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Minimum 10-Year Clinical Outcomes and Survivorship of Meniscal Allograft Transplantation With Fresh-Frozen Allografts Using the Bridge-in-Slot Technique

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Background: Meniscal allograft transplantation (MAT) has been shown to provide clinical benefits in patients with symptomatic meniscal deficiency in the short term and midterm. There is, however, a paucity of data regarding long-term outcomes after MAT using fresh-frozen allografts and the bridge-in-slot technique.

Purpose: To report clinical outcomes and revision rates after primary MAT with fresh-frozen allografts and the bridge-in-slot technique in a large case series of patients at a 10-year minimum follow-up.

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

Methods: A retrospective review of prospectively collected data was performed on patients undergoing primary MAT between 2001 and 2012. Lysholm, International Knee Documentation Committee subjective form, and Knee injury and Osteoarthritis Outcome Score subscales were collected preoperatively and at 1-, 2-, 5-, and minimum 10-year follow-ups. Cox proportional hazards modeling was used to identify variables associated with reoperation and failure, defined as revision MAT or conversion to arthroplasty. Reoperation was defined as a subsequent surgical intervention on the transplanted meniscus, including partial or total meniscectomy, meniscal repair, or failure as defined in the previous sentence.

Results: A total of 174 patients undergoing MAT met the inclusion criteria and were followed for a mean of 12.7 ± 2.7 years (range, 10.0-21.0 years). The mean age at surgery was 28.3 ± 10.1 years. The patients were predominantly female (n = 92; 53%), and medial MAT was the most commonly performed procedure (n = 91; 52%). Concomitant procedures were performed in 115 patients (66%), with the most common procedure being osteochondral allograft transplantation (n = 59; 34%). Patients demonstrated statistically significant postoperative improvements at all time points for all patient-reported outcome measures ($P \leq .0001$). A total of 65 patients (37%) underwent a meniscal reoperation at a mean time of 6.6 ± 5.5 years (range, 0.3-16.7 years) postoperatively. A total of 40 patients (23%) met the criteria for failure at a mean time of 7.3 ± 5.0 years (range, 1.0-17.4 years) after MAT, with 22 of these patients having undergone a previous meniscal reoperation. At the final follow-up, 13 patients (7%) had undergone revision MAT and 27 (15%) had converted to arthroplasty. The MAT survival rates free of meniscal reoperation and failure were 73% and 85% at 10 years and 60% and 72% at 15 years, respectively. At the time of the final follow-up, 86% of patients reported that they were satisfied with their overall postoperative condition.

Conclusion: Primary MAT demonstrates efficacy and durability with high rates of patient satisfaction at a minimum 10-year follow-up. Patients should be counseled that although reoperation rates may approach 40% at 15 years, rates of overall revision MAT and conversion to arthroplasty remain low at long-term follow-up.

Keywords: knee; meniscus; allografts; clinical assessment/grading scales; articular cartilage

Meniscal pathology is a common cause of knee pain and disability, with a reported incidence as high as 61 per 100,000 persons in the general population.[1,14] The meniscus serves a critical role in knee biomechanics, acting to provide shock absorption and load transmission.[17]

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Meniscal pathology or deficiency, most commonly in the form of a tear or meniscectomy, results in a substantial decrease in effective contact area; an associated increase in peak pressures; and an elevated risk of accelerated, posttraumatic osteoarthritis.[2,24] Recently, improved understanding of the negative biomechanical consequences of meniscal insufficiency has placed a growing emphasis on meniscal repair and restoration. Although meniscal repair is increasingly being performed, partial meniscectomy remains common given the presence of complex, irreparable tears. Many patients demonstrate benefit from meniscectomy in the setting of symptomatic tears; however, others demonstrate symptoms refractory to meniscectomy, often termed "postmeniscectomy syndrome," thought to be related to the pathologic load distribution and increased forces present in the meniscus-deficient knee. In these patients, meniscal allograft transplantation (MAT) has been shown to reliably provide clinical benefit.[4,5,9,34]

Multiple surgical techniques exist for MAT, including soft tissue fixation, bone plugs, keyholes, and the bridge-in-slot technique. Additionally, there are various allograft preservation methods, including cryopreserved, fresh, fresh-frozen, and lyophilized grafts. Ten-year survival rates after MAT have been estimated to be as high as 74%, although previous studies have been limited to small sample sizes or pooled outcomes, including patients who have <10-year minimum follow-up.[11,20,26] Although evidence favoring soft tissue or bone fixation techniques remains controversial, limited long-term outcome data exist for bone-bridge techniques using fresh-frozen allografts.[13,19] Thus, additional studies reporting on long-term outcomes after MAT are merited.

Therefore, the purpose of this study was to report on clinical outcomes and survivorship after primary MAT in a large case series of patients with a 10-year minimum follow-up. We hypothesized that (1) patients who underwent MAT would demonstrate sustained improvements in clinical outcomes at long-term follow-up when compared with the preoperative baseline, and (2) survivorship would be satisfactory and similar to previously reported rates in studies with long-term follow-up.

