Outcomes After the Operative Treatment of Bucket-Handle Meniscal Tears in Children and Adolescents

Dennis E. Kramer,*[†] MD, Leslie A. Kalish,[‡] ScD, Daniel J. Martin,[§] BSN, RN, Yi-Meng Yen,[†] MD, PhD, Mininder S. Kocher,[†] MD, MPH, Lyle J. Micheli,[†] MD, and Benton E. Heyworth,[†] MD

Investigation performed at Boston Children's Hospital, Harvard Medical School, Boston, Massachusetts, USA

Background: Bucket-handle meniscal tears (BHMTs), which we define as vertical longitudinal tears of the meniscus with displacement of the torn inner fragment toward the intercondylar notch region, are a well-recognized tear pattern. Optimizing the management of BHMTs in younger patients is important, as preserving meniscal tissue may limit future joint degeneration.

Purpose/Hypothesis: The purpose of this study was to review the patient demographics, clinical presentation, operative details, outcomes, and risk factors for a reoperation associated with operatively treated BHMTs in a pediatric population. We hypothesized that the repair of BHMTs in adolescents would yield a higher reoperation rate than meniscectomy in our population.

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

Methods: A departmental database was queried to identify all patients 19 years or younger who presented with a BHMT and underwent surgery between October 2002 and February 2013. Clinical, radiological, and surgical data were retrospectively collected, and risk factors for a reoperation and persistent pain were assessed in all patients with longer than or equal to 6 months of follow-up.

Results: A total of 280 BHMTs were treated arthroscopically by 1 of 8 sports medicine fellowship–trained surgeons. The mean age at surgery was 15.5 ± 2.5 years (range, 2.1-19.2 years), and most patients were male (177/280; 63%). Most injuries occurred during sports (203/248; 82%) and involved the medial meniscus (157/280; 56%). Concurrent anterior cruciate ligament (ACL) surgery was performed in 103 cases (37%). Meniscal repair was performed in 181 cases (65%) and was more common in younger patients ($P = .01$) and for the lateral meniscus ($P < .001$). Among 185 (66%) cases with longer than or equal to 6 months of adequate follow-up data (which included 126 meniscal repairs [68%]), a meniscus-related reoperation occurred in 45 (24%) cases. A reoperation related to the original BHMT injury or surgery was more common after meniscal repair than after meniscectomy (40/126 [32%] vs 5/59 [8%], respectively) ($P = .001$) and less common with concurrent ACL surgery ($P = .07$), although this was not statistically significant. Among patients injured during sports and with adequate follow-up, all but 1 patient (176/177; 99%) returned to sports; a slower rate of return was seen in those undergoing meniscal repair ($P = .002$) and concurrent ACL surgery ($P < .001$). At final follow-up, 170 of 185 patients (92%) were pain free. For the 15 patients with persistent pain at final follow-up, no identifiable risk factors for persistent pain were identified.

Conclusion: Most BHMTs in younger patients occurred in males and during sports and affected the medial meniscus. Concurrent ACL surgery was indicated in approximately one-third of cases and was associated with a lower reoperation rate and slower return to sports. Two-thirds of patients underwent meniscal repair, over two-thirds of whom did not require a reoperation during the study period, despite the high activity levels in this age group.

Keywords: meniscal repair; bucket-handle tear; pediatric sports medicine; knee; adolescent athletes

Evidence suggests that with increased youth sports participation, meniscal tears in younger patients are becoming more common.[5] Bucket-handle meniscal tears (BHMTs)

represent a severe version of the injury but remain a well-recognized tear pattern seen in this younger population,[12] occurring in approximately 14% of all meniscal tears according to a recent cross-sectional study on 293 pediatric and adolescent patients.[31] For the purposes of this study, we define BHMTs as vertical longitudinal tears of the meniscus with displacement of the torn inner fragment

toward the intercondylar notch region. Optimizing the management of BHMTs is particularly important, however, because they typically involve large portions of the meniscus and are inherently unstable.

While the concept remains incompletely investigated, pediatric meniscal tears are believed to have a greater healing potential compared with adult tears.[9] This is likely multifactorial and may relate to increased vascularity of the developing meniscus, the absence of underlying degenerative changes to the meniscal tissue, and the relative frequency of such repairs occurring in the setting of concurrent anterior cruciate ligament (ACL) reconstruction.[33] In children and adolescents, the preservation of meniscal tissue, when possible, is paramount. Studies have shown that the removal of even a small medial BHMT increases contact stresses by 65% and that debridement of the posterior horn of the medial meniscus increases contact stresses in ways comparable with subtotal meniscectomy.[3,12] Such evidence has led most authors to recommend meniscal repair whenever possible in this young age group,[11,18,23-25,27,28] despite prior studies suggesting lower healing rates for BHMT repair compared with the inherently more stable nondisplaced meniscal tear patterns.[18,27]

While younger age has been associated with higher success rates for meniscal repair,[21,23,34] few studies have specifically analyzed the results of meniscal repair in children, and none, to our knowledge, has focused specifically on BHMT repair. The purpose of this report was therefore to review the demographic features, clinical presentation, operative details, clinical outcomes, and risk factors for a reoperation and for persistent pain in a large younger cohort with operatively treated BHMTs. Given the scope of practice at the study institution, the study population included not only adolescent athletes but also younger children with BHMTs, about which the published literature is sparse.

