Revision and Conversion to Arthroplasty Are Low Among Adolescents Undergoing Meniscal Allograft Transplantation Using the Bridge-In-Slot Technique at Midterm Follow-Up

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Purpose: To report midterm outcomes after primary medial and lateral meniscal allograft transplantation (MAT) with fresh-frozen allografts implanted with the bridge-in-slot technique in the adolescent patient population. **Methods:** Adolescent patients less than 18 years old at the time of primary MAT from 1999 to 2016 were retrospectively identified. International Knee Documentation Committee (IKDC) subjective form, Lysholm, and Knee Injury and Osteoarthritis Outcome Score (KOOS) subscales scores were collected before surgery and at 1-year, 2-year, and a minimum 5-year follow-up. Thresholds for achieving clinically significant outcomes were calculated, and the proportion of patients achieving minimal clinically important difference (MCID), patient-acceptable symptomatic state (PASS), and substantial clinical benefit (SCB) was determined. Meniscus reoperation (partial, subtotal, or total meniscectomy, repair, or failure) and failure (revision MAT or conversion to arthroplasty) rates were determined. **Results:** Forty-four (female n = 33; male n = 11) of 62 identified patients met inclusion criteria and were followed for a mean of 9.5 ± 3.8 years (range, 5.0-17.7). Lateral MAT was performed in most patients (n = 35/44 [80%]). Isolated MAT was performed in 27 (61%) patients. Common concomitant procedures included osteochondral allograft transplantation (32%), autologous chondrocyte implantation (18%), and anterior cruciate ligament reconstruction (14%). MCID, PASS, and SCB were achieved by patients at a minimum 5-year follow-up for IKDC (62%; 76%; 31%), Lysholm (62%; 79%; 23%), and KOOS questionnaires (Pain [65%; 81%; 41%], Symptoms [58%; 81%; 47%], Activities of Daily Living [53%; 77%; 35%], Sport [86%; 75%; 50%], and Quality of Life [59%; 81%; 59%]), respectively. Fourteen patients (32%) underwent reoperation at an average of 5.0 ± 4.3 years (range, 0.8-14.0) after MAT. Three (7%) patients met criteria for failure, requiring revision MAT an average of 3.8 ± 1.1 years (range, 2.8-4.9) after transplantation. No patients underwent arthroplasty. Overall survival free from failure at 1, 2, 5, and 10 years was 100%, 100%, 93%, and 93%, respectively. At the time of final follow-up, 80% of patients reported satisfaction with their current physical status. **Conclusion:** Primary MAT in adolescent patients resulted in significant and durable functional improvements at mid- to long-term follow-up. At an average of 9.5 years after surgery, meniscal reoperation rate was 32% whereas graft survival free of revision MAT was 93%. Adolescents undergoing MAT demonstrated similar functional outcomes and graft survivability when compared to available adult MAT literature. **Level of Evidence:** Level IV, retrospective case series.

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The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: A.B.Y. reports personal fees from Arthrex, Joint Restoration Foundation, Medwest Associates, Stryker Corporation, and Olympus America. M.H. reports personal fees from Smith & Nephew, Medwest Associates, and Medical Device Business Services. D.D. reports personal fees from Southern Edge Orthopaedics, Smith & Nephew, and Linvatec Corporation. E.J.C. reports personal fees from Great Lakes Orthopaedics. B.J.C. reports grants from Arthrex; and personal fees from Arthrex, Acumed, Aesculap Biologics, Anika Therapeutics, Vericel Corporation, Terumo BCT, Pacira Pharmaceuticals, Ossio, Bioventus, Endo Pharmaceuticals, and GE Healthcare; is a past president of the Arthroscopy Association of North America, editor-in-chief of Operative Techniques in Sports Medicine, and a board member of the International Cartilage Repair Society. All other authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

Received December 21, 2022; accepted July 31, 2023.

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0749-8063/221668/$36.00
https://doi.org/10.1016/j.arthro.2023.07.059

Youth meniscus injuries are increasingly common and may be attributable to increases in organized athletic competition, sport specialization, and injury awareness.[1-5] Meniscus injuries can occur in isolation or in conjunction with other injuries such as anterior cruciate ligament (ACL) tears, focal chondral injuries, and tibial fractures.[1,5] Discoid menisci have also been identified as risk factors for meniscus injury.[6,7]

Current treatment guidelines for meniscus injuries recommend that meniscal tissue be preserved whenever feasible, because subtotal or total meniscectomy has been shown to increase contact forces and negatively impact long-term joint health.[8,9] Meniscus preservation is especially relevant in adolescents because this population will place greater demand on the knee joint over a longer period of time than older adults.[4,10] Although the meniscus is thought of as a relatively avascular structure, meniscus tissue is richly vascular at birth and maintains some degree of vascularity to allow for growth before regressing into the periphery by adulthood.[11,12] Therefore adolescent menisci are generally thought to be more amenable to surgical repair, given better blood flow and healing potential.[13,14] Longitudinal vertical and bucket-handle tears are fairly common meniscal injury patterns and can routinely be managed with arthroscopic repair. However, radial, oblique, horizontal, and complex tears are historically thought to fare poorly after repair and often go on to partial meniscectomy.[1,14,15]

