Journal Pre-proof

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

Kyle R. Wagner, MD, Joshua T. Kaiser, MD, Ryan A. Quigley, MD, Mario Hevesi, MD PhD, Dhanur Damodar, MD, Zachary D. Meeker, BS, Eric J. Cotter, MD, Adam B. Yanke, MD PhD, Brian J. Cole, MD MBA

PII: S0749-8063(23)00662-X

DOI: https://doi.org/10.1016/j.arthro.2023.07.059

Reference: YJARS 58681

To appear in: *Arthroscopy: The Journal of Arthroscopic and Related Surgery*

Received Date: 21 December 2022

Revised Date: 30 July 2023

Accepted Date: 31 July 2023

Please cite this article as: Wagner KR, Kaiser JT, Quigley RA, Hevesi M, Damodar D, Meeker ZD, Cotter EJ, Yanke AB, Cole BJ, Revision and Conversion to Arthroplasty are Low Among Adolescents Undergoing Meniscal Allograft Transplantation Using the Bridge-In-Slot Technique at Midterm Follow-Up, *Arthroscopy: The Journal of Arthroscopic and Related Surgery* (2023), doi: https://doi.org/10.1016/j.arthro.2023.07.059.

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

Running Title: Meniscal Allograft Transplants in Adolescents

Authors: Kyle R. Wagner[1] MD, Joshua T. Kaiser[1] MD, Ryan A. Quigley[1] MD, Mario Hevesi[1] MD PhD, Dhanur Damodar[1] MD, Zachary D. Meeker[1] BS, Eric J. Cotter[1] MD, Adam B. Yanke[1] MD PhD, Brian J. Cole[1] MD MBA

[1]Midwest Orthopaedics at Rush University Medical Center, Chicago, IL, USA

Approved by Rush Institutional Review Board – ORA# 22050101-IRB01

Corresponding Author:

Brian J. Cole MD MBA

Associate Chairman and Professor, Department of Orthopedics

Chairman, Department of Surgery, Rush OPH

Section Head, Cartilage Restoration Center at Rush

Rush University Medical Center

1611 W Harrison, Suite 300

Chicago, IL 60612

312-432-2381

Brian.cole@rushortho.com

Email Addresses:

Joshua T. Kaiser: joshkaiser28@gmail.com

Kyle R. Wagner: kylewagner85@gmail.com

Ryan A. Quigley: rq0007@mix.wvu.edu

Mario Hevesi: hevesimario@gmail.com

Dhanur Damodar: dhanurdamodar@gmail.com

Zachary D. Meeker: zmeeker8@gmail.com

Eric J. Cotter: eric.cotter21@gmail.com

Adam B. Yanke: adam.yanke@rushortho.com

Social Media Handles:

Kyle R. Wagner: kylewagner85@gmail.com

Twitter: @KyleWagsMD

Instagram: kylewagsss

Joshua T. Kaiser: joshkaiser28@gmail.com

Instagram: joshkaiser28

Ryan A. Quigley: rq0007@mix.wvu.edu

Mario Hevesi: hevesimario@gmail.com

Twitter: @MarioHevesiMD

Instagram: mariohevesimd

Dhanur Damodar: dhanurdamodar@gmail.com

Zachary D. Meeker: zmeeker8@gmail.com

Eric J. Cotter: eric.cotter21@gmail.com

Adam B. Yanke: adam.yanke@rushortho.com

Twitter: @AdamYankeMD

Instagram: adamyankemd

Brian J. Cole

Twitter: @BrianColeMD

Instagram: brianjcolemd

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

Abstract:

Purpose: To report midterm outcomes following 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 1999-2016 were retrospectively identified. International Knee Documentation Committee (IKDC) subjective form, Lysholm, and Knee Injury and Osteoarthritis Outcome Score (KOOS) subscales scores were collected preoperatively and at 1-year, 2-years, and a minimum of 5-years 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 (OCA) (32%), autologous chondrocyte implantation (ACI) (18%), and anterior cruciate ligament reconstruction (ACLR) (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. Eleven patients (25%) underwent reoperation at an average of 5.9 ± 4.5 years (range: 0.8 – 14.0) following MAT. Three (7%) patients met criteria for failure, requiring revision MAT an average of 3.8 ± 1.1 years (range: 2.8-4.9) post-transplant. 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 postoperatively, meniscal reoperation rate was 25% while 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

Introduction:

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, as 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 prior to 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 following repair and often go on to partial meniscectomy.[1,14,15]