METHODS

Patient Population

Before study initiation, approval was obtained from the local institutional review board at Rush University Medical Center (ORA: 22032405). A prospectively collected database of patient-reported outcome measures (PROMs) from a single institution was queried for patients who had undergone primary MAT with a single surgeon between 2001 and 2012 with a minimum 10-year follow-up. Patients were included regardless of the presence of concomitant procedures at the time of MAT. Inclusion criteria consisted of (1) primary MAT, (2) minimum 10-year follow-up, and (3) consent for research participation. Exclusion criteria consisted of (1) <10 years of follow-up, (2) cryopreserved allografts, (3) use of the bone plug technique, and (4) patients who had undergone revision MAT. Patients were evaluated for both reoperation and failure. Reoperation was defined as surgical intervention of the transplanted meniscus, including partial or total meniscectomy, meniscal repair, or subsequent failure. Failure was defined as revision MAT or conversion to unicompartmental knee arthroplasty (UKA) or total knee arthroplasty (TKA).[7]

Indications and Preoperative Planning

All MATs were performed by the senior author (B.J.C.), a fellowship-trained orthopaedic surgeon with a high-volume MAT and joint preservation practice. The indications for MAT were patients who had previously undergone subtotal or total meniscectomy, had pain localized to their meniscectomized compartment, and had failed comprehensive nonoperative management. An age <50 years was preferred but was not a strict contraindication after considering the patient's current function and goals for treatment. Contraindications included those with inflammatory arthritis or marked obesity.[5] A Kellgren-Lawrence grade ≤2 is preferred on preoperative radiographs, while a grade ≥3 is a relative contraindication.[7]

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Because of the nature of the senior author's practice, the nonoperative management of the referring surgeon had failed for many patients before their initial clinic visit at our institution. The senior author, however, preferred a trial of physical therapy, bracing, and steroid injections for at least 6 to 8 weeks before MAT.

Indications for concomitant osteochondral allograft transplantation (OCA), osteotomy, or anterior cruciate ligament (ACL) reconstruction (ACLR) were a focal, full-thickness cartilage defect (International Cartilage Regeneration & Joint Preservation Society grade 3 or 4); malalignment; or a full-thickness ACL tear seen on preoperative magnetic resonance imaging scans, respectively.

Meniscal allograft sizing was done as described by Pollard et al.[22] Standard preoperative imaging included anteroposterior extension weightbearing views, posteroanterior 45° of flexion weightbearing views, nonweightbearing 45° of flexion lateral views, axial views of the patellofemoral joint, 3-foot standing long-axis views, and magnetic resonance imaging to assess for concomitant ligamentous or articular cartilage injury.[18]

Surgical Technique

The senior author preferred the bridge-in-slot technique for medial and lateral MATs with fresh-frozen, nonirradiated meniscal grafts (JRF Ortho) and, if present, treated concomitant pathology such as malalignment, focal cartilage defects, or ligamentous insufficiency.[8,27,29] Before transplantation, the meniscus was assessed in addition to the anterior and posterior cruciate ligaments as well as the chondral surfaces of the medial, lateral, and patellofemoral compartments. The meniscus was debrided until a bleeding peripheral rim of 1 to 2 mm was left, and anterior and posterior horns were subsequently resected. To prepare the meniscal slot, an initial slot guide was first made with a 4.5-mm bur and a guide pin was then placed using the slot guide. A 7-mm reamer was used to overream the guide pin, and the slot was refined using a box cutter, dilating rasp, and bone-cutting shaver.

During tibial slot preparation, the allograft was thawed in normal saline on a sterile surgical table. Once thawed, a bone bridge was created using a reciprocating saw between the anterior and posterior meniscal horns of the donor allograft. A polydioxanone suture was placed through the posterior third of the meniscus, which was used for meniscal insertion into the joint and subsequently the tibial slot. With the knee in flexion, a 7 × 23–mm bioabsorbable interference screw was used to secure the bone bridge within the tibial tunnel. Approximately 8 to 10 nonabsorbable 2-0 ultra–high molecular weight vertical mattress sutures were then used to secure the meniscus using an inside-out technique. After confirming satisfactory meniscal placement and stability, incisions were closed in the standard fashion.

Rehabilitation Protocol and Postoperative Management

Patients remained heel-touch weightbearing in a knee brace locked in full extension for the first 2 weeks. At postoperative week 2, patients began heel-touch weightbearing with crutches until week 6, whereby patients progressed to full weightbearing. At postoperative week 8, patients progressed through closed-chain activities until they were cleared for sport-specific exercises by the senior author at a minimum of 5 months postoperatively. Patients were, however, discouraged from returning to pivoting or cutting sports because of the higher risk for meniscal reinjury.

At the first visit postoperatively, radiographs were obtained to ensure proper bone slot placement and assess concomitant procedures, if performed. Subsequent imaging was performed if patients had recurrence of symptoms and failed nonoperative management. Oral nonsteroidal anti-inflammatory drugs, physical therapy, cortisone injections, and platelet-rich plasma injections were used for patients who developed symptoms postoperatively.

Outcome Score Collection

The Lysholm, International Knee Documentation Committee (IKDC) subjective form, and Knee injury and Osteoarthritis Outcome Score (KOOS) subscales (Pain, Symptoms, Activities of Daily Living [ADL], Sport and Recreation (Sport/Rec), and Quality of Life [QOL]), were completed preoperatively and at 1, 2, 5, and a minimum of 10 years of follow-up.

Statistical Analysis

Descriptive statistics for continuous variables were reported as means with standard deviation, whereas binomial variables were presented as frequencies and proportions. Mann-Whitney U and paired t tests were used for comparing preoperative and postoperative PROMs. Postoperative satisfaction was assessed with a "yes" or "no" answer to the question, "Taking into account all the activities you have during your daily life, your level of pain, and also your functional impairment, do you consider that your current state is satisfactory?" Thresholds for achieving clinically significant outcomes (CSOs) were calculated using methods previously described.[16] 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.