Even after conservative partial meniscectomy, outcomes in youth populations are suboptimal. Long-term outcome studies have found that up to 80% of children and adolescents have evidence of degenerative changes as early as 5 years after meniscectomy, whereas 75% and 60% report persistent pain and dissatisfaction with clinical outcomes, respectively.[9,16] Previously, there was hesitation to indicate meniscal allograft transplantation (MAT) in children and adolescents because of concerns about allograft longevity and the unknown effects of transplantation on skeletal development.[4,17] Initial short-term outcome reports have demonstrated consistent improvement in pain, function, and activity levels, suggesting that MAT is a viable treatment option for children and adolescents.[6,10,18] However, the majority of available outcomes are limited by short-term follow-up. Studies with increased follow-up are needed in this patient population to evaluate for durability of clinical benefit, as well as allograft survivorship.

The purpose of this investigation was to report midterm outcomes after primary medial and lateral MAT with fresh-frozen allografts implanted with the bridge-in-slot technique in the adolescent patient population. The authors hypothesized that at a minimum 5-year follow-up, MAT in the adolescent population would demonstrate significant improvements in patient-reported outcomes, as well as allograft survivorship similar to reported rates of previous studies for adult populations.

Methods

Patient Population

Local Institutional Review Board approval was obtained before study initiation. A prospectively collected database from a single institution was retrospectively reviewed for patients who underwent primary MAT with a single surgeon between 1999 to 2016. Patients who underwent any concomitant procedures at the time of MAT were included. Inclusion criteria included the following: (1) primary MAT for symptomatic meniscal deficiency for which conservative treatment had failed, (2) age 18 years or younger at the time of primary surgery, and (3) minimum 5-year follow-up. Patient-reported outcomes and an updated surgical history were collected to calculate reoperation and failure rates. Subsequent meniscal reoperation was defined as partial, subtotal, or total meniscectomy, meniscal repair, or MAT failure. MAT failure was defined as revision MAT or conversion to unicompartmental or total knee arthroplasty.[19]

Surgical Technique

All MATs were performed by the senior author, a fellowship-trained orthopaedic surgeon who operates a high-volume joint preservation clinical practice. For both medial and lateral MAT, the senior author used fresh-frozen, nonirradiated meniscal grafts fixated in bone troughs using the bridge-in-slot technique.[20-22] As previously described, the Pollard method was used for allograft matching.[23] If present, the senior author will also treat associated pathology or abnormalities at the time of MAT, such as lower extremity malalignment, focal chondral defects, or ligamentous instability. Realigning osteotomy was typically performed concomitantly with MAT if patients had $\geq$5 degrees of mechanical axis malalignment on coronal radiographs. At the time of transplantation, the meniscus is then debrided to a bleeding peripheral rim of 1 to 2 mm. The anterior and posterior horns are subsequently resected. To prepare the meniscal slot (approximately 8 mm wide and 10 mm deep), an initial slot guide is first made using a 4.5 mm burr. In the presence of an open physis, intraoperative imaging can confirm the protection of the physis in relation to the bone trough. A guide pin is then placed using an over-the-top style slot guide. A 7 mm reamer is used to over-ream the guide pin, and the slot is refined using a box cutter, dilating rasp, and a bone-cutting shaver using a dovetail technique. When possible, the back wall of the tibia is preserved to help prevent posterior displacement, but at times it may be necessary to remove to improve the overall seating of the allograft. While the tibial slot is being prepared, the allograft is thawed in normal saline solution on the sterile back surgical table.

The meniscal allograft bone bridge is created using reciprocating saw between the anterior and posterior horn of the donor allograft. A 0-polydioxanone suture is then placed through the posterior third of the meniscus to assist with allograft insertion into the joint and positioning within the tibial slot. We do not generally use transosseous sutures within the slot. With the knee in flexion, a knotless suture anchor (SwiveLock; Arthrex, Naples, FL) is placed anteriorly on the far side of the meniscal allograft to secure the allograft bone bridge to the recipient tibial tunnel. For circumferential fixation, approximately 8 to 10 vertical mattress sutures are placed using an inside-out technique (FiberWire; Arthrex). In one case where medial MAT and concomitant ACL reconstruction was performed, a modified bone block technique was used. In this patient, the bone block was split and the posterior block was shuttled into the joint after femoral fixation of the ACL graft. The posterior block was then fixated with transosseous sutures, inside-out repair was performed, and finally transosseous sutures were used to fixate the anterior horn. After satisfactory meniscus placement and stability are confirmed, incisions are closed in standard fashion.