Even following 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 five years post-meniscectomy, while 75% and 60% report persistent pain and dissatisfaction with clinical outcomes, respectively.[9,16] Previously, there was hesitation to indicate MAT in children and adolescents due to 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 following primary medial and lateral meniscal allograft transplantation (MAT) with fresh-frozen allografts implanted with the bridge-in-slot technique in the adolescent patient population. The authors hypothesized that at a minimum five-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 prior to study initiation. A prospectively collected database from a single institution was retrospectively reviewed for patients who underwent primary MAT with a single surgeon between 1999-2016. 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, or meniscal repair. 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 orthopedic surgeon who operates a high-volume joint preservation clinical practice. For both medial and lateral MAT, the senior author utilized fresh-frozen, non-irradiated 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 ≥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 utilizing 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 in order to improve the overall seating of the allograft. While the tibial slot is being prepared, the allograft is thawed in normal saline 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 (PDS) 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 employ transosseous sutures within the slot. With the knee in flexion, a knotless suture anchor (SwiveLock, Arthrex, Inc., 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, Inc., Naples, FL). 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 performed, and finally transosseous sutures were used to fixate the anterior horn. After confirming satisfactory meniscus placement and stability, incisions are closed in standard fashion.

<u>Rehabilitation Protocol</u>:

Between postoperative weeks 0-2, patients begin heel touch weight bearing with crutches hinged knee brace locked in full extension for all activities. Exercise during this time period is limited to heel slides, quad sets, patellar mobs, and straight leg raises. Knee flexion is also limited from 0 to 90 degrees when non-weight bearing. During weeks 2-8 postoperatively, patients maintain heel touch weight bearing with crutches, with progression to full weight bearing by 6-8 weeks. When non-weight bearing during this timeframe, the knee immobilizer should continue to be worn and locked at 0-90 degrees 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 2-8, 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 post-operatively 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 (SXS), Activities of Daily Living (ADL), Sport, and Quality of Life (QOL), and Lysholm scores were collected preoperatively and at 1-year, 2-year, and at a minimum 5-year follow up. All procedures prior to 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, paired or unpaired t-tests were utilized when comparing preoperative and postoperative patient-reported outcome measures. Shapiro-Wilk testing determined normality of the data. Fisher's Exact test was used if frequencies for variables were less than 5 and Chi-square analysis was 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 (ROC) curve with an area under the curve (AUC) of less than 0.7 and 0.8 was considered an acceptable and excellent predictor, respectively. Kaplan-Meier survival analysis was utilized to determine survival probabilities. Cox proportional hazards modelling was utilized to evaluate associations between preoperative and intraoperative variables with failure. P-values less than 0.05 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 prior to 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 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 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 two (4.5%) patients were previously treated with anterior cruciate ligament reconstruction (ACLR) or osteochondritis dissecans fixation prior to primary MAT, respectively. In 27 (61%) patients, a concomitant procedure was performed, the most common being osteochondral allograft transplantation (OCA) (n = 14/44, 32% [lateral formal condyle (LFC), N = 13; medial femoral condyle (MFC), N = 1), autologous chondrocyte implantation (ACI) (n = 8/44, 18% [MFC, N = 1; LFC, N = 6; patellar and LFC, N = 1]) and ACLR (n = 6/44, 14%) (Table 1).

<u>Patient-Reported Outcomes</u>

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, Figure 1, Supplemental Table 1). Of note, while 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 postoperatively (p = .048). This was an isolated finding as no other PROM demonstrated a significant decline in scores between the short-term and most recent follow-up timepoints.

<u>Clinically Significant Outcomes</u>

Three patients met criteria for failure prior to 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 (Supplemental Table 1). 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 subjective IKDC form was achieved by a minority of patients (N = 5/16, 31%). At the time of final follow-up, however, 80% of patients stated they were satisfied with their overall postoperative condition.

<u>Reoperations and failures</u>

Fourteen patients (32%) underwent a reoperation on the ipsilateral knee at an average 5.0 ± 4.3 years (range: 0.8 – 14.0) following 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 (n=2) and total meniscectomy (n=2), and meniscal repair (n=1). Two patients who had a subsequent total meniscectomy underwent RMAT at a mean 2.68 years following meniscectomy. The remaining two patients who received a subtotal meniscectomy have not undergone subsequent surgeries at a mean 6.2 years of follow-up. An additional three patients underwent non-meniscal reoperations including synovectomy and lysis of adhesions (n=1), articular cartilage debridement (n=1), and OCA (n=1) at a mean 1.3 years following MAT.