RESULTS

Patient Characteristics

A total of 174 patients (age, 28.36 ± 10.1 years; 92 women [53%], 82 men [47%]; body mass index [BMI], 25.7 ± 4.1) met study inclusion criteria (Figure 1) and were followed for a mean of 12.7 ± 2.7 years (range, 10.0-21.0 years) (Table 1). A total of 36 and 3 patients had follow-up beyond 15 and 20 years, respectively. Medial meniscal transplantation was performed in 91 patients (52%), and lateral meniscal

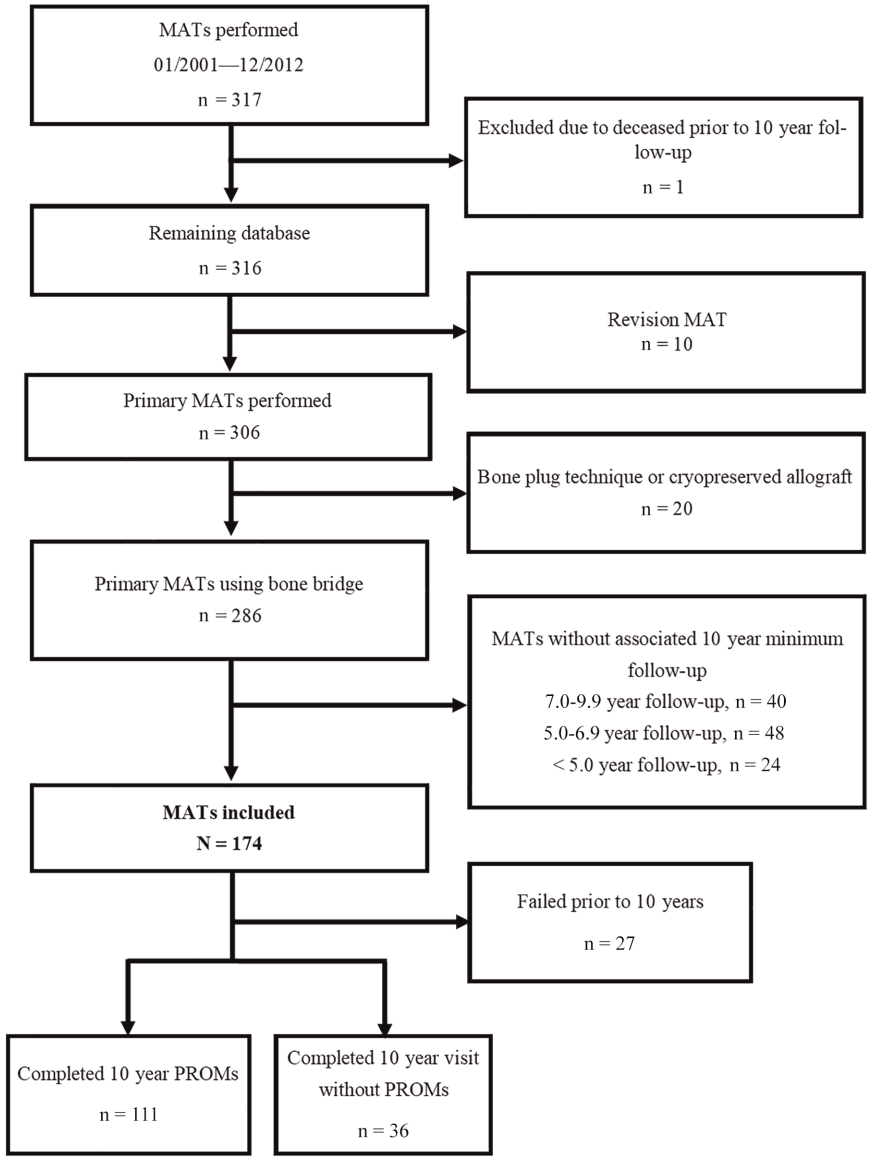

Figure 1. During the time frame selected, 317 patients underwent meniscal allograft transplantation (MAT). Patients were excluded if they had died before the 10-year follow-up, had undergone a revision MAT, had undergone MAT using the bone plug technique or a cryopreserved allograft, or did not have 10 years of follow-up. Patients were included whether or not they had completed the 10-year minimum patient-reported outcome measures (PROMs).

transplantation was performed in 83 patients (48%). An isolated MAT procedure was performed in 59 (34%) patients, while the most common concomitant procedure was OCA (34%), followed by ACLR (14%), and autologous chondrocyte implantation (11%) (Table 1).

Patient-Reported Outcomes

Significant postoperative improvement in mean scores was observed for all PROMs (Lysholm, IKDC, and KOOS) at every time point analyzed ($P \leq .0001$) (Figure 2). This finding was also appreciated when stratifying by those who underwent primary MAT ($P \leq .019$) or who had a major concomitant procedure ($P \leq .0003$). Further subgroup analysis showed a benefit in those who underwent a concomitant cartilage procedure ($P \leq .015$); however, the present study was underpowered to perform subgroup analysis on concomitant ACLR or realignment osteotomy. Scores did not significantly decrease at the most recent follow-up when compared with baseline and 1-, 2-, 5-, and 10-year time points. Conversely, KOOS ADL scores significantly improved at 2 years and the final follow-up compared with at 1 year (P = .030 and .003, respectively) (see Appendix Table A1, available in the online version of this article). There was a trend toward higher KOOS ADL scores at the 5-year follow-up as compared with 1-year scores, but this did not achieve significance (P = .099). At the final follow-up, the KOOS QOL score was significantly higher than at 1 year (P = .043).