Rehabilitation Protocol

Between postoperative weeks 0 and 2, patients begin heel touch weightbearing with crutches and wear a hinged knee brace locked in full extension for all activities. Exercise during this time is limited to heel slides, quad sets, patellar mobs, and straight leg raises. Knee flexion is also limited from 0° to 90° when non-weightbearing. During weeks 2 to 8 after surgery, patients maintain heel touch weightbearing with crutches, with progression to full weightbearing by 6 to 8 weeks. When non-weightbearing during this timeframe, the knee immobilizer should continue to be worn and locked at 0° to 90° but can be removed for sleep. Bracing can be discontinued at 8 weeks. Additionally, patients should continue range-of-motion exercises as tolerated between weeks 2 to 8, with no restriction thereafter. Closed chain exercises are slowly introduced, with gradual return to functioning activities at 12 to 20 weeks. Patients are allowed to return to full activity by 5 months after surgery once cleared by the attending physician.

Data Collection

International Knee Documentation Committee (IKDC) subjective form, and Knee injury and Osteoarthritis Outcome Score (KOOS) subscales (Pain, Symptoms, Activities of Daily Living, Sport, and Quality of Life), and Lysholm scores were collected before surgery and at 1-year, 2-year, and at a minimum 5-year follow-up. All procedures before index surgery related to the operative knee, concomitant procedures, as well as the incidence of reoperations and failures were recorded. Postoperative satisfaction was assessed with a “yes” or “no” answer to the question, “Considering all the activities you have during your daily life, your level of pain, and your functional impairment, do you consider that your current state is satisfactory?”

Statistical Analysis

Descriptive statistics for binomial variables were reported as frequencies (proportions) and continuous variables were reported as means with standard deviations. Mann-Whitney U, Wilcoxon signed rank, and paired or unpaired *t*-tests were used when comparing preoperative and postoperative patient-reported outcome measures (PROMs). Shapiro-Wilk testing determined normality of the data. Fisher’s exact test and χ^2 analysis were used for comparing categorical variables. Thresholds for achieving clinically significant outcomes (CSOs) were established using a distribution method for minimal clinically important difference (MCID).[24] Patient-acceptable symptomatic state (PASS) and substantial clinical benefit (SCB) were derived using an anchor-based method.[24] A receiver operating characteristic curve with an area under the curve of less than 0.7 and 0.8 was considered an acceptable and excellent predictor, respectively. Kaplan-Meier survival analysis was used to determine survival probabilities. Cox proportional hazards modeling was used to evaluate associations between preoperative and intraoperative variables with failure. P values < .05 were considered statistically significant. Statistical analyses were performed using RStudio Version 4.1.1 (RStudio, Boston, MA).

Results

Demographics

Sixty-two patients met study inclusion criteria during initial database review. Forty-four of the 62 identified patients (71%) agreed to participate in the study and were consented before data analysis. The remaining 18 patients who underwent MAT during the timeframe were unable to be reached for follow-up (n = 16) or refused study participation (n = 2). The mean age of included patients was 16.1 ± 1.9 years, and 33 patients were female (75%) (Table 1). The mean BMI was 23.4 ± 3.4 kg/m^2 and patients were followed up for a mean of 9.5 ± 3.8 years (range, 5.0-17.7). Medial meniscus transplantation was performed in 9 patients (20%) and lateral meniscus transplantation was performed in 35 patients (80%). Eleven patients (25%) were diagnosed

Table 1. Demographics and Intraoperative Variables

Characteristic	Postoperative Status: None, N = 30*	Reop, N = 11*	Fail, N = 3*	*P* Values: None vs Reop†	None vs Failure†
Sex (female)	20 (67%)	11 (100%)	2 (67%)	**.039**	>.999
Age (yr)	16.3 ± 1.1	15.9 ± 1.2	15.5 ± 2.2	.303	.594
BMI	24.1 ± 2.9	21.6 ± 4.3	23.4 ± 3.6	.072	.810
Lateral meniscus transplanted	24 (80%)	8 (73%)	3 (100%)	.660	>.999
Concomitant procedure	21 (81%)	5 (45%)	1 (33%)	.051	.136
OCA	12 (40%)	1 (9%)	1 (33%)	.127	>.999
ACI	5 (17%)	3 (27%)	0 (0%)	.660	>.999
HTO	1 (3%)	0 (0%)	0 (0%)	>.999	>.999
DFO	4 (13%)	0 (0%)	0 (0%)	.559	>.999
MFX	3 (10%)	0 (0%)	0 (0%)	.551	>.999
ACLR	5 (17%)	1 (9%)	0 (0%)	>.999	>.999

ACI, autologous chondrocyte implantation; ACLR, anterior cruciate ligament reconstruction; BMI, body mass index; DFO, distal femoral osteotomy; HTO, high tibial osteotomy; MFX, microfracture; OCA, osteochondral allograft transplantation; Reop, reoperation.