Female patients were significantly more likely to undergo a meniscal reoperation ($p = 0.039$). 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 (Figure 2A). Three (7%) patients met criteria for failure at an average of 3.8 ± 1.1 years (range: 2.8-4.9) post-transplant. 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 (Figure 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 Supplemental Table 2.

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 post-operatively was 71% 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 is largely based on outcomes in adult populations.[25,26] Recent meta-analyses of adult MAT outcomes literature indicates MAT survivability ranges between 85.8% and 89.2% depending on compartment laterality at five-years and 74% at 10-years postoperatively.[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 paper by Riboh et al., while three were performed at a mean 3.8 years following primary MAT in the present study.

More recently in 2021, Smith et al. 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.[4] The final cohort included 67 patients with a mean age of 16.6 years, though 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 ACI (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 was 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. 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. 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 due to 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 as log-rank testing found no difference in survivability or reoperation based on concomitant surgery of any kind (Figure 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 under 40 years ($p = .902$). 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.[28,29]

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. found no differences in failure between lateral and medial MAT.[25] However, superior Lysholm and pain scores were observed for lateral MAT. The study was limited, however, by a small sample size as only three studies reported PROMs (42 medial and 51 lateral MATs). Further, 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.[30,31] Lastly, 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).[32,33] Optimal fixation techniques remain debated as comparisons are difficult due to 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. 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.[34] The findings of Ramme et al., in conjunction with the outcomes of the present study, suggests that MAT can serve as a viable treatment modality in the management of discoid lateral meniscal tears.

Lastly, patients undergoing MAT may return to competitive and recreational sports, as tolerated and as has been previously reported by our group.[35,36] 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.[37] 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 as the cohort of patients in this study were 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, as the eighteen 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 re-operations. 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 following 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 postoperatively, meniscal reoperation rate was 25% while 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.

References

1. Shieh A, Bastrom T, Roocroft J, Edmonds EW, Pennock AT. Meniscus Tear Patterns in Relation to Skeletal Immaturity: Children Versus Adolescents. *Am J Sports Med*. 2013;41(12):2779-2783. doi:10.1177/0363546513504286

2. Bellisari G, Samora W, Klingele K. Meniscus tears in children. *Sports Med Arthrosc Rev*. 2011;19(1):50-55. doi:10.1097/JSA.0b013e318204d01a

3. Purvis JM, Burke RG. Recreational injuries in children: incidence and prevention. *J Am Acad Orthop Surg*. 2001;9(6):365-374. doi:10.5435/00124635-200111000-00002

4. Smith HE, Lyons MM, Patel NM. Epidemiology of Meniscal Allograft Transplantation at Children's Hospitals in the United States. *Orthop J Sports Med*. 2021;9(9):1-5. doi:10.1177/23259671211034877

5. Stanitski CL, Harvell JC, Fu F. Observations on acute knee hemarthrosis in children and adolescents. *J Pediatr Orthop*. 1993;13(4):506-510. doi:10.1097/01241398-199307000-00016

6. Riboh JC, Tilton AK, Cvetanovich GL, Campbell KA, Cole BJ. Meniscal Allograft Transplantation in the Adolescent Population. *Arthroscopy*. 2016;32(6):1133-1140.e1. doi:10.1016/j.arthro.2015.11.041

7. Kocher MS, Logan CA, Kramer DE. Discoid Lateral Meniscus in Children: Diagnosis, Management, and Outcomes. *J Am Acad Orthop Surg*. 2017;25(11):736-743. doi:10.5435/JAAOS-D-15-00491

8. Rao AJ, Erickson BJ, Cvetanovich GL, Yanke AB, Bach BR, Cole BJ. The Meniscus-Deficient Knee: Biomechanics, Evaluation, and Treatment Options. *Orthop J Sports Med*. 2015;3(10):1-13. doi:10.1177/2325967115611386

9. Manzione M, Pizzutillo PD, Peoples AB, Schweizer PA. Meniscectomy in children: a long-term follow-up study. *Am J Sports Med*. 1983;11(3):111-115. doi:10.1177/036354658301100301

10. Middleton S, Asplin L, Stevenson C, Thompson P, Spalding T. Meniscal allograft transplantation in the paediatric population: early referral is justified. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(6):1908-1913. doi:10.1007/s00167-019-05437-y

11. Fox AJS, Wanivenhaus F, Burge AJ, Warren RF, Rodeo SA. The human meniscus: A review of anatomy, function, injury, and advances in treatment. *Clinical Anatomy*. 2015;28(2):269-287. doi:10.1002/ca.22456

12. Bryceland JK, Powell AJ, Nunn T. Knee Menisci. *Cartilage*. 2017;8(2):99-104. doi:10.1177/1947603516654945

13. Liechti DJ, Constantinescu DS, Ridley TJ, Chahla J, Mitchell JJ, Vap AR. Meniscal Repair in Pediatric Populations: A Systematic Review of Outcomes. *Orthop J Sports Med*. 2019;7(5):2325967119843355. doi:10.1177/2325967119843355

14. Jackson T, Fabricant PD, Beck N, Storey E, Patel NM, Ganley TJ. Epidemiology, Injury Patterns, and Treatment of Meniscal Tears in Pediatric Patients: A 16-Year Experience of a Single Center. *Orthop J Sports Med*. 2019;7(12):2325967119890325. doi:10.1177/2325967119890325

15. Vinagre G, Cruz F, Alkhelaifi K, D'Hooghe P. Isolated meniscus injuries in skeletally immature children and adolescents: state of the art. *J ISAKOS*. 2022;7(1):19-26. doi:10.1136/jisakos-2020-000496

16. Räber DA, Friederich NF, Hefti F. Discoid Lateral Meniscus in Children. Long-Term Follow-up After Total Meniscectomy. *J Bone Joint Surg Am*. 1998;80(11):1579-1586.

17. Tuca M, Luderowski E, Rodeo S. Meniscal transplant in children. *Curr Opin Pediatr*. 2016;28(1):47-54. doi:10.1097/MOP.0000000000000306

18. Riboh JC, Tilton AK, Cvetanovich G, Campbell KA, Cole BJ. Outcomes of Meniscal Allograft Transplantation in the Pediatric Athlete. *Orthop J Sports Med*. 2015;3(7_suppl2):1-6. doi:10.1177/2325967115S00128

19. Getgood A, Laprade RF, Verdonk P, et al. International Meniscus Reconstruction Experts Forum (IMREF) 2015 Consensus Statement on the Practice of Meniscal Allograft Transplantation. Am J Sports Med. 2017 May;45(5):1195-1205. doi:10.1177/0363546516660064

20. Mascarenhas R, Yanke AB, Frank RM, Butty DC, Cole BJ. Meniscal allograft transplantation: preoperative assessment, surgical considerations, and clinical outcomes. *J Knee Surg*. 2014;27(6):443-458. doi:10.1055/s-0034-1382080

21. Garcia GH, Christian DR, Redondo ML, Liu JN, Yanke AB, Cole BJ. 3 - Meniscus Transplantation. In: Thompson SR, Schmitz MR, eds. *Complications in Orthopaedics: Sports Medicine*. Elsevier; 2019:17-27. doi:10.1016/B978-0-323-54598-3.00003-5

22. Gomoll A, Farr J, Cole BJ. CHAPTER 47 - Allograft Meniscus Transplantation: Bridge in Slot Technique. In: Gomoll AH, Rihn J, Cole BJ, Sekiya JK, eds. *Surgical Techniques of the Shoulder, Elbow, and Knee in Sports Medicine*. W.B. Saunders; 2008:459-469. doi:10.1016/B978-1-4160-3447-6.50049-1

23. Pollard ME, Kang Q, Berg EE. Radiographic sizing for meniscal transplantation. *Arthroscopy*. 1995;11(6):684-687. doi:10.1016/0749-8063(95)90110-8

24. Liu JN, Gowd AK, Redondo ML, et al. Establishing Clinically Significant Outcomes After Meniscal Allograft Transplantation. *Orthop J Sports Med*. 2019;7(1):1-9. doi:10.1177/2325967118818462

25. Bin SI, Nha KW, Cheong JY, Shin YS. Midterm and Long-term Results of Medial Versus Lateral Meniscal Allograft Transplantation: A Meta-analysis. *Am J Sports Med. 2018 Apr;46(5):1243-1250.* doi:10.1177/0363546517709777

26. Novaretti JV, Patel NK, Lian J, et al. Long-Term Survival Analysis and Outcomes of Meniscal Allograft Transplantation With Minimum 10-Year Follow-Up: A Systematic Review. *Arthroscopy*. 2019;35(2):659-667. doi:10.1016/j.arthro.2018.08.031

27. Kimura Y, Yamamoto Y, Sasaki S, et al. Meniscus Allograft Transplantation Obtained From Adult Patients Undergoing Total Knee Arthroplasty May be Used for Younger Patients After Lateral Discoid Meniscus Meniscectomy. *Arthrosc Sports Med Rehabil*. 2021;3(6):e1679-e1685. doi:10.1016/j.asmr.2021.07.024

28. De Bruycker M, Verdonk PeterCM, Verdonk RC. Meniscal allograft transplantation: a meta-analysis. *SICOT J*. 2017;3(33):1-15. doi:10.1051/sicotj/2017016

29. Grassi A, Di Paolo S, Coco V, et al. Survivorship and Reoperation of 324 Consecutive Isolated or Combined Arthroscopic Meniscal Allograft Transplants Using Soft Tissue Fixation. *Am J Sports Med*. 2023;51(1):119-128. doi:10.1177/03635465221131522

30. Medial and Lateral Meniscus Allograft Transplantation Showed No Difference With Respect to Graft Survivorship and Clinical Outcomes: A Comparative Analysis With a Minimum 2-Year Follow-Up. *Arthroscopy*. 2020;36(12):3061-3068. doi:10.1016/j.arthro.2020.07.025

31. Wagner KR, Kaiser JT, Knapik DM, et al. Patient-Specific Variables Associated with Failure to Achieve Clinically Significant Outcomes After Meniscal Allograft Transplantation at Minimum 5-Year Follow-Up. *Arthroscopy*. Published online April 26, 2023:S0749-8063(23)00307-9. doi:10.1016/j.arthro.2023.03.031

32. Zhang S, Li H, Li H, Hua Y. Bone bridge fixation has superior biomechanics on posterior knees to bone plug fixation after lateral meniscal allograft transplantation - A biomechanical study simulating partial weight-bearing conditions. *Knee*. 2021;32:64-71. doi:10.1016/j.knee.2021.08.007

33. Ow ZGW, Cheong CK, Hai HH, et al. Securing Transplanted Meniscal Allografts Using Bone Plugs Results in Lower Risks of Graft Failure and Reoperations: A Meta-analysis. *Am J Sports Med*. 2022;50(14):4008-4018. doi:10.1177/03635465211042014

34. Ramme AJ, Strauss EJ, Jazrawi L, Gold HT. Cost effectiveness of meniscal allograft for torn discoid lateral meniscus in young women. *Phys Sportsmed*. 2016;44(3):278-282. doi:10.1080/00913847.2016.1197762

35. Liu JN, Agarwalla A, Garcia GH, et al. Return to Sport and Work After High Tibial Osteotomy With Concomitant Medial Meniscal Allograft Transplant. *Arthroscopy*. 2019;35(11):3090-3096. doi:10.1016/j.arthro.2019.05.053

36. Chalmers PN, Karas V, Sherman SL, Cole BJ. Return to high-level sport after meniscal allograft transplantation. *Arthroscopy*. 2013;29(3):539-544. doi:10.1016/j.arthro.2012.10.027

37. Rosso F, Bisicchia S, Bonasia DE, Amendola A. Meniscal Allograft Transplantation: A Systematic Review. *Am J Sports Med*. 2015;43(4):998-1007. doi:10.1177/0363546514536021

Figure Legends

Figure 1: Preoperative and postoperative patient-reported outcomes following 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. * indicates a mean significantly greater compared to preoperative scores ($p < 0.05$). ** indicates a significant increase compared to most-recent scores ($p = 0.048$).

Figure 2: Kaplan-Meier survival analysis for (A) meniscal reoperation and (B) graft failure werestratified 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 ($p = 0.110$ and 0.710, respectively).

Table 1: Demographics and Intraoperative Variables

	Post-operative Status			p-values	
Characteristic	**None, N = 30**[1]	**Reop, N = 11**[1]	**Fail, N = 3**[1]	**None vs. Reop**[2]	**None vs. Failure**[2]
Sex (female)	20 (67%)	11 (100%)	2 (67%)	**0.039**	>0.999
Age (years)	16.29 ± 1.11	15.90 ± 1.16	15.53 ± 2.16	0.303	0.594
BMI	24.1 ± 2.9	21.6 ± 4.3	23.4 ± 3.6	0.072	0.810
Lateral meniscus transplanted	24 (80%)	8 (73%)	3 (100%)	0.660	>0.999
Concomitant procedure	21 (81%)	5 (45%)	1 (33%)	0.051	0.136
OCA	12 (40%)	1 (9%)	1 (33%)	0.127	>0.999
ACI	5 (17%)	3 (27%)	0 (0%)	0.660	>0.999
HTO	1 (3%)	0 (0%)	0 (0%)	>0.999	>0.999
DFO	4 (13%)	0 (0%)	0 (0%)	0.559	>0.999
MFX	3 (10%)	0 (0%)	0 (0%)	0.551	>0.999
ACLR	5 (17%)	1 (9%)	0 (0%)	>0.999	>0.999

[1]categorical variables listed as n (% of respective cohort); continuous variables listed as mean ± SD

[2]Fisher's exact test; Wilcoxon rank sum test

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

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.

Table 2: Patient-Reported Outcomes 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

Patient-reported outcome scores at preoperative, 1-year, 2-year, and a minimum 5-year follow-up. Questionnaires included are Lysholm, International Knee Documentation Committee (IKDC) subjective form, and Knee osteoarthritis and outcome score (KOOS) subscales (ADL, activities of daily living; Pain; QOL, quality of life; Sport; SXS, symptoms). Significance determined by Wilcoxon Signed-Rank testing. Continuous variables listed as mean ± SD.

‡ - significantly greater (p = .048), compared to most-recent follow-up

Table 3: Clinically Significant Outcomes at Five-Year Minimum

Characteristic	N = 41[1]
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%)

Table 3: Clinically Significant Outcomes at Five-Year Minimum

Characteristic	N = 41[1]
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%)

[1]Patients were included if they did not fail prior to five-year follow-up.

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.

Supplemental Table 1: 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**

Legend: Thresholds for minimal clinically important difference (MCID), patient acceptable symptomatic state (PASS), and substantial clinic benefit (SCB) were calculated using both revision and primary meniscal allograft transplantation cohorts. Patient reported outcome measures analyzed included Lysholm, subjective International Knee Documentation Committee (IKDC), and Knee Injury and Osteoarthritis Outcome Score (KOOS) subscales. ADL, activities of daily living; AUC, area under the curve; QOL, quality of life; SN, sensitivity; SP, specificity.

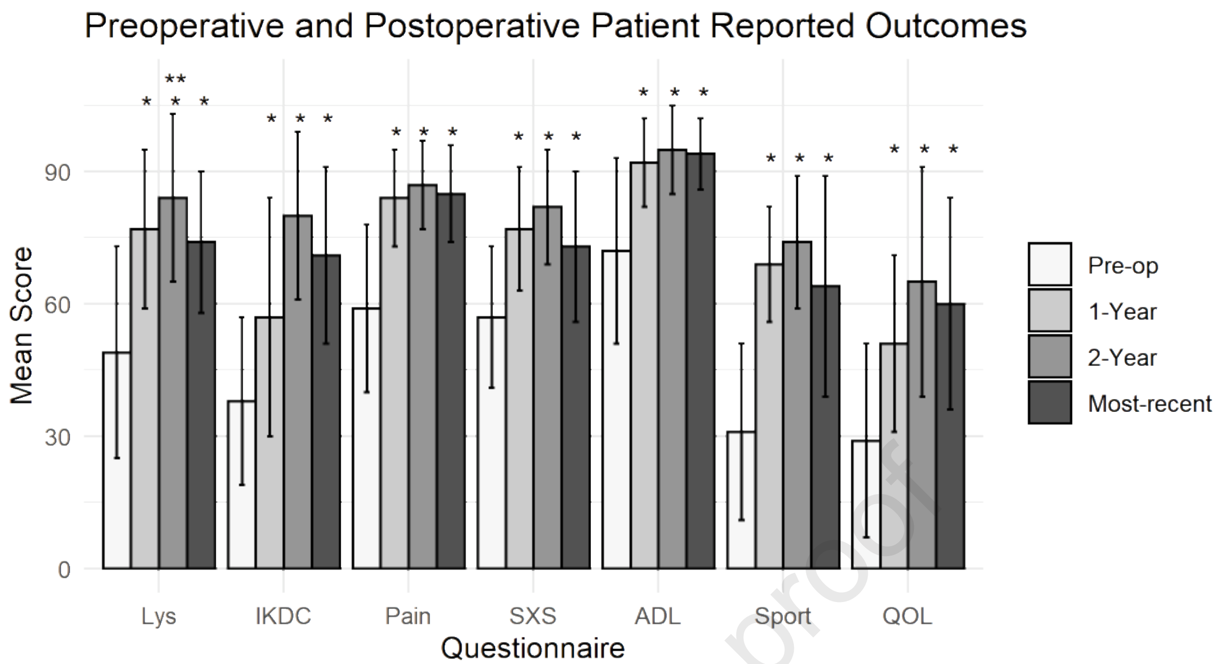
Supplemental Table 2: Reoperation and Failure Data Stratified by Meniscal Laterality

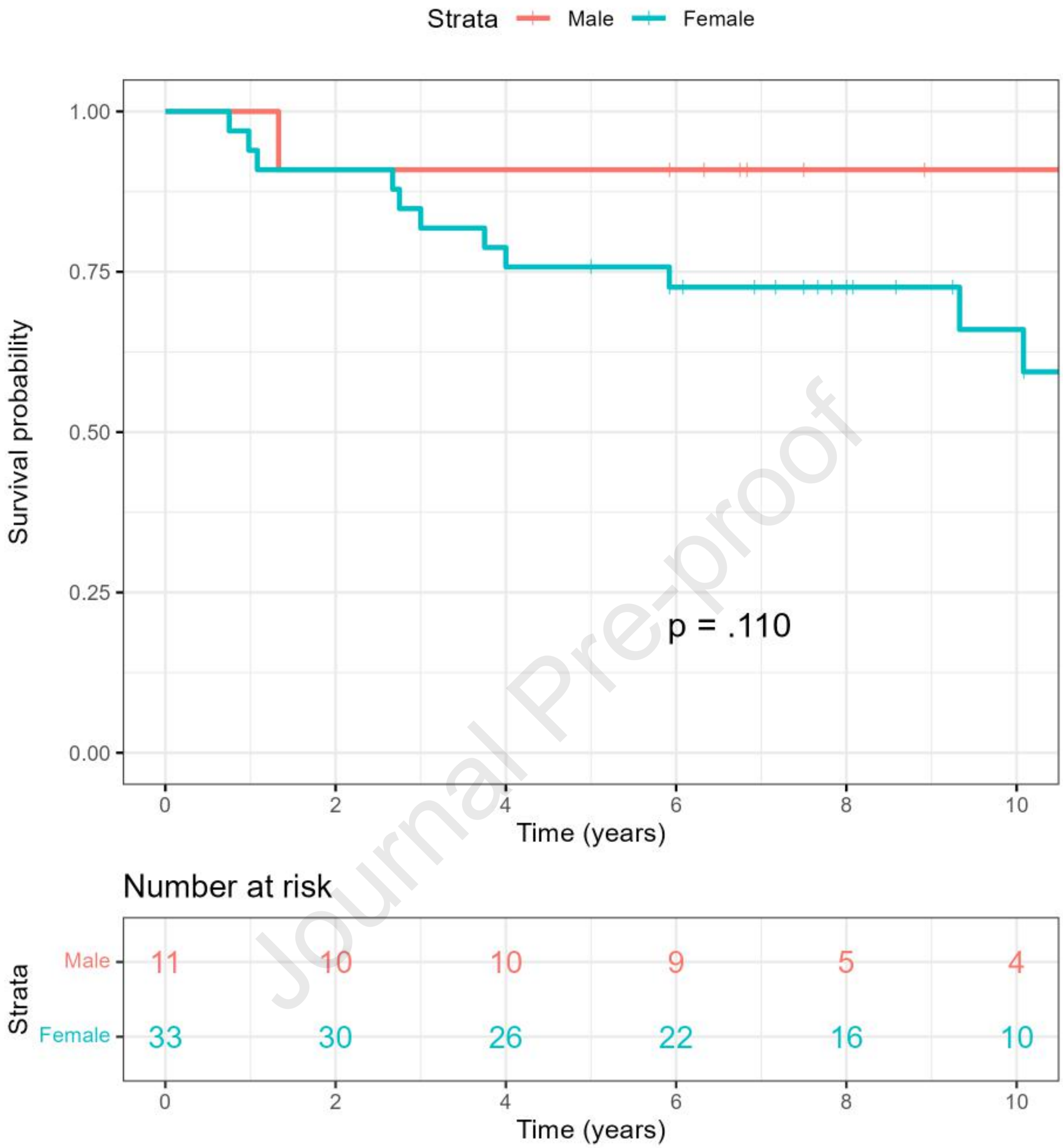
Variable	**Lateral**[1]	**Medial**[1]	**p-value**
Meniscal reoperation type			>0.999[2]
None	24 (69%)	6 (67%)	
Partial meniscectomy	7 (20%)	2 (22%)	
Total Meniscectomy	3 (9%)	1 (11%)	
Repair	1 3%)	0 (0%)	
Time to reoperation	4.3 ± 4.1	8.0 ± 4.6	0.291[3]

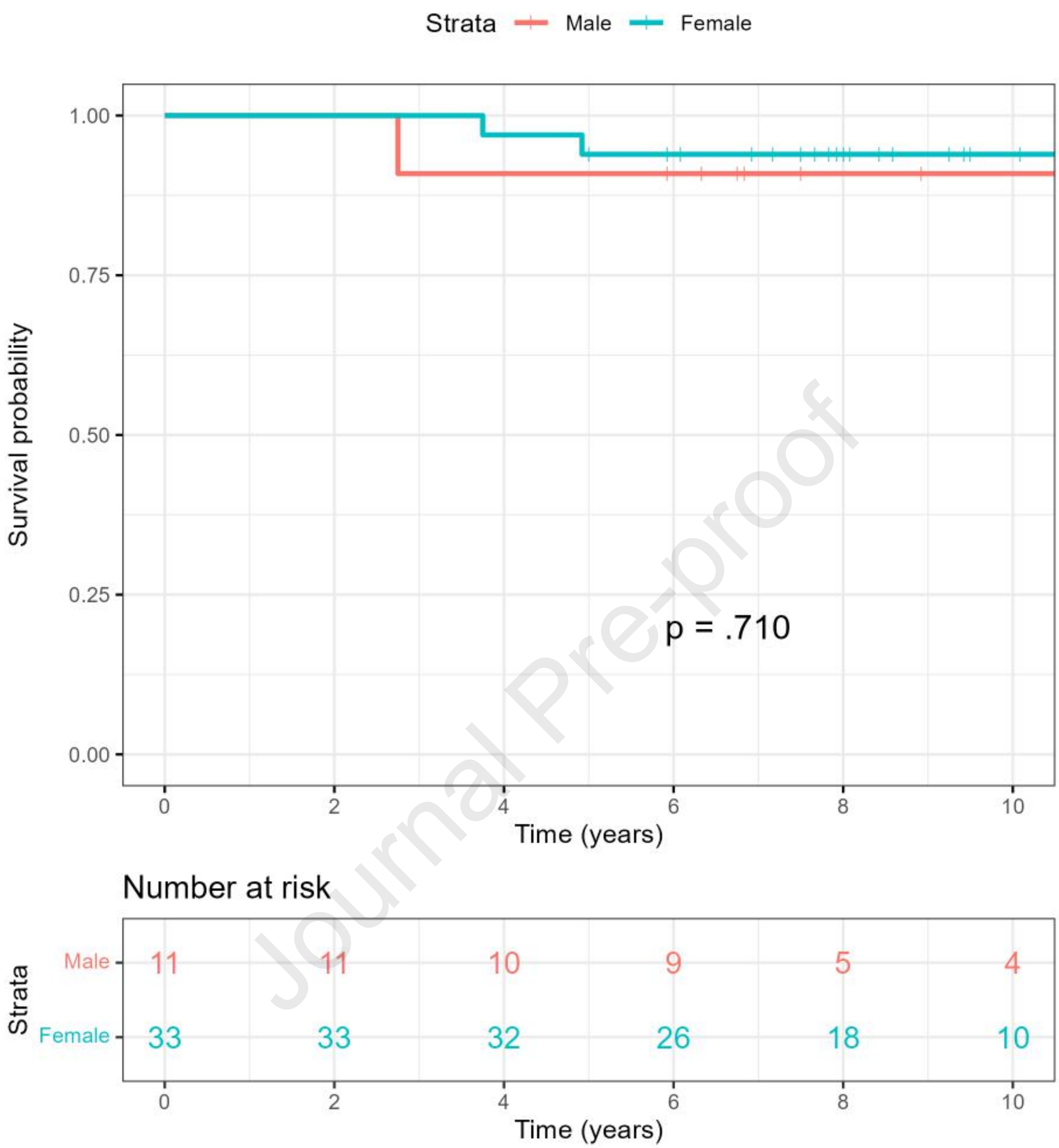
Supplemental Table 2: Reoperation and Failure Data Stratified by Meniscal Laterality			
Variable	**Lateral[1]**	**Medial[1]**	**p-value**
Failure	3 (9%)	0 (0%)	>0.999[2]

[1]categorical variables listed as n (% of respective medial or lateral meniscal allograft transplantation group); continuous variables listed as mean ± standard deviation.
[2]Fisher's exact test
[3]Wilcoxon rank-sum test

483


Preoperative and Postoperative Patient Reported Outcomes
Mean Score
0
30
60
90
Lys
IKDC
Pain
SXS
ADL
Sport
QOL
Questionnaire
Pre-op
1-Year
2-Year
Most-recent


Strata
Male
Female
Survival probability
1.00
0.75
0.50
0.25
0.00
p = .110
0
2
4
6
8
10
Time (years)
Number at risk
Strata
Male
Female
11
10
10
9
5
4
33
30
26
22
16
10
Time (years)



Strata
Male
Female
1.00
0.75
0.50
0.25
0.00
Survival probability
p = .710
0
2
4
6
8
10
Time (years)
Number at risk
Strata
Male
11
11
10
9
5
4
Female
33
33
32
26
18
10
Time (years)