TABLE 1
Patient Characteristics and Intraoperative Variables[a]

	Postoperative			*P* Values[b]	
Characteristic	None, n = 109	Reoperation, n = 25	Failure, n = 40	None vs Reoperation	None vs Failure
Female sex	53 (48.6)	17 (68.0)	22 (55.0)	.080	.490
Age, y	27.3 ± 9.4	25.1 ± 10.4	33.3 ± 10.3	.180	**.002**
BMI	26.0 ± 4.2	23.8 ± 4.0	26.4 ± 3.6	**.044**	.556
Meniscal transplant	56 (51.3)	13 (52.0)	16 (40.0)	.955	.218
Concomitant procedure	77 (70.6)	12 (48.0)	26 (65.0)	**.031**	.509
OCA	38 (34.9)	5 (20.0)	16 (40.0)	.151	.563
OAT	1 (0.9)	0 (0)	1 (2.5)	>.999	.466
ACI	15 (13.7)	2 (8.0)	2 (5.0)	.739	.159
MFX	9 (8.3)	1 (4.0)	0 (0)	.687	.113
Particulated juvenile articular cartilage allograft	1 (0.9)	0 (0)	1 (2.5)	>.999	.466
HTO	7 (6.4)	0 (0)	4 (10.0)	.347	.487
DFO	2 (1.8)	1 (4.0)	1 (2.5)	.465	>.999
ACLR	14 (12.8)	4 (16.0)	6 (15.0)	.745	.732
Follow-up ≥15 y	26 (23.8)	6 (24.0)	4 (10.0)	.988	.062
Follow-up ≥20 y	3 (2.8)	0 (0)	0 (0)	>.999	.564
Mean follow-up, y	12.8 ± 2.7	12.3 ± 2.7	7.6 ± 5.1		

[a]Data are presented as n (% of respective group) or mean ± SD. Reoperations consist of any surgery related to the transplanted meniscus (evaluation because of meniscal symptoms, debridement, or meniscectomy). Failure is defined as knee arthroplasty or revision meniscal allograft transplantation. Those who had a reoperation and later met the criteria for failure were only included in the failure column. Boldface *P* values indicate statistical significance. ACI, autologous chondrocyte implantation; ACLR, anterior cruciate ligament reconstruction; BMI, body mass index; DFO, distal femoral osteotomy; HTO, high tibial osteotomy; MFX, microfracture; OATS, osteochondral autograft transfer system; OCA, osteochondral allograft transplantation.
[b]Pearson chi-square test, Wilcoxon rank-sum test, or Fisher exact test.

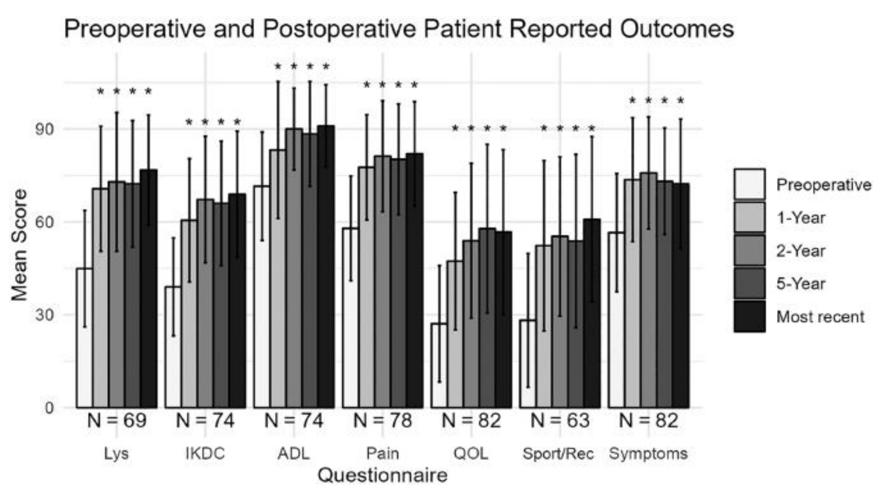

Figure 2. Mean patient-reported outcome measure scores after primary meniscal allograft transplantation. Questionnaires included the Lysholm (Lys), International Knee Documentation Committee (IKDC) subjective form, and Knee injury and Osteoarthritis Outcome Score (KOOS) subscales at preoperative, 1-year, 2-year, 5-year, and most recent follow-up time points. The KOOS subscales are abbreviated as follows: ADL (Activities of Daily Living), QOL (Quality of Life), Sport/Rec (Sport and Recreation), and Symptoms. Error bars represent SD and asterisks represent significant improvement, compared with preoperative scores ($P < .05$).