METHODS

After institutional review board approval, computerized medical records were queried to identify all patients aged ≤19 years who presented with a BHMT and underwent surgery between October 2002 and February 2013 at the study institution, which is a tertiary care pediatric specialty hospital and regional referral center. Patients who had undergone prior meniscal surgery (at our institution or at an outside hospital) and then presented with a BHMT that was treated at our institution were included. Patients were excluded if they did not undergo BHMT surgery at our

institution or if they had an underlying medical or musculoskeletal comorbidity, such as an inflammatory joint disorder, that might confound meniscal healing in a manner not applicable to the general population of active pediatric patients. The resulting search yielded 280 patients, for whom demographic, clinical, and operative variables were retrospectively collected from medical records in all patients. All patients had been treated by 1 of 8 different sports medicine fellowship–trained surgeons.

Patient data recorded included age, sex, body mass index (BMI), mechanism of injury, sport during which the injury occurred, date of injury, date of presentation and date of surgery, preoperative knee range of motion, ability to ambulate on presentation, and history of ipsilateral knee surgery. A "chronic" BHMT was designated for patients with a >90-day interval from injury to surgery. Imaging data, as articulated in formal magnetic resonance imaging (MRI) reports, were reviewed to record meniscal tear features, such as tear location and presence of a discoid meniscus, along with the presence of concurrent injuries, such as ACL tears. Procedural data were collected from operative reports and included date of surgery, surgeon, procedure (categorized as either repair or meniscectomy), and features of the repair, such as technique (categorized as "all-inside," "inside-out," "outside-in," or "hybrid" techniques, with the latter involving the utilization of 2 techniques), number of repair sutures used (with each all-inside meniscal repair implant being considered equivalent to 1 inside-out or outside-in meniscal repair suture), and concurrent procedures performed, including ACL reconstruction.

The decision as to whether to repair the BHMT was made by the operating surgeon at the time of surgery. The study surgeons' common indications for the repair of BHMTs included (1) viable, reducible, adequate-quality meniscal tissue; (2) adequate presumed vascularity of the tear site; and (3) a repairable tear pattern. Patient age, tear chronicity, medial versus lateral meniscus, and presence of concurrent ACL surgery were not formally part of the decision-making process for repair in the study population. In general, reducible BHMTs in the red-red or red-white zone with adequate quality of the torn tissue were repaired. For BHMTs with a concomitant diagnosis of a discoid lateral meniscus, all tears were seen in the red-white or red-red zone, so saucerization/partial meniscectomy of excess central/white-white tissue was performed in association with meniscal repair so as to create a lateral meniscus of similar width and thickness to a normal lateral meniscus. Indications for the treatment and repair of BHMTs did not change over the study time period.

*Address correspondence to Dennis E. Kramer, MD, Division of Sports Medicine, Department of Orthopedic Surgery, Boston Children's Hospital, Harvard Medical School, 300 Longwood Avenue, Boston, MA 02115, USA (email: dennis.kramer@childrens.harvard.edu).

†Division of Sports Medicine, Department of Orthopedic Surgery, Boston Children's Hospital, Harvard Medical School, Boston, Massachusetts, USA.

‡Institutional Centers for Clinical and Translational Research, Boston Children's Hospital, Harvard Medical School, Boston, Massachusetts, USA.

§Boston Children's Hospital, Harvard Medical School, Boston, Massachusetts, USA.

Analyses of reoperations and of self-reported knee pain at the most recent follow-up were restricted to 185 of the 280 study patients (66%) with a minimum of 6 months (time from surgery to last clinic visit) of adequate follow-up data. Among these 185 patients, the mean follow-up was 24.7 ± 20.6 months, and the median was 16.7 months (range, 6.0-97.5 months). The percentage of those who returned to sports was calculated in patients whose initial injury occurred while playing sports and in whose records there was adequate detail of their return-to-sports (RTS) status; this included 177 patients. The evaluation of the time to RTS was further restricted to 165 patients with a known RTS date (or censoring date).

Surgical Technique

Given that the study spanned 10 years and involved techniques described by 8 different surgeons, a variety of surgical repair techniques were pursued. However, arthroscopic surgery was performed in all cases, and in most cases, descriptions were provided of the tear edges being refreshed and the capsule abraded with a meniscal rasp or shaver at the site of repair, with variable use of meniscal rimming or capsular "trephination" with a spinal needle. All-inside repair implants included either Fast-Fix (Smith & Nephew) or RapidLoc (DePuy Synthes) devices. Inside-out repair was performed using standard zone-specific meniscal repair cannulas and double-armed needles with either 2-0 nonabsorbable Ethibond (Ethicon), Ti-Cron (Medtronic), or FiberWire (Arthrex) or absorbable polydioxanone suture (Ethicon). The isolated all-inside technique utilized no additional incisions. Inside-out and outside-in repairs involved a separate incision to retrieve the suture ends and secure the repair to the knee capsule. For cases in which the tear was deemed irreparable, partial meniscectomy was carried out with an attempt to preserve as much meniscal tissue as possible but leave a smooth central edge and stable peripheral attachments. Tears that were deemed irreparable generally had either poor-quality/damaged tear tissue that would not support modern repair techniques or were not reducible or stable at their preinjury location because of chronic deformation of the tear tissue.

Rehabilitation

Postoperative rehabilitation and RTS criteria varied slightly between surgeons and varied over time within individual surgeons themselves. All patients who underwent meniscal repair were given crutches for a period of 2 to 6 weeks of protected weightbearing (either partial weightbearing, 50% body weight, or touch-down weightbearing, 10% body weight) and were placed in a hinged knee brace that restricted knee motion when ambulating for at least 4 weeks, and in most cases 6 weeks, after surgery. Physical therapy was initiated between 2 and 6 weeks after surgery in all patients and continued for at least 2 to 3 months, focusing on knee range of motion and strengthening exercises. Patients who underwent meniscectomy were initially allowed to bear weight as tolerated (100% body weight)

without a brace. RTS was generally considered after 6-week follow-up in the meniscectomy group and after the 3- to 4-month follow-up visits in the repair group but was contingent on the patient regaining full knee motion and strength in both groups.

Statistical Analysis

Percentages were compared with respect to categorical characteristics using the Fisher exact test or Cochran-Armitage trend test. The trend test was used for a number of ordered categorical variables: age ($\leq$10, 11-14, 15-19 years), BMI ($<$18.5, 18.5-24.9, 25.0-29.9, $\geq$30.0 kg/m^2), flexion contracture (loss of extension $<$10°, 10°-24°, $\geq$25°), interval from injury to presentation $\leq$30, 31-90, $>$90 days), and number of repair sutures/implants ($<$3, 3, 4, $>$4). The Kaplan-Meier method was used to estimate the probabilities of a reoperation and RTS over time. Time to a reoperation and time to RTS distributions were compared between groups using the log-rank test. Logistic regression and proportional hazards models were used to evaluate adjusted comparisons of dichotomous and time-to-event outcomes, respectively. We considered covariates that were significant in the unadjusted analyses as a starting point in building these models. *P* values were 2-sided and considered statistically significant at the .05 level. All statistical analyses were conducted with SAS 9.3 software (SAS Institute).

RESULTS

Preoperative characteristics of the 280 patients (mean age, 15.5 ± 2.5 years; range, 2.1-19.2 years) are shown in Table 1. The median time from the date of injury to the date of presentation was 14 days, and the median time from presentation to surgery was 19 days. Seventy patients (27%) were classified as having chronic BHMTs (surgery $>$90 days after injury), usually because of delayed presentation. Patients commonly presented with swelling (83%), but most were ambulatory (71%), and just over one-half (51%) lacked $\geq$10° of knee extension. A discoid lateral meniscus was involved in 11% of cases.

Surgical data are presented in Table 2. While 8 different sports medicine surgeons performed $\geq$1 surgical procedures in the cohort, 1 surgeon (L.J.M.) performed approximately half of the procedures. Approximately two-thirds of patients (65%) underwent meniscal repair. Concurrent injuries occurred in about half of the patients, most commonly ACL tears (n = 120; 43%) and non-BHMTs of the other meniscus (n = 29; 10%). Table 3 examines the association between the rates of repairs performed and patient/injury characteristics. Meniscal repair was significantly less common in older patients and more common in lateral meniscal tears, in nonchronic tears, in patients who presented with an inability to ambulate preoperatively because of an injury, and in those with a shorter duration from injury to presentation.

Regarding the patients' postoperative clinical course, there were no reported surgical complications, such as

TABLE 1
Patient Characteristics[a]

Characteristic	Value
Age at surgery (n = 280), y	15.5 ± 2.5 (2.1-19.2)
≤10	13 (5)
11-14	92 (33)
15-19	175 (63)
Male sex (n = 280)	177 (63)
Body mass index (n = 174), kg/m^2	23.4 ± 4.8 (14.4-40.2)
<18.5	24 (14)
18.5-24.9	92 (53)
25.0-29.9	40 (23)
≥30.0	18 (10)
Prior meniscal repair (n = 274)	19 (7)
Discoid meniscus (n = 280)	30 (11)
Location of tear (n = 280)	
Lateral only	123 (44)
Medial only	155 (55)
Both	2 (1)
Concurrent ACL tear (n = 279)	120 (43)
Chronic tear (>90 days) (n = 259)	70 (27)
Ambulatory on presentation (n = 272)	193 (71)
Swelling on presentation (n = 269)	223 (83)
Extension loss (n = 181), deg	
<10	89 (49)
10-24	60 (33)
≥25	32 (18)
Injury to presentation (n = 253), d	
≤30	170 (67)
31-90	49 (19)
>90	34 (13)
Sports injury (n = 248)	203 (82)
Sport involved[b] (n = 203)	
Basketball	42 (21)
Football	36 (18)
Soccer	35 (17)
Baseball/softball	14 (7)
Ice hockey	10 (5)
Wrestling	10 (5)
Skiing/snowboarding	7 (3)
Biking	7 (3)
Lacrosse	6 (3)
Running	5 (2)
Other	31 (15)

[a]Data are shown as n (%) or mean ± SD (range). ACL, anterior cruciate ligament.
[b]Among those who were injured during sports.

TABLE 2
Surgical Data[a]

Variable	Value
Surgeon (n = 280)	
A	142 (51)
B	49 (18)
C	30 (11)
D	26 (9)
All others (n = 4 surgeons)	33 (12)
Concurrent ACL surgery (n = 280)	103 (37)
Surgery type (n = 280)	
Repair	181 (65)
Meniscectomy	99 (35)
Repair technique[b] (n = 181)	
All-inside	85 (47)
Inside-out	10 (6)
Outside-in	0 (0)
Hybrid (multiple techniques)	86 (48)
No. of sutures/implants[b] (n = 179)	3.4 ± 1.4 (1-10)
<3	45 (25)
3	53 (30)
4	53 (30)
>4	28 (16)

[a]Data are shown as n (%) or mean ± SD (range). ACL, anterior cruciate ligament.
[b]Among those who underwent repair surgery.

last visit 10 months postoperatively. While patients with a low BMI (<18.5 kg/m^2) did have higher rates of pain at the last visit (3/14 [21%] vs 4/67 [6%], 1/24 [4%], and 0/11 [0%], respectively, in higher BMI categories; trend test, $P = .05$), no other variables were identified as risk factors for pain at the last visit. At final follow-up, patients who had undergone meniscectomy versus meniscal repair had similar rates of pain reported at the last visit (6/59 [10%] vs 9/126 [7%], respectively; $P = .57$).

Of the 185 patients with ≥6 months of follow-up, 57 (31%) underwent reoperation, for a variety of reasons. Twelve reoperations occurred for reasons that were not clearly influenced by or related to the prior BHMT (5 meniscal tears in the contralateral compartment of the ipsilateral knee, 4 new ACL tears, 1 plica excision, 1 osteochondritis dissecans lesion, 1 chondral injury). Therefore, 45 of 185 patients (24%) remained for whom the indication for reoperation was directly related to the original BHMT injury or surgery. The corresponding Kaplan-Meier curve for time to a meniscus-related reoperation for all patients with ≥6 months of follow-up is shown in Figure 1. Patients who underwent an initial meniscal repair had a higher rate of meniscus-related reoperations (40/126; 32%) than those who underwent meniscectomy (5/59; 8%) ($P = .001$) (Table 4). The corresponding Kaplan-Meier curve for time to a meniscus-related reoperation for repair versus meniscectomy is illustrated in Figure 2.

In the subgroup of 12 patients who had undergone prior knee surgery with ≥6 months of follow-up, the results were similar: a meniscus-related reoperation was more common in the repair group (3/6; 50%) than the meniscectomy group (1/6; 17%). There were 17 patients in whom an ACL injury

infections, deep venous thromboses, neurovascular injuries, or implant-related complications (outside of the potential association with postoperative pain). Among the 185 patients (including 126 who underwent meniscal repair) with ≥6 months of follow-up, at the time of the last clinic visit, 170 (92%) were pain free, 11 (6%) had mild pain that was improving, and another 4 (2%) had unchanging persistent pain, which required further workup. Further workup in these 4 patients revealed 1 case of patellar instability, 1 patient with patellofemoral pain, and 1 patient with pain and locking, despite a normal postoperative MRI finding, who was observed over time, with no further intervention reported. The fourth patient was lost to follow-up after his

TABLE 3
Meniscal Repair Rate by Patient Characteristic[a]

Characteristic	n (%)	P Value
All patients	181/280 (65)	
Age at surgery, y		.01
≤10	9/13 (69)	
11-14	70/92 (76)	
15-19	102/175 (58)	
Sex		>.99
Male	114/177 (64)	
Female	67/103 (65)	
Body mass index, kg/m^2		.56
<18.5	17/24 (71)	
18.5-24.9	61/92 (66)	
25.0-29.9	24/40 (60)	
≥30.0	12/18 (67)	
Prior meniscal repair		.14
Yes	9/19 (47)	
No	167/255 (65)	
Discoid meniscus		.84
Yes	19/30 (63)	
No	162/250 (65)	
Sports injury		.17
Yes	135/203 (67)	
No	25/45 (56)	
Location of tear		<.001
Lateral only	94/123 (76)	
Medial only	86/155 (55)	
Both	1/2 (50)	
Concurrent ACL tear		.53
Yes	80/120 (67)	
No	100/159 (63)	
Chronic tear (>90 days)		<.001
Yes	25/70 (36)	
No	140/189 (74)	
Ambulatory on presentation		<.001
Yes	108/193 (56)	
No	66/79 (84)	
Extension loss, deg		.12
<10	54/89 (61)	
10-24	41/60 (68)	
≥25	24/32 (75)	
Injury to presentation, d		<.001
≤30	123/170 (72)	
31-90	28/49 (57)	
>90	13/34 (38)	
Surgeon		.10
A	97/142 (68)	
B	28/49 (57)	
C	14/30 (47)	
D	20/26 (77)	
All others	22/33 (67)	
Concurrent ACL surgery		.60
Yes	69/103 (67)	
No	112/177 (63)	

[a]ACL, anterior cruciate ligament.

was identified and not directly treated at the time of BHMT surgery (15 patients with partial ACL tears diagnosed on MRI that were felt to be stable intraoperatively, 1 patient who underwent staged BHMT repair followed by delayed ACL reconstruction, and 1 patient with an ACL graft tear

who did not want revision ACL reconstruction). We performed a subgroup analysis of these 17 patients and found that 6 (35%) underwent meniscectomy and 11 (65%) underwent meniscal repair. Four of the 6 meniscectomies and 8 of the 11 repairs had ≥6 months of clinical follow-up, and in this group, 0 of 4 meniscectomies underwent a reoperation, while 5 of 8 (63%) repairs underwent a reoperation (P = .08). The total reoperation rate for this group was 42% (5/12), which is higher than the reoperation rate of the entire cohort (24%).

Associations between the meniscus-related reoperation rate and other characteristics are shown in Table 4. Concurrent ACL surgery was associated with a lower meniscus-related reoperation rate (P = .07), although this was not statistically significant. In the adjusted analysis using proportional hazards regression, the associations between time to a meniscus-related reoperation and type of meniscal surgery (repair vs meniscectomy) and concurrent ACL surgery were similar to unadjusted analyses (P = .001 and P = .06, respectively). Among the meniscal repair methods, those using the all-inside technique had lower meniscus-related reoperation rates than those using the inside-out or hybrid technique (P = .01). All other factors examined, including tear chronicity, discoid menisci, and surgeon volume, were not significantly associated with meniscus-related reoperations.

Findings for the 45 patients who underwent a meniscus-related reoperation included a recurrent BHMT in 24 patients (53%), a non-BHMT retear of the same meniscus in 16 patients (36%), and arthrofibrosis in 5 patients (11%). At the time of the reoperation, the procedures performed included partial meniscectomy in 26 patients, revision meniscal repair in 14 patients, including 7 of the 24 patients with recurrent BHMTs, and arthroscopic lysis of adhesions in 5 patients. Of these 45 patients, 25 had at least 6 months of follow-up after the first reoperation, and 7 (28%) of these patients underwent a second reoperation, which was also related to the initial BHMT. Ten patients who underwent revision meniscal repair at the time of the reoperation had at least 6 months of follow-up after their reoperation, and 5 of 10 (50%) required a second reoperation (meniscectomy for a second retear).

Of the 70 patients with chronic tears, 25 (36%) were repaired during the index operation. Of these 25 patients with chronic tears that were repaired, 20 had at least 6 months of follow-up after the index repair. Five of these 20 (25%) required a reoperation for meniscus-related reasons, and 1 required a reoperation for arthrofibrosis.

All but 1 of 177 patients (99%) whose original injuries were related to sports and who were evaluable for the RTS endpoint were able to return to sports during the follow-up period. Of 165 patients with data on the timing of RTS, about two-thirds did so within 6 months and >95% within 12 months. There was a longer time to RTS among those undergoing meniscal repair than among those undergoing meniscectomy (P = .002) (Figure 3). At 6 months after surgery, 79% of the meniscectomy group had returned to sports compared with 63% of the repair group (P = .002). RTS rates were also lower at 6 months after surgery in patients aged <15 years (61% able to return; P = .02) and in those
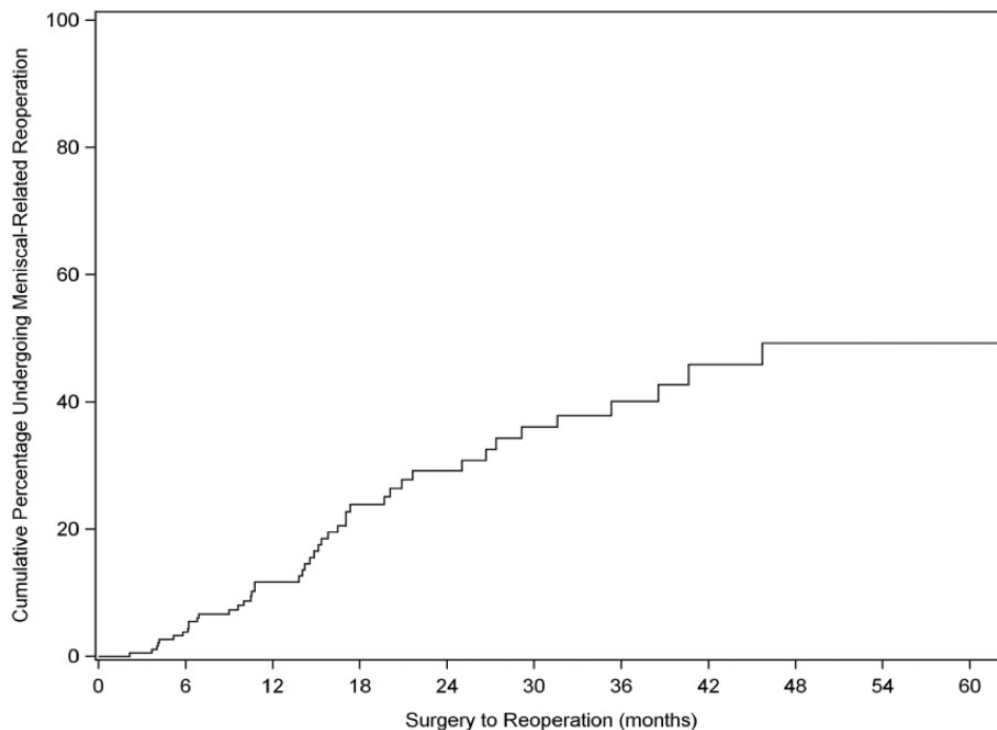
Figure 1. Kaplan-Meier curve indicating the probability of a meniscus-related reoperation over time for all procedures.

who underwent concurrent ACL surgery (44%; $P < .001$), although this was obviously confounded by the ACL injury. In a predictive model with type of meniscal surgery and concurrent ACL surgery, both predictors remained highly significant ($P < .001$ for both) for delayed RTS.

DISCUSSION

The current study on the operative treatment of a large pediatric and adolescent cohort of BHMTs may provide novel insight into the demographic characteristics of the pediatric subpopulation that experiences this injury and their natural history after surgical management. Most injuries occurred during sports such as basketball, football, and soccer and more commonly involved the medial meniscus. Meniscal repair was performed in approximately two-thirds of cases, more commonly in younger patients and for the lateral meniscus. Concurrent ACL surgery was common and was associated with a lower reoperation rate. The overall rate of reoperations was 24%, which was expectedly higher after meniscal repair (32%) than partial meniscectomy (8%). RTS was common but was slower in the meniscal repair and concurrent ACL surgery groups, which was also an anticipated result because of the imposition of a longer rehabilitation protocol on these groups compared with patients in the partial meniscectomy group.

There are limited published data reported on the repair of BHMTs in the adolescent population. Mintzer et al[21] reported on 29 adolescents who underwent meniscal repair but did not include any BHMT repair. Other studies have included a subset of adolescents with BHMT repair among

a larger population of patients undergoing meniscal repair.[1,2,17,18,21,23,31] Krych et al[17] reported on 45 isolated meniscal repairs in adolescents with a mean age of 16 years, which included 29 BHMT repairs. The authors reported clinical success in 68% of displaced bucket-handle tears at a mean follow-up of 5.8 years,[17] which is remarkably similar to the current study, despite their having a significantly smaller study population. Seventeen of their repairs (38%) failed at a mean time of 17 months (range, 3-61 months) and required a reoperation. In another series, Krych et al[18] included 17 BHMTs in a series of 99 meniscal repairs performed in association with ACL reconstruction in patients aged ≤18 years. They reported an overall clinical success rate of 74%, which dropped to 59% for BHMT repair.[18] In the current series, the group of patients with BHMTs and concurrent ACL surgery may have had a relatively higher "clinical success" rate in that 82% did not undergo a reoperation related to their meniscal tear, but factors related to the retrospective nature of both studies preclude direct comparisons.

Other studies have reported on the results of BHMT repair in a mostly adult population.[10,11,25,28,30] Feng et al[11] evaluated 64 patients with a mean age of 25 years (range, 14-47 years) who underwent second-look arthroscopic surgery and found an 82% rate of complete healing, 7% rate of partial healing, and 10% rate of failure at a mean of 25 months postoperatively. However, all but 1 repair in the Feng et al[11] series were performed in conjunction with ACL reconstruction. O'Shea and Shelbourne[25] similarly found an 89% healing rate on second-look arthroscopic surgery (55% complete, 34% partial) in BHMT repairs in

TABLE 4
Meniscus-Related Reoperation Rate in Patients With ≥6 Months of Follow-up[a]

Characteristic	n (%)	P Value	Characteristic	n (%)	P Value
All patients	45/185 (24)		Ambulatory on presentation		.21
Age at surgery, y		.15	Yes	28/126 (22)	
≤10	3/11 (27)		No	14/54 (26)	
11-14	12/69 (17)		Extension loss, deg		.62
15-19	30/105 (29)		<10	14/61 (23)	
Sex		.40	10-24	14/46 (30)	
Male	23/108 (21)		≥25	5/21 (24)	
Female	22/77 (29)		Injury to presentation, d		.70
Body mass index, kg/m²		.15	≤30	28/111 (25)	
<18.5	2/14 (14)		31-90	6/33 (18)	
18.5-24.9	19/67 (28)		>90	4/21 (19)	
25.0-29.9	2/24 (8)		Surgeon		.09
≥30.0	3/11 (27)		A	32/98 (32)	
Prior meniscal repair		.77	B	3/35 (9)	
Yes	4/12 (33)		C	4/18 (22)	
No	40/170 (24)		D	5/17 (29)	
Discoid meniscus		>.99	All others	1/17 (6)	
Yes	4/18 (22)		Concurrent ACL surgery		.07
No	41/167 (25)		Yes	15/84 (18)	
Sports injury		.37	No	30/101 (30)	
Yes	35/132 (27)		Surgery type		.001
No	5/29 (17)		Meniscectomy	5/59 (8)	
Location of tear		.30	Repair	40/126 (32)	
Lateral only	17/82 (21)		Repair technique[b]		.01
Medial only	28/103 (27)		All-inside	13/58 (22)	
Concurrent ACL tear		.28	Inside-out or hybrid	27/68 (40)	
Yes	20/96 (21)		No. of sutures/implants[b]		.30
No	25/88 (28)		<3	7/34 (21)	
Chronic tear (>90 days)		.21	3	17/41 (41)	
Yes	8/46 (17)		4	12/35 (34)	
No	30/123 (23)		>4	4/15 (27)	

[a]ACL, anterior cruciate ligament.
[b]Among those who underwent repair surgery.

patients with a mean age of 22 years (range, 14-53 years) performed in a staged manner before ACL reconstruction.

The 4 youngest patients in our series ranged from ages 2 to 6 years. Three of these patients (aged 2, 3, and 5 years) presented with mechanical symptoms including block to extension, difficulty with ambulation, and knee locking. All patients underwent MRI and surgical treatment that documented and confirmed the diagnosis of a discoid lateral meniscus with a displaced BHMT that was torn and flipped into the intercondylar notch region. The 6-year-old patient presented with an acute traumatic BHMT of the medial meniscus (MRI documented and surgically confirmed) after an all-terrain vehicle accident.

Interestingly, a significant percentage of our patients presented with chronic BHMTs, of which about one-third underwent meniscal repair. Importantly, when this group of selectively chosen patients was compared against those with more acute tears, tear chronicity was not associated with a higher rate of reoperation. This supports the notion that certain chronic tears may be repairable in the younger population with expected success rates similar to acute tears. This particular finding is critical to pediatric and adult orthopaedic surgeons alike, who may struggle with

surgical decision making in the setting of a chronic BHMT in a young person. While tear chronicity has traditionally been perceived as being inversely proportional to the healing rate, these data may support attempts toward meniscal preservation in such a scenario.

We selected 3 months as the differentiation point between acute and chronic injuries, in accordance with previous studies.[19,26,32] A recent study on adults also reported good clinical outcomes (based on MRI, clinical examination, and patient-reported outcomes) and a low (17%) failure rate (using Barrett et al's[4] predefined clinical criteria such as the absence of joint-line pain) after the repair of chronic BHMTs of the medial meniscus at 2- to 9-year follow-up in 24 patients with a mean age of 23 years (range, 15-40 years).[10] Those authors defined chronic tears as ≥2 months from the time of injury to the time of surgery, but their mean time between injury and surgery was 10 months (range, 2-60 months).[10]

While the current study found a lower reoperation rate with the all-inside technique versus other techniques, this likely reflects the features of tear pattern variation, which was not assessed because of the lack of details in some of the operative notes regarding the tear pattern. We
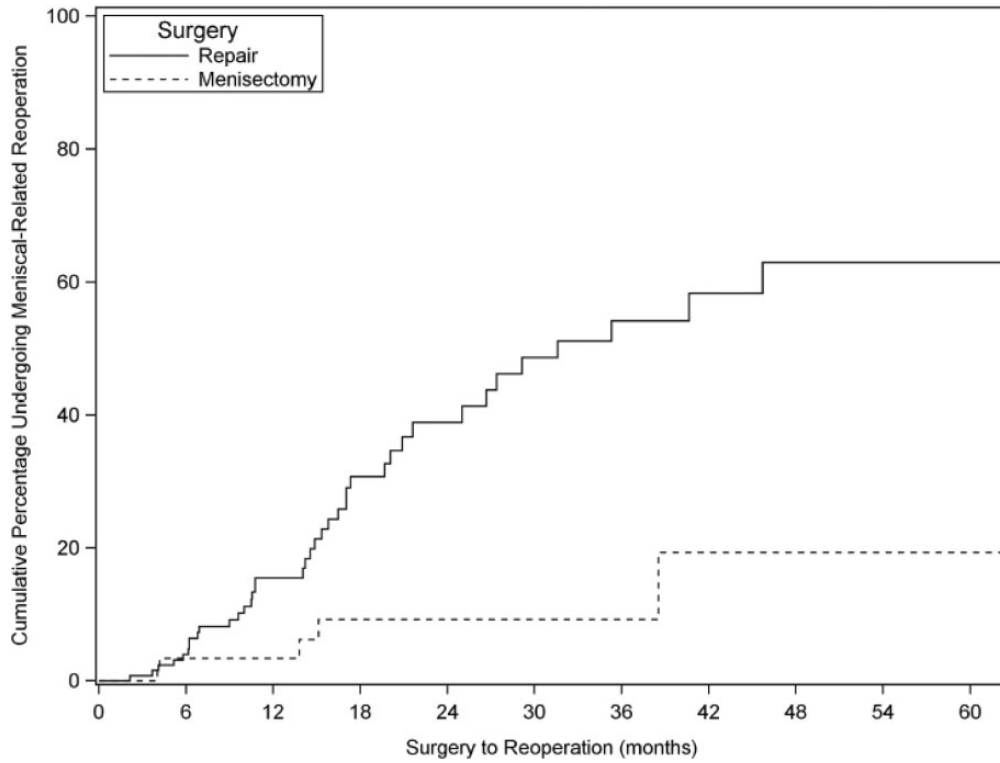
Figure 2. Kaplan-Meier curve indicating the probability of a meniscus-related reoperation over time for meniscal repair versus meniscectomy.
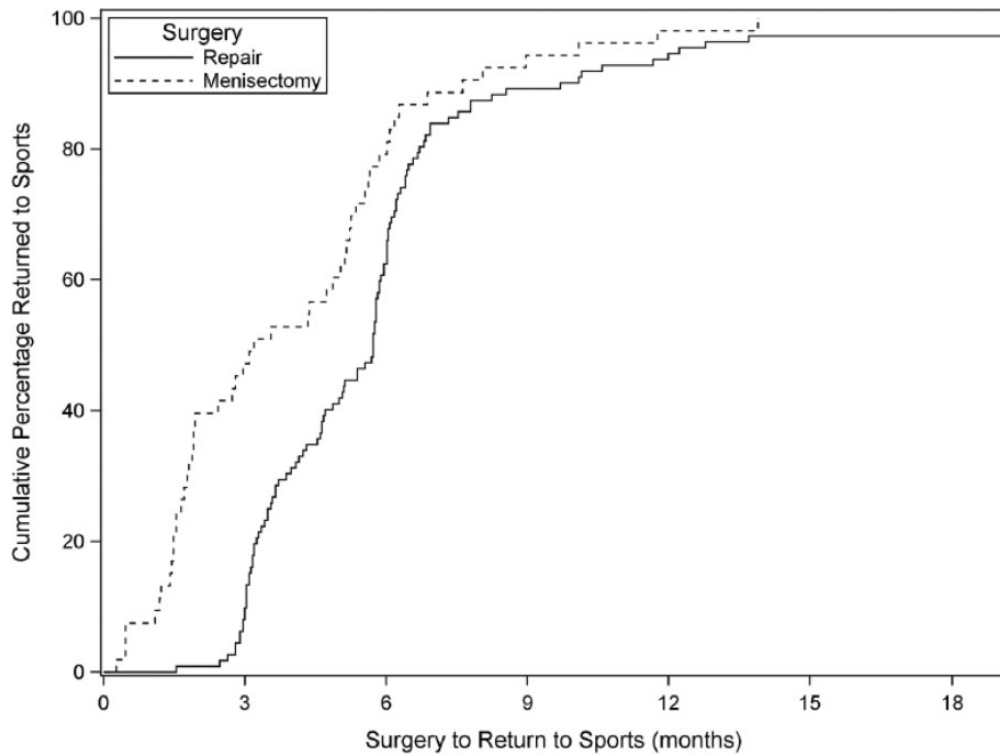

Figure 3. Kaplan-Meier curve indicating the probability of patients returning to sports after surgery over time for meniscal repair versus meniscectomy.

hypothesized that simpler tear patterns may have been more likely to undergo all-inside repair than complex tears but were unable to investigate this because of the retrospective nature of the study. Interestingly, a recent systematic review of 19 (mostly adult) studies[13] compared the effectiveness and complications of inside-out repair versus all-inside repair for isolated meniscal tears, which included BHMTs. The authors found similar failure rates (17%-19%) and subjective outcomes for both techniques. More nerve symptoms were associated with inside-out repair, and more implant-related complications were identified with the all-inside technique.[13]

Concurrent ACL surgery was associated with a lower meniscus-related reoperation rate in our series, which is similar to findings from many other studies.[10,14,15,23,35,36] In addition, we found no statistically significant effect of meniscal laterality (medial vs lateral) on the reoperation rate or residual pain, similar to other authors[16] but different from studies that demonstrated higher healing rates in the lateral meniscus.[7,8,14,18] Interestingly, our data also did not show a relationship for either surgeon volume or repair of a discoid BHMT on postoperative outcomes studied.

While most authors recommend the repair, when possible, of a BHMT, few studies have directly compared the results of meniscectomy and meniscal repair. It is unclear if the repaired meniscus resumes normal function. Shelbourne and Dersam[29] reported slight clinical improvement in the meniscal repair group for the repair of lateral BHMTs in the setting of ACL reconstruction. However, Shelbourne and Carr[28] also questioned whether BHMTs ever resume normal function, as many patients in their series remained symptomatic despite healing. Meniscectomy, however, has been shown to have potentially devastating consequences in younger patients. Long-term data indicate that partial meniscectomy may accelerate the incidence of osteoarthritis, which could adversely affect not only the athletic participation but also the basic activity level and daily ambulatory function of this younger age group.[3,6,12,20,22] In 1 study with a 5-year follow-up after partial or total meniscectomy in 20 children with a mean age of 15 years, 75% of patients were symptomatic, 80% demonstrated early osteoarthritis, and 60% were dissatisfied with their results.[20] Future studies are necessary to determine whether meniscal preservation through repair will lower the long-term rate of the development of osteoarthritis in our young population.

Half of the small number of patients who underwent revision meniscal repair of a previously repaired BHMT required a third operation. However, the potential consequences of meniscectomy described above make the treatment decision of revision repair versus meniscectomy difficult. The "cup half full" perspective is that even if primary repair of a BHMT fails, approximately half may be able to be re-repaired with a reasonable short-term clinical result. Clearly, patient and family counseling is necessary before a reoperation to clarify options and expectations in these clinical scenarios.

The limitations of this study include its retrospective nature, relatively short clinical follow-up, lack of postoperative subjective and functional outcomes, and varied patient and tear characteristics. While several surgeons performed the procedures over a 10-year period, all were fellowship-trained pediatric sports medicine specialists using standard techniques. An assessment of healing via postoperative MRI or second-look arthroscopic surgery was not routinely conducted on asymptomatic patients, and reporting of complications or reoperations in our series was dependent on follow-up within the study institution, notably with a mobile adolescent population. However, the sheer volume of the study population relative to those in previous studies provided some understanding of important demographic and clinical factors as well as trends in outcomes after both partial meniscectomy and repair.

CONCLUSION

Most BHMTs in adolescents occurred in male patients and during sports and affected the medial meniscus slightly more than the lateral meniscus. A concurrent ACL tear was a common feature of the presentation of BHMTs and concurrent ACL surgery was associated with a lower reoperation rate but expectably slower RTS. Meniscal preservation in the form of repair was pursued for two-thirds of our adolescent population, which, despite having a higher reoperation rate than partial meniscectomy, was successful in more than two-thirds of cases. Meniscal preservation may also be considered for a chronic BHMT, as these had similar reoperation rates to the general study population.

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