Reoperations consist of any surgery related to the transplanted meniscus (arthroscopic evaluation due to meniscal symptoms, debridement, meniscectomy) but excludes revision meniscal allograft transplantation. Failure defined as revision meniscal allograft transplantation or conversion to unicompartmental or total knee arthroplasty.

*Categorical variables listed as n (% of respective cohort); continuous variables listed as mean ± SD.

†Fisher's exact test; Wilcoxon rank sum test.

with a discoid lateral meniscal tear and were referred to the senior author for management for symptoms refractory to meniscectomy. All included patients had undergone a prior meniscectomy at a mean time 1.2 ± 0.9 years (range, 0.1-3.9) prior to MAT. Nine (20%) and 2 (4.5%) patients were previously treated with anterior cruciate ligament reconstruction (ACLR) or osteochondritis dissecans fixation before primary MAT, respectively. In 27 (61%) patients, a concomitant procedure was performed, the most common being osteochondral allograft transplantation (n = 14/44, 32% [lateral formal condyle {LFC}, n = 13; medial femoral condyle, n = 1]), autologous chondrocyte implantation (n = 8/44, 18% [medial femoral condyle, n = 1; LFC, n = 6; patellar and LFC, n = 1]) and ACLR (n = 6/44, 14%) (Table 1).

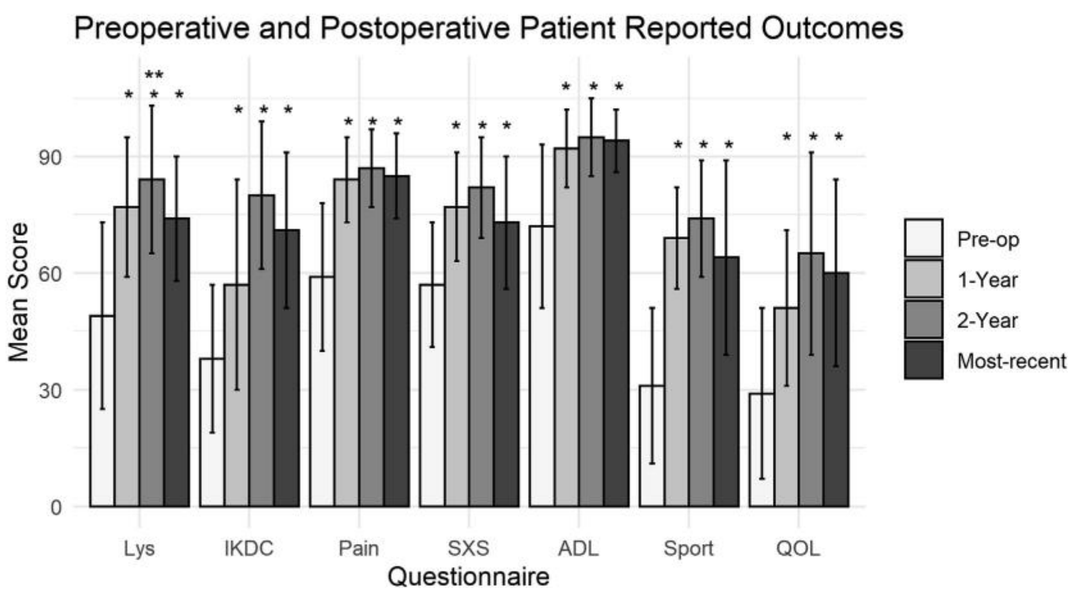

Fig 1. Preoperative and postoperative patient-reported outcome measures after primary meniscal allograft transplantation were collected. Mean scores for Lysholm (Lys), International Knee Documentation Committee (IKDC) subjective form, and Knee Injury and Osteoarthritis Outcome Score (KOOS) subscale questionnaires increased at 1-year, 2-year, and most-recent follow-up timepoints when compared to baseline scores. ADL, activities of daily living; QOL, quality of life; SXS, symptoms. Error bars represent standard deviation. Asterisk indicates a mean significantly greater compared to preoperative scores ($P < .05$). Double asterisk indicates a significant increase compared to most-recent scores ($P = .048$).

Table 2. Patient-Reported Outcome Measures in Patients Free of Graft Failure at 5-Year Minimum Follow-Up

Characteristic	Baseline	1-Year	*P* value	2-Year	*P* Value	Most Recent	*P* Value
Lysholm	49 ± 24	77 ± 18	.005	84 ± 19*	.001	74 ± 16	.018
IKDC	38 ± 19	57 ± 27	.042	80 ± 19	<.001	71 ± 20	.005
ADL	72 ± 21	92 ± 10	.014	95 ± 10	.001	94 ± 8	.006
Pain	59 ± 19	84 ± 11	.016	87 ± 10	<.001	85 ± 11	.001
QOL	29 ± 20	51 ± 20	.001	65 ± 26	.007	60 ± 24	.006
Sport	31 ± 20	69 ± 13	.003	74 ± 15	.021	64 ± 25	.002
SXS	57 ± 16	77 ± 14	.001	82 ± 13	<.001	73 ± 17	.004

ADL, activities of daily living; IKDC, International Knee Documentation Committee subjective form; KOOS, Knee Osteoarthritis and Outcome Score; QOL, quality of life; SXS, symptoms.

Patient-reported outcome scores at preoperative, 1-year, 2-year, and a minimum 5-year follow-up. Questionnaires included are Lysholm, IKDC subjective form, and KOOS subscales (activities of daily living; Pain; QOL; Sport; SXS). Significance determined by Wilcoxon signed-rank testing. Continuous variables listed as mean ± SD.

*Significantly greater (P = .048), compared to most-recent follow-up.

Patient-Reported Outcome Measures

Significant improvements in all patient-reported outcome measures for each postoperative timepoint analyzed (1-year, 2-year, and most-recent follow-up) were appreciated when compared to preoperative scores ($P < .05$, Fig 1, Appendix Table A1). Of note, although Lysolm scores at final follow-up were significantly improved when compared to baseline (P = .018), a significant decrease was observed in Lysholm scores when comparing final follow-up outcome scores to scores at 2 years after surgery (P = .048). This was an isolated finding, as no other PROMs demonstrated a significant decline in scores between the short-term and most recent follow-up timepoints (Table 2).

Table 3. Clinically Significant Outcomes at Five-Year Minimum Follow-Up

Characteristic	N = 41*
MCID	
IKDC	10/16 (62%)
Lysholm	8/13 (62%)
Pain	11/17 (65%)
Symptoms	11/19 (58%)
Sport	12/14 (86%)
ADL	9/17 (53%)
QOL	10/17 (59%)
PASS	
IKDC	25/33 (76%)
Lysholm	23/29 (79%)
Pain	26/32 (81%)
Symptoms	26/32 (81%)
Sport	24/32 (75%)
ADL	24/31 (77%)
QOL	25/31 (81%)
SCB	
IKDC	5/16 (31%)
Lysholm	3/13 (23%)
Pain	7/17 (41%)
Symptoms	9/19 (47%)
Sport	7/14 (50%)
ADL	6/17 (35%)
QOL	10/17 (59%)

ADL, activities of daily living; IKDC, International Knee Documentation Committee subjective form; KOOS, Knee Injury and Osteoarthritis Outcome Score; MCID, minimal clinically important difference; PASS, patient acceptable symptomatic state; QOL, quality of life; SCB, substantial clinical benefit.

*Patients were included if they did not fail before 5-year follow-up.

Clinically Significant Outcomes

Three patients met criteria for failure before 5-year follow-up and were excluded from CSO analysis. Thresholds for achieving CSOs were calculated, with all PROMs achieving an area under the curve (AUC) ≥ .700 for PASS (Appendix Table A1). Conversely, only the Lysholm form had an acceptable AUC for SCB (AUC = .750). The proportions of patients achieving CSOs were calculated (Table 3). A majority of patients achieved MCID and PASS for each PROM analyzed. SCB for the KOOS QOL form was achieved by a majority of patients (N = 10/17, 59%). At the time of final follow-up, however, 80% of patients stated they were satisfied with their overall postoperative condition.

Reoperations and Failures

Fourteen patients (32%) underwent a reoperation on the ipsilateral knee at an average 5.0 ± 4.3 years (range, 0.8-14.0) after MAT. Eleven patients underwent a reoperation and did not subsequently meet criteria for failure (Table 1). The most common reoperation was partial meniscectomy (n = 9), followed by subtotal meniscectomy (n = 2), total meniscectomy (n = 2), and meniscal repair (n = 1). Two patients who had a subsequent total meniscectomy underwent revision MAT at a mean 2.68 years after meniscectomy. The remaining 2 patients who received a subtotal meniscectomy have not undergone subsequent surgeries at a mean 6.2 years of follow-up. An additional 3 patients underwent non-meniscal reoperations, including synovectomy and lysis of adhesions (n = 1), articular cartilage debridement (n = 1), and osteochondral allograft transplantation (n = 1) at a mean 1.3 years after MAT.

Female patients were significantly more likely to undergo a meniscal reoperation (P = .039).

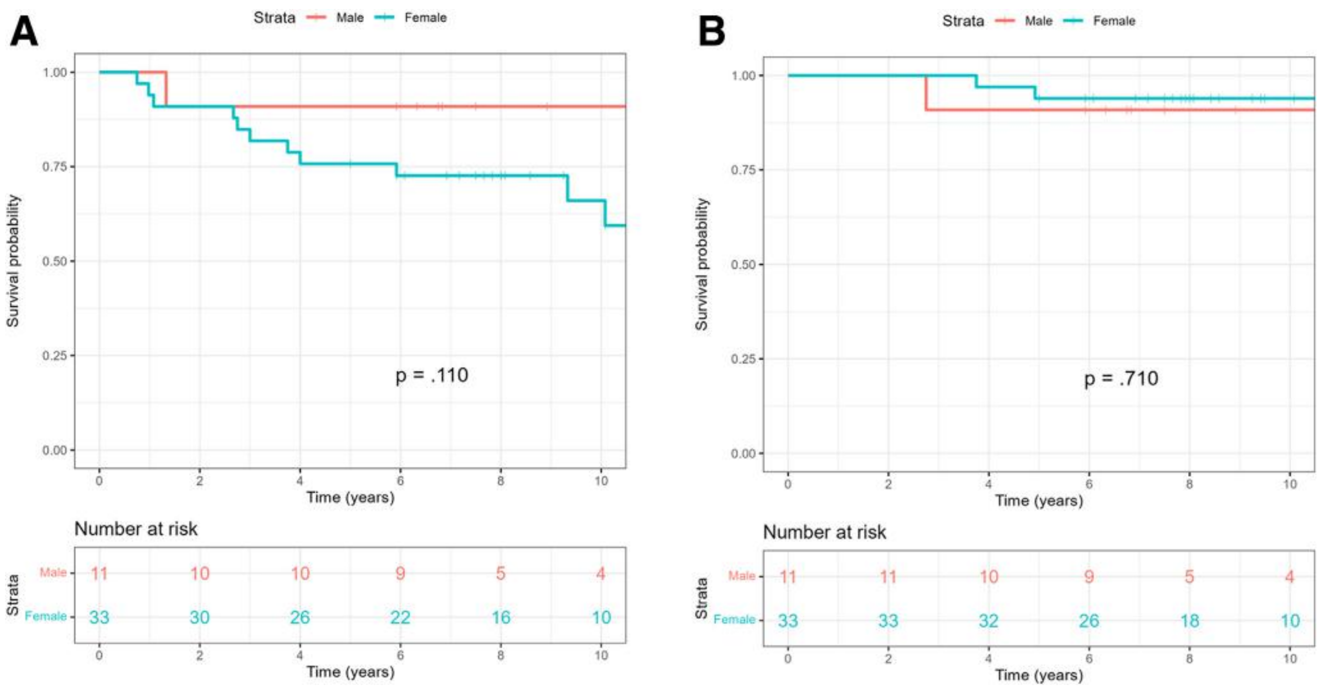

Fig 2. Kaplan-Meier survival analysis for (A) meniscal reoperation and (B) graft failure were stratified by sex. Overall probability of being reoperation-free at 1, 2, 5, and 10 years were 96%, 91%, 80%, 71%, respectively. Survival free from failure at 1, 2, 5, and 10 years were 100%, 100%, 93%, 93%, respectively. Log-rank testing demonstrated no significant difference in survival distributions between male and female sex for reoperation and failure (*P* = .110 and .710, respectively).

Kaplan-Meier estimations were performed to assess probability of requiring a reoperation. Overall probability of being reoperation-free at 1, 2, 5, and 10 years was 96%, 91%, 80%, 71%, respectively (Fig 2A). Three (7%) patients met criteria for failure at an average of 3.8 ± 1.1 years (range, 2.8-4.9) after transplantation. All three patients were treated with revision MAT. No patients were converted to arthroplasty or received subsequent realignment osteotomy. MAT survival free from failure at 1, 2, 5, and 10 years was 100%, 100%, 93%, 93%, respectively (Fig 2B). Log-rank testing found no difference in survival free from failure based on sex (*P* = .710), meniscus laterality (*P* = .485), or concomitant surgery of any kind (*P* = .234), including corrective alignment procedures (*P* = .696), ACLR (*P* = .525), or cartilage procedures (*P* = .718). Log-rank testing also found no difference in reoperation rates based on sex (*P* = .110), meniscus laterality (*P* = .910), or concomitant surgery of any kind (*P* = .118), including corrective alignment procedures (*P* = .324), ACLR (*P* = .483), or cartilage procedures (*P* = .765). Reoperations and failure data stratified by meniscal laterality is present in Appendix Table A2.

Discussion

The primary findings of this study were Lysholm, IKDC subjective form, and all KOOS subscale outcome measures were significantly improved in the short-term postoperative period and were sustained at final, midterm follow-up. Additionally, a majority of patients achieved MCID and PASS for all questionnaires examined at midterm follow-up. The survivorship free from reoperation and failure at 5 years after surgery was 80% and 93%, respectively. The results demonstrate that MAT is a safe, effective treatment option for indicated patients in this select population even when performed at the time of other major concomitant procedures. This study is of important clinical relevance given the overall lack of substantial literature documenting MAT outcomes in the adolescent patients at midterm follow-up.

Previous data regarding meniscal allograft transplantation are largely based on outcomes in adult populations.[25,26] Recent meta-analyses of adult MAT outcomes literature indicate that MAT survivability ranges between 85.8% and 89.2%, depending on compartment laterality, at 5 years and 74% at 10 years after surgery.[25,26] Despite the bevy of literature on MAT outcomes in adults, only a handful of case series studying MAT within adolescent populations exist, and those available are limited by short-term follow-up. Nevertheless, reported outcomes demonstrate a level of functional success and survivability consistent with the findings in adult populations and the results of this case series.

A previous clinical report of adolescent patients who underwent MAT performed by the senior author was conducted in 2016. This study included 32 patients (mean age 15.4 years) at a minimum 2-year follow-up.[6] Similar to the present study, a significant proportion of patients (48%) underwent a concomitant procedure at the time of MAT. Substantially fewer patients underwent meniscal reoperation (6%) or any reoperation (22%) when compared to the present study (32% and 39%, respectively). Additionally, no revision MATs were performed in the 2016 article by Riboh et al.,[6] whereas 3 were performed at a mean 3.8 years after primary MAT in the present study.

More recently in 2021, Smith et al.[4] completed a review of a public database of 49 children's hospitals to evaluate the epidemiology of MAT procedures in patients 25 years old or younger. The final cohort included 67 patients with a mean age of 16.6 years, although final follow-up timeframes were not reported. The most common concomitant procedures performed at time of MAT were ACLR (n = 11 [16.4%]) and either osteochondral graft or autologous chondrocyte implantation (n = 6 [9%]). The authors reported a reoperation rate of 18% (n = 12) among the included patients, with reoperations occurring a median of 224 days (range, 47-949 days) after transplantation. However, because the data were sourced from a public registry, direct patient follow-up could not be obtained, which prevented analysis of both clinical outcomes and additional treatment that may have occurred at a facility outside of the database.

In a study of 23 patients undergoing MAT at a median age of 17, Middleton et al.[10] reported that all patient-reported outcomes measured had significantly improved at most-recent follow-up (mean, 3.8 years) when compared to preoperative baseline. None of the 23 patients in the cohort met criteria for failure, defined as graft removal or meniscectomy resulting in functional deficiency.[10] Additionally, Kimura et al.[27] reported successful outcomes in a small cohort of 6 pediatric patients at a mean follow-up of 5.2 years using meniscal allografts donated from adult patients undergoing total knee arthroplasty. No failures were reported in this cohort, defined more conservatively as graft removal, complications, or subsequent surgery.[27] With failure definitions varying widely between studies, it is hard to compare failure rates. The present study reported a 7% failure rate because of revision MAT, which is comparable to adult studies at similar time points.[22]

Chondral concomitant procedures were performed with notable frequency in the present study, as well as in the studies published by both Riboh et al.[6] and Smith et al.[4] It is worth noting that previous studies have demonstrated that concomitant chondral procedures did not affect outcomes in MAT.[23] Similar results were redemonstrated in the present investigation because log-rank testing found no difference in survivability or reoperation based on concomitant surgery of any kind (Fig 2). The variable closest to significance for association with reoperations was sex ($P = .110$). There was a significantly greater frequency of female patients who underwent reoperation and did not subsequently fail ($P = .039$). At a minimum 2-year follow-up, Frank et al., using the same database as the present study, found no increase in reoperations between male and female patients younger than 40 years ($P = .902$).[28] Female patients were, however, more likely to undergo subsequent revision MAT ($P = .003$). The association between sex on reoperation rates has not been seen in other, large database studies.[29,30]

Additionally, a majority of cases in the present study were of lateral MAT (80%). In a 2018 meta-analysis of midterm and long-term studies, Bin et al.[25] found no differences in failure between lateral and medial MAT. However, superior Lysholm and pain scores were observed for lateral MAT. The study was limited, however, by a small sample size because only 3 studies reported PROMs (42 medial and 51 lateral MATs). Furthermore, various allograft fixation and processing techniques were included. More recent studies with fresh-frozen allografts using bone fixation have not appreciated similar differences in PROMs.[31,32] Last, the present study used the bone bridge using the trough or bridge-in-slot technique, which is one option among many others (such as soft tissue fixation, bone plugs, keyhole bone bridge).[33,34] Optimal fixation techniques remain debated because comparisons are difficult because of frequency of concomitant procedures, different patient populations, and surgeon experience.

The present study reported that 11 patients (25%) were diagnosed with a discoid lateral meniscal tear as the primary indication for MAT. These tears have been shown to increase the risk of early-onset osteoarthritis and subsequent total knee arthroplasty (TKA).[7] In 2016, Ramme et al.[35] demonstrated that in young women aged between 25-30 with torn discoid lateral menisci, MAT reduced pain, improved function, and was more effective at delaying TKA when compared to partial meniscectomy. Partial meniscectomy required TKA at an average of 12.5 years, compared to 17.3 years in the subset of patients that underwent MAT. However, MAT was more resource intensive, requiring $14,470 of care-related expenditure compared to $10,430 in partial meniscectomy patients.[35] The findings of Ramme et al.,[35] in conjunction with the outcomes of the present study, suggest that MAT can serve as a viable treatment modality in the management of discoid lateral meniscal tears.

Last, patients undergoing MAT may return to competitive and recreational sports as tolerated, which has been previously reported by our group.[36,37] Although the present study did not examine return-to-sport data, it is crucial to have comprehensive discussions about these data to establish expectations with adolescent patients. In the senior author's practice, patients are informed about the high risk of retear if they return to pivoting sports, which may necessitate subsequent surgeries. Ultimately, thorough preoperative discussions that focus on patient-specific goals help patients assess the risk associated with a traumatic meniscal retear and the need to limit their involvement in sports.

Overall, this study illustrates that midterm outcomes of MAT in this cohort of adolescent patients significantly increases in functional outcomes, with low probability of graft failure. However, further research of MAT outcomes in this demographic remains warranted. A primary area of future study should evaluate the chondroprotective effects of MAT in adolescents through imaging studies, especially in light of inconclusive results in studies of adult populations.[38] Long-term reporting of MAT outcomes remains necessary to better elucidate overall treatment prognosis and consequences of the procedure.

Limitations

This study is not without limitations. Performance bias may be evident because the cohort of patients in this study was treated by a single surgeon who operates a high-volume MAT practice. Therefore the outcomes in this cohort may not be generalizable for adolescent patients undergoing primary MAT at other institutions. Given the overall follow-up rate of 71%, a possible transfer bias is present, because the 18 patients who were not included may differ in outcomes from patients in the present study, thus potentially confounding the results. Additionally, 61% of patients in this cohort experienced concomitant procedures, which may impact functional outcomes, reoperation rates, and graft survivability compared to patients who are treated with isolated MAT. The present study was also confined to a retrospective analysis of functional scores and reoperations. Advanced imaging of each patient at final follow-up to evaluate chondral or meniscal status of the knee was not routinely obtained. Therefore conclusions regarding about physeal safety after MAT are limited.[6]

Conclusion

Primary MAT in adolescent patients resulted in significant and durable functional improvements at mid- to long-term follow-up. At an average of 9.5 years after surgery, meniscal reoperation rate was 32% whereas graft survival free of revision MAT was 93%. Adolescents undergoing MAT demonstrated similar functional outcomes and graft survivability when compared to available adult MAT literature.

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Appendix

Appendix Table A1. Thresholds for Achieving Clinically Significant Outcomes

	Threshold	SN	SP	AUC
MCID				
IKDC	11.5			
Lysholm	11.9			
KOOS				
Pain	12.0			
Symptoms	11.1			
Sport	13.2			
QOL	18.4			
ADL	13.9			
PASS				
IKDC	54.2	95.0	100.0	0.995
Lysholm	61.0	89.4	100.0	0.964
KOOS				
Pain	72.2	100.0	100.0	0.999
Symptoms	57.1	89.4	75.0	0.822
Sport	42.5	94.7	100.0	0.999
QOL	46.8	94.7	100.0	0.986
ADL	88.1	89.5	100.0	0.973
SCB				
IKDC	30.6	60.0	85.7	0.686
Lysholm	24.5	75.0	71.4	0.750
KOOS				
Pain	16.5	83.3	50.0	0.583
Symptoms	17.6	66.7	62.5	0.562
Sport	40.0	40.0	100.0	0.667
QOL	9.4	50.0	71.4	0.464
ADL	22.5	40.0	87.5	0.575

ADL, activities of daily living; AUC, area under the curve; IKDC, International Knee Documentation Committee; KOOS, Knee Injury and Osteoarthritis Outcome Score; MCID, minimal clinically important difference; PASS, patient acceptable symptomatic state; QOL, quality of life; SCB, substantial clinical benefit; SN, sensitivity; SP, specificity.

Thresholds for MCID, PASS, and SCB were calculated using both revision and primary meniscal allograft transplantation cohorts. Patient-reported outcome measures analyzed included Lysholm, subjective IKDC, and KOOS subscales.

Appendix Table A2. Reoperation and Failure Data Stratified by Meniscal Laterality

Variable	Lateral*	Medial*	*P* Value
Meniscal reoperation type			>.999†
None	24 (69%)	6 (67%)	
Partial meniscectomy	7 (20%)	2 (22%)	
Total Meniscectomy	3 (9%)	1 (11%)	
Repair	1 (3%)	0 (0%)	
Time to reoperation	4.3 ± 4.1	8.0 ± 4.6	.291‡
Failure	3 (9%)	0 (0%)	>.999†

*Categorical variables listed as n (% of respective medial or lateral meniscal allograft transplantation group); continuous variables listed as mean ± standard deviation.

†Fisher's exact test.

‡Wilcoxon rank-sum test.