Clinically Significant Outcomes

Thresholds for achieving CSOs were calculated at a 10-year minimum follow-up (Table 2). A majority of patients achieved the minimal clinically important difference (MCID), Patient Acceptable Symptom State (PASS), and substantial clinical benefit (SCB) for each PROM analyzed with the exception of the SCB for the Lysholm (48%), IKDC

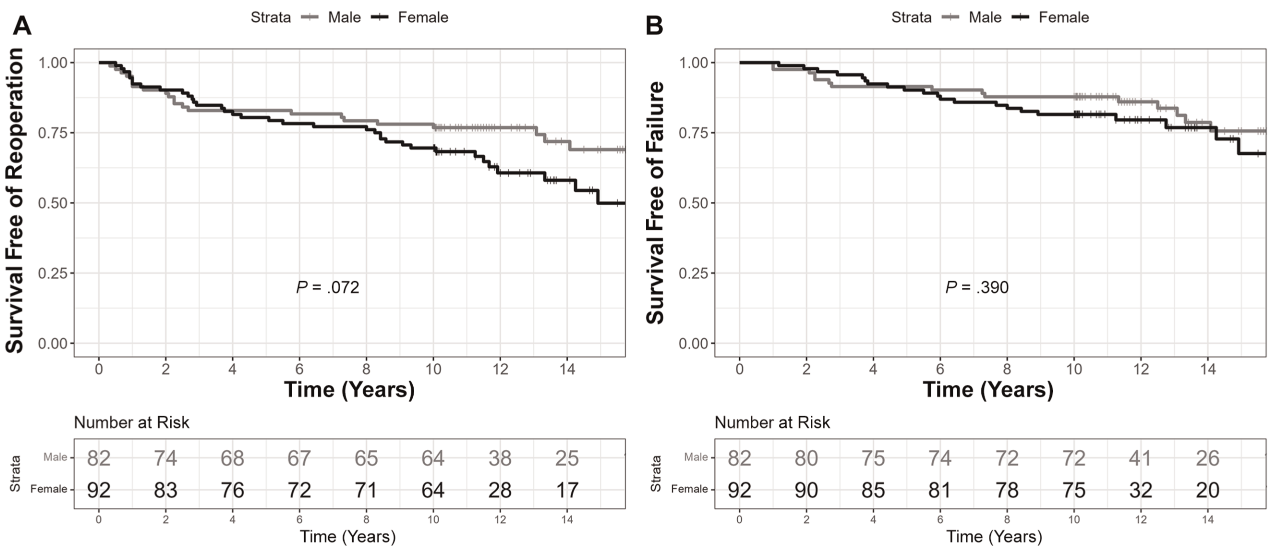

Figure 3. Sex-stratified Kaplan-Meier survival analysis for (A) reoperation and (B) failure (revision meniscal allograft transplantation or unicompartmental knee arthroplasty/total knee arthroplasty). The overall survival rates free from reoperation were 92.0%, 89.7%, 81.6%, 73.0%, and 59.9% at 1, 2, 5, 10, and 15 years, respectively. The overall survival rates free from failure were 98.9%, 97.7%, 90.8%, 84.5%, and 72.1% at 1, 2, 5, 10, and 15 years, respectively. The log-rank test demonstrated no significant difference in survival distributions between male and female sex for reoperation (*P* = .072) and failure (*P* = .390).

TABLE 2
Patient Achievement of MCID, PASS, and SCB at 10 Years[a]

	MCID		PASS					SCB				
	Threshold	n/N Achieving (%)	Threshold	n/N Achieving (%)	SN	SP	AUC	Threshold	n/N Achieving (%)	SN	SP	AUC
Lysholm	10.0	62/69 (89.8)	71.5	73/104 (70.2)	85.1	90.5	.947	32.0	33/69 (47.8)	83.3	62.9	.681
IKDC	10.4	64/74 (86.5)	55.7	82/110 (74.5)	91.4	91.0	.945	37.7	26/74 (35.1)	57.8	80.5	.718
KOOS												
Pain	10.3	61/78 (78.2)	72.2	83/105 (79.0)	89.7	81.8	.871	25.1	36/78 (46.1)	80.0	75.2	.843
SXS	11.5	50/82 (61.0)	69.6	62/106 (58.5)	68.6	90.9	.860	14.7	45/82 (54.9)	75.0	65.5	.770
ADL	9.7	50/74 (67.6)	95.7	59/105 (56.2)	72.0	90.2	.850	15.3	38/74 (51.4)	66.6	56.0	.619
Sport/Rec	13.3	47/63 (74.6)	52.5	67/105 (63.8)	76.4	89.7	.870	32.5	39/63 (61.9)	86.6	52.1	.677
QOL	13.3	60/82 (73.2)	46.8	70/106 (66.0)	79.4	90.9	.899	31.1	40/82 (48.8)	76.1	65.5	.751

[a]Thresholds for the minimal clinically important difference (MCID), Patient Acceptable Symptom State (PASS), and substantial clinical benefit (SCB) were calculated for the Lysholm, 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; Sport/Rec, Sport and Recreation; SXS, Symptoms.

subjective form (35%), and KOOS Pain (46%) and QOL (49%) questionnaires. At the time of the final follow-up, however, 86% of patients stated they were satisfied with their overall postoperative condition.

Reoperation, Revision, and Conversion to Arthroplasty

At the final follow-up, 65 patients (37%) had undergone repeat MAT-associated intervention (meniscectomy, revision MAT, or TKA). Patients who underwent reoperation isolated to their MAT graft most commonly underwent partial meniscectomy (n = 31), total meniscectomy (n = 11), and meniscal repair (n = 4) at a mean time of 6.6 ± 5.5 years (range, 0.3-16.7 years) after index MAT. Of note, an additional 20 patients (11%) underwent surgical intervention of the ipsilateral knee not related to the meniscus (chondroplasty [n = 8], plica excisions [n = 4], synovectomy [n = 3], lysis of adhesions [n = 2], suprapatellar pouch release [n = 1], microfracture [n = 1], and hardware removal after distal femoral osteotomy [n = 1]). Those who underwent a meniscal reoperation and did not subsequently experience failure had fewer concomitant procedures (*P* = .031) and a lower BMI (*P* = .044) than those who did not have a meniscal reoperation. Overall survival free from reoperation was 92.0%, 89.7%, 81.6%, 73.0%, and 59.9% at 1, 2, 5, 10, and 15 years, respectively (Figure 3A). Log-rank testing demonstrated a trend toward significance

TABLE 3
Baseline Patient-Reported Outcome Measures[a]

Characteristic	Preoperative			P Values[b]	
	None	Reoperation	Failure	None vs Reoperation	None vs Failure
Lysholm	44.3 ± 18.7	51.4 ± 21.5	42.4 ± 19.0	.275	.632
IKDC	38.4 ± 16.6	43.0 ± 15.3	35.1 ± 14.0	.457	.522
KOOS					
ADL	70.4 ± 18.0	79.0 ± 15.9	69.4 ± 15.0	.133	.705
Pain	58.1 ± 16.3	60.8 ± 20.2	54.6 ± 15.9	.348	.387
QOL	26.3 ± 18.1	32.1 ± 21.9	25.5 ± 18.3	.372	.780
Sport/Rec	26.9 ± 22.7	29.5 ± 16.8	28.6 ± 24.9	.468	.862
SXS	56.7 ± 18.2	58.6 ± 21.0	57.8 ± 21.4	.737	.966

[a]Data are presented as mean ± SD. ADL, Activities of Daily Living; IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; QOL, Quality of Life; Sport/Rec, Sport and Recreation; SXS, Symptoms.
[b]Wilcoxon rank-sum test.

TABLE 4
Cox Regression Analysis for Variables Associated With Failure[a]

Characteristic	HR	95% CI	P Value	q Value[b]
Age, y	1.04	1.01-1.07	**.016**	0.127
Female sex	1.26	0.67-2.35	.476	0.697
BMI >25.0	1.34	0.67-2.68	.402	0.697
BMI >30.0	1.53	0.66-3.52	.342	0.697
Lateral meniscal transplant	1.26	0.67-2.36	.479	0.697
Concomitant procedure	0.92	0.48-1.77	.806	0.859
Cartilage procedure	1.26	0.61-2.60	.544	0.697
OATS	0.93	0.12-7.01	.946	0.946
OCA	1.62	0.86-3.08	.145	0.465
ACI	0.30	0.07-1.27	.050	0.205
Particulated juvenile articular cartilage allograft	2.97	0.40-21.8	.361	0.697
DFO	1.90	0.26-14.0	.567	0.697
HTO	1.42	0.50-4.03	.533	0.697
ACLR	1.16	0.48-2.79	.746	0.852

[a]Cartilage procedure is defined as concomitant osteochondral autograft transfer system (OATS) or osteochondral allograft transplantation (OCA), autologous chondrocyte implantation (ACI), microfracture (MFX), or particulated juvenile articular cartilage allograft. Boldface *P* value indicates statistical significance. ACLR, anterior cruciate ligament reconstruction; BMI, body mass index; DFO, distal femoral osteotomy; HR, hazard ratio; HTO, high tibial osteotomy.
[b]False discovery rate correction for multiple testing.

in survival distributions between male and female sex for reoperation (P = .072), with women demonstrating a potentially higher risk of reoperation.

A total of 23% (40/174) of patients met criteria for MAT failure at a mean time of 7.3 ± 5.0 years (range, 1.0-17.4 years) after MAT. The most common criteria met were TKA (55%; n = 22/40), revision MAT (33%; n = 13/40), and UKA (13%; n = 5/40). Of those patients who met MAT failure criteria, 55% (22/40) had undergone a previous meniscectomy or repair after their index MAT. Baseline PROMs did not significantly differ between those who did or did not undergo reoperation as well as with those who experienced failure (Table 3). Patients who met criteria for failure were older in age than those who did not experience failure (P = .031). Cox proportional hazards regression determined increasing age to be associated with risk of MAT failure (P = .016; HR = 1.04; 95% CI, 1.01-1.07) (Table 4).

The survival rates free of failure (revision MAT or UKA/TKA) were determined to be 98.9%, 97.7%, 90.8%, 84.5%, and 72.1% at 1, 2, 5, 10, and 15 years, respectively (Figure 3B). Log-rank testing found no difference in survivability from failure based on sex, overweight (BMI ≥25.0) or obese (BMI ≥30.0) status, smoker status, meniscal laterality (medial vs lateral), or worker's compensation (WC) status ($P \geq .061$).

DISCUSSION

The primary finding from this investigation was that primary MAT demonstrates both efficacy and durability at a minimum 10-year follow-up. Additionally, we found that patients should be counseled that although reoperation rates may approach 40% at 15 years, rates of overall revision MAT and conversion to arthroplasty remain satisfactorily low at long-term follow-up.

Varying definitions of failure exist in the MAT literature and introduce additional heterogeneity when comparing studies.[20] Inclusion of clinical outcomes in a failure definition, such as a Lysholm survey score <65, may not accurately assess postoperative, patient-specific satisfaction. Dichotomous responses to satisfaction questionnaires are important to report, such as the 86% satisfaction rate in the present study. However, these results may lack nuance for specific domains of patient well-being that are tested by PROMs. Therefore, a strength of the present study is that it assessed achievement of CSOs for PROMs at a 10-year minimum follow-up using cohort-specific thresholds.[10,25] The 86% satisfaction rate was not ubiquitous among each CSO examined, although a majority of patients did achieve the MCID and PASS for each PROM examined. The SCB was obtained by many patients; however, it was not as frequently achieved as the MCID or PASS. Longevity in patient satisfaction after MAT can be appreciated as even after taking up to 11 months to achieve MCID or PASS after MAT, patients may continue to obtain these CSOs at long-term follow-up.[12] Additionally, mean scores tended to improve at later time points, particularly when compared with 1-year scores. This is contrary to previous studies that have reported possible depreciation in mean PROM scores in certain populations.[23]

Compared with studies with similar allograft preparation techniques, Van Der Straeten and colleagues[30] studied 313 patients who underwent MAT with fresh or fresh-frozen allografts. The cumulative survivorship was 15.1% at 24 years using a failure definition of subsequent TKA or graft removal. However, the authors reported a mean follow-up of only 6.8 years (range, 0.2-24.3 years) and did not report the number of patients included in the analysis who met 10-, 15-, or 20-year follow-up thresholds. In a study of 48 patients who underwent combined OCA and MAT at a mean follow-up of 6.8 years (range, 1.7-17.1 years), Getgood et al[6] reported a 10-year survivorship of 73%. However, the authors defined failure as removal or revision of either the OCA or MAT allograft, which limits direct comparison to studies solely evaluating MAT survivorship. Getgood et al[6] used fresh-frozen grafts unless an OCA shell allograft of the ipsilateral tibial plateau was performed, in which case a fresh meniscal allograft was used. In a study of predominantly fresh-frozen grafts, Kim et al[15] examined 49 consecutive MATs at a minimum follow-up of 8 years. Having a broader definition of failure as TKA, subtotal graft resection, or inferior Lysholm scores, Kim and colleagues reported 10- and 15-year survivorship rates of 98.0% and 93.3%, respectively. The comparatively inferior survivorship reported here is difficult to explain because of similar indications for surgery. One exception might be the exclusion of patients undergoing concomitant osteotomy; however, the present study did not detect a negative association with osteotomy and treatment failure. Kim et al used various surgical techniques, including the bone-bridge, bone plug, and keyhole techniques. To our knowledge, no head-to-head comparison study of these techniques exists, yet studies comparing soft tissue and bone fixation techniques have shown similar outcomes.[13] Nevertheless, the graft survivorship reported in the present study is similar to other long-term studies examining both fresh and fresh-frozen grafts. Additional long-term studies using lyophilized allografts exist and show improvement in Tegner and Lysholm scores, yet lyophilized allografts were found to be associated with notable graft shrinkage and more severe Fairbank changes.[28,35] Reported 10-year survivorship for cryopreserved allografts range from 45% to 90.3%, although definitions of failure used in the various studies are heterogeneous.[11,31,32] When compared with survivorship across all graft preparation and surgical techniques with long-term follow-up, the present study reports higher survivorship than the 10-year survival rate of 73.5% reported by Novaretti et al.[20]

This investigation identified a trend toward improved survivorship for concomitant autologous chondrocyte implantation or microfracture. In total, 24 patients in the present case series had either a concomitant autologous chondrocyte implantation or microfracture, and only 2 cases met criteria for failure (91.7% 10-year survivorship), which is higher than other reports at short-term and mid-term follow-up.[3,21] Comparisons with other studies are difficult, however, because cartilage restoration failure was not considered as part of our definition. Apart from these findings, only patient age was found to be a risk factor significantly associated with failure. In a recent systematic review conducted by Wang et al,[33] prognostic factors for MAT failure were examined in studies with a 2-year minimum follow-up (mean, 6.0 years). The review reported conflicting evidence with respect to the influence of patient age on survivorship. Only the presence of full-thickness chondral lesions was reliably associated with inferior MAT survivorship, whereas patient sex, BMI, tobacco use, and concomitant osteotomy or ACLR at the time of MAT were not found to be associated with failure.

Establishing long-term outcomes is critical for young patients who have limited options in a symptomatic, meniscus-deficient state. Although many studies examining early outcomes after MAT exist, few long-term studies exist, particularly with follow-up beyond 10 years. Even fewer studies report on outcomes of fresh-frozen grafts transplanted using the bone-bridge technique, highlighting the clinical use of the data presented in this study.

Limitations

This study is not without limitations. This study does not include postoperative radiographic findings and is limited to clinical outcomes. Therefore, we cannot comment on MAT prevention of long-term changes in radiographic evidence of osteoarthritis. Although the IKDC and KOOS Sport/Rec questionnaires indirectly examine sporting activity, we did not examine long-term return to sport and previous performance rates. Patients included in this study were treated by a single surgeon at a high-volume institution, which may limit the generalizability of these findings for patients undergoing primary MAT at other institutions with other surgeons. All retrospective reviews are subject to the inherent biases related to recall and complete record keeping. A substantial portion of patients had <10-year follow-up, which may have introduced selection bias. Finally, no control group was used, which limits the internal validity of this study.

CONCLUSION

Primary MAT demonstrates efficacy and durability with high rates of patient satisfaction at a minimum 10-year follow-up. Patients should be counseled that although reoperation rates may approach 40% at 15 years, rates of overall revision MAT and conversion to arthroplasty remain satisfactorily low at long-term follow-up.

REFERENCES

1. Baker BE, Peckham AC, Pupparo F, Sanborn JC. Review of meniscal injury and associated sports. *Am J Sports Med*. 1985;13(1):1-4. doi:10.1177/036354658501300101
2. Baratz ME, Fu FH, Mengato R. Meniscal tears: the effect of meniscectomy and of repair on intraarticular contact areas and stress in the human knee: a preliminary report. *Am J Sports Med*. 1986;14(4):270-275. doi:10.1177/036354658601400405
3. Farr J, Rawal A, Marberry KM. Concomitant meniscal allograft transplantation and autologous chondrocyte implantation: minimum 2-year follow-up. *Am J Sports Med*. 2007;35(9):1459-1466. doi:10.11 777/0363546507301257
4. Frank R, Gilat R, Haunschild ED, et al. Do outcomes of meniscal allograft transplantation differ based on age and sex? A comparative group analysis. *Arthroscopy*. 2022;38(2):452-465.e3. doi:10.1016/J.ARTHRO.2021.05.029
5. Frank RM, Cole BJ. Meniscus transplantation. *Curr Rev Musculoskelet Med*. 2015;8(4):443-450. doi:10.1007/S12178-015-9309-4
6. Getgood A, Gelber J, Gortz S, et al. Combined osteochondral allograft and meniscal allograft transplantation: a survivorship analysis. *Knee Surg Sport Traumatol Arthrosc*. 2015;23:946-953. doi:10.1007/s00167-015-3525-8
7. 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;45(5):1195-1205. doi:10.1177/0363546516660064
8. Gilat R, Cole BJ. Meniscal allograft transplantation: indications, techniques, outcomes. *Arthroscopy*. 2020;36(4):938-939. doi:10.1016/J.ARTHRO.2020.01.025
9. Grassi A, Bailey JR, Filardo G, Samuelsson K, Zaffagnini S, Amendola A. Return to sport activity after meniscal allograft transplantation: at what level and at what cost? A systematic review and meta-analysis. *Sports Health*. 2019;11(2):123-133. doi:10.1177/1941738118819723
10. Harris JD, Brand JC, Cote M, Waterman B, Dhawan A. Guidelines for proper reporting of clinical significance, including minimal clinically important difference, patient acceptable symptomatic state, substantial clinical benefit, and maximal outcome improvement. *Arthroscopy*. 2023;39(2):145-150. doi:10.1016/j.arthro.2022.08.020
11. Hommen JP, Applegate GR, Del Pizzo W. Meniscus allograft transplantation: ten-year results of cryopreserved allografts. *Arthroscopy*. 2007;23(4):388-393. doi:10.1016/J.ARTHRO.2006.11.032
12. Huddleston HP, Polce EM, Gilat R, et al. Time to achieving clinically significant outcomes after meniscal allograft transplantation. *Cartilage*. 2022;13(3):19476035221102568. doi:10.1177/19476035221102568
13. Jauregui JJ, Dong Wu Z, Meredith S, Griffith C, Packer JD, Frank Henn R III. How should we secure our transplanted meniscus? A meta-analysis. *Am J Sports Med*. 2018;46(9):2285-2290. doi:10.1177/0363546517720183
14. Jorgensen U, Sonne-Holm S, Lauridsen F, Rosenklint A. Long-term follow-up of meniscectomy in athletes. A prospective longitudinal study. *J Bone Joint Surg Br*. 1987;69(1):80-83. doi:10.1302/0301-620X.69B1.3818740
15. Kim JM, Bin SI, Lee BS, et al. Long-term survival analysis of meniscus allograft transplantation with bone fixation. *Arthroscopy*. 2017;33(2):387-393. doi:10.1016/J.ARTHRO.2016.07.017
16. Liu JN, Gowd AK, Redondo ML, et al. Establishing clinically significant outcomes after meniscal allograft transplantation. *Orthop J Sports Med*. 2019;7(1):2325967118818462. doi:10.1177/2325967118818462
17. Makris EA, Hadidi P, Athanasiou KA. The knee meniscus: structure-function, pathophysiology, current repair techniques, and prospects for regeneration. *Biomaterials*. 2011;32(30):7411-7431. doi:10.1016/J.BIOMATERIALS.2011.06.037
18. 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
19. Myers P, Tudor F. Meniscal allograft transplantation: how should we be doing it? A systematic review. *Arthroscopy*. 2015;31(5):911-925. doi:10.1016/j.arthro.2014.11.020
20. Novaretti J V, 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
21. Ogura T, Bryant T, Minas T. Biological knee reconstruction with concomitant autologous chondrocyte implantation and meniscal allograft transplantation: mid- to long-term outcomes. *Orthop J Sports Med*. 2016;4(10):2325967116668490. doi:10.1177/2325967116668490
22. 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
23. Riboh JC, Tilton AK, Cvetanovich GL, Campbell KA, Cole BJ. Meniscal allograft transplantation in the adolescent population. *Arthroscopy*. 2016;32(6):1133-1140. doi:10.1016/j.arthro.2015.11.041
24. Roos H, Laurbn M, Adalberth T, et al. Knee osteoarthritis after meniscectomy: prevalence of radiographic changes after twenty-one years, compared with matched controls. *Arthritis Rheum*. 1998;41(4):687-693. doi:10.1002/1529-0131
25. Rossi MJ, Brand JC, Lubowitz JH. