------------|-------|
| **Tear location**      |                  |                     |       |
| Anterior horn          | 25               | 16                  | .004  |
| Midbody                | 18               | 35                  | <.001 |
| Posterior horn         | 31               | 81                  | <.001 |
| Intrasubstance delamination | 60          | 2                   | <.001 |
| Multiple locations     | 21               | 29                  | .009  |
| **Zone**               |                  |                     |       |
| Red-red zone           | 42               | 39                  | .681  |
| Red-white zone         | 52               | 54                  | .749  |
| White-white zone       | 41               | 43                  | .754  |
| **Tear type**          |                  |                     |       |
| Bucket handle          | 6                | 30                  | <.001 |
| Horizontal tear        | 21               | 11                  | <.001 |
| Vertical tear          | 6                | 34                  | <.001 |
| Flap                   | 8                | 8                   | .885  |
| Parrot beak            | 7                | 9                   | .377  |
| Radial                 | 6                | 9                   | .335  |
| Degenerative           | 47               | 22                  | <.001 |
| Complex                | 6                | 9                   | .129  |
| Oblique                | 1                | 1                   | .645  |
| **Associated lesion**  |                  |                     |       |
| Isolated meniscal tear | 81               | 22                  | <.001 |
| Anterior cruciate      | 5                | 62                  | <.001 |
| Parameniscal cyst      | 4                | 1                   | .012  |
| Medial collateral      | 0                | 4                   | .002  |
| Ligament injury        |                 |                     |       |
| Tibial spine fracture  | 0                | 4                   | .004  |
| Osteochondritis        | 11               | 4                   | <.001 |
| Dissecans lesion       |                 |                     |       |
| **Repeat surgeries**   |                  |                     |       |
| Reinjury rate          | 7                | 10                  | .288  |

*Values are expressed as percentages. The percentages may total more than 100% because patients may have met criteria for multiple categories. Bolded P values indicate statistically significant differences between patients with and without a discoid meniscus (P ≤ .05).*
able to comment on which patients may have remained symptomatic or which patients benefited most from specific treatments. Patients may have presented to other medical institutions for follow-up care, and clinical data from these visits was not be available for our analysis. Additionally, our study is vulnerable to selection bias inherent in its retrospective design.

CONCLUSION

This study is the largest analysis of meniscal tears in children and gives valuable insight into the injury patterns of different types of meniscal tears seen in skeletally immature patients. Given the study size and breadth of the catchment area, this study may provide the most reliable data on patterns of meniscal tears in this population to date.

REFERENCES

1. Accadbled F, Cassard X, Sales de Gauzy J, Cauhuc JP. Meniscal tears in children and adolescents: results of operative treatment. J Pediatr Orthop B. 2007;16(1):56-60.
2. Bloome DM, Blevins FT, Paletta GA Jr, Newcomer JK, Cashmore B, Turker R. Meniscal repair in very young children. Arthroscopy. 2000;16(5):545-549.
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. Clark CR, Ogden JA. Development of the menisci of the human kneejoint: morphological changes and their potential role in childhood meniscal injury. J Bone Joint Surg Am. 1983;65(4):538-547.
5. Cohen M, Amaro JT, Ejnisman B, et al. Anterior cruciate ligament reconstruction after 10 to 15 years: association between meniscectomy and osteoarthritis. Arthroscopy. 2007;23(6):629-634.
6. Duchman KR, Westermann RW, Spindler KP, et al. The fate of meniscus tears left in situ at the time of anterior cruciate ligament reconstruction: a 6-year follow-up study from the MOON cohort. Am J Sports Med. 2015;43(11):2688-2695.
7. Dumont GD, Hogue GD, Padalecki JR, Okoro N, Wilson PL. Meniscal and chondral injuries associated with pediatric anterior cruciate ligament tears: relationship of treatment time and patient-specific factors. Am J Sports Med. 2012;40(9):2128-2133.
8. Gallacher P, Gilbert R, Kanes G, Roberts S, Rees D. Outcome of meniscal repair prior compared with concurrent ACL reconstruction. Knee. 2012;19(4):461-463.
9. Kalliakmanis A, Zourotos S, Bousgas D, Nikolaou P. Comparison of arthroscopic meniscal repair results using 3 different meniscal repair devices in anterior cruciate ligament reconstruction patients. Arthroscopy. 2008;24(7):810-816.
10. Kramer DE, Micheli LJ. Meniscal tears and discoid meniscus in children: diagnosis and treatment. J Am Acad Orthop Surg. 2009;17(11):698-707.
11. Krych AJ, McIntosh AL, Voll AE, Stuart MJ, Dahm DL. Arthroscopic repair of isolated meniscal tears in patients 18 years and younger. Am J Sports Med. 2008;36(7):1283-1289.
12. Krych AJ, Pitts RT, Dajani KA, Stuart MJ, Levy BA, Dahm DL. Surgical repair of meniscal tears with concomitant anterior cruciate ligament reconstruction in patients 18 years and younger. Am J Sports Med. 2010;38(6):976-982.
13. Magnussen RA, Pedroza AD, Donaldson CT, Flanigan DC, Kaeding CC. Time from ACL injury to reconstruction and the prevalence of additional intra-articular pathology: is patient age an important factor? Knee Surg Sports Traumatol Arthrosc. 2013;21(9):2029-2034.
14. Menge TJ, Dean CS, Chahla J, Mitchell JJ, LaPrade RF. Anterior horn meniscal repair using an outside-in suture technique. Arthrosc Tech. 2016;5(5):e1111-e6.
15. Millett PJ, Willis AA, Warren RF. Associated injuries in pediatric and adolescent anterior cruciate ligament tears: does a delay in treatment increase the risk of meniscal tear? Arthroscopy. 2002;18(9):955-959.
16. Nelson CG, Bonner KF. Inside-out meniscus repair. Arthrosc Tech. 2013;2(4):e453-e460.
17. Noyes FR, Barber-Westin SD. Arthroscopic repair of meniscal tears extending into the avascular zone in patients younger than twenty years of age. Am J Sports Med. 2002;30(4):589-600.
18. Noyes FR, Barber-Westin SD. Treatment of meniscus tears during anterior cruciate ligament reconstruction. Arthroscopy. 2012;28(1):123-130.
19. Pujol N, Panarella L, Selmi TA, Neyret P, Fitzian D, Beausils P. Meniscal healing after meniscal repair: a CT arthrography assessment. Am J Sports Med. 2008;36(8):1489-1495.
20. Roos H, Laurén M, Adalberth T, Roos EM, Jonsson K, Lohmander LS. Knee osteoarthritis after meniscectomy: prevalence of radiographic changes after twenty-one years, compared with matched controls. Arthritis Rheum. 1998;41(4):687-693.
21. Starke C, Kopf S, Petersen W, Becker R. Meniscal repair. Arthroscopy. 2009;25(9):1033-1044.
22. Vaquero J, Vidal C, Cubillo A. Intra-articular traumatic disorders of the knee in children and adolescents. Clin Orthop Relat Res. 2005;432:97-106.
23. Vavken P, Tepolt FA, Kocher MS. Concurrent meniscal and chondral injuries in pediatric and adolescent patients undergoing ACL reconstruction. J Pediatr Orthop. 2018;38(2):105-109.
24. Weiss CB, Lundberg M, Hamberg P, DeHaven KE, Gillquist J. Nonoperative treatment of meniscal tears. J Bone Joint Surg Am. 1989;71(8):811-822.
25. Werner BC, Yang S, Looney AM, Gwathmey FW Jr. Trends in pediatric and adolescent anterior cruciate ligament injury and reconstruction. J Pediatr Orthop. 2016;36(5):447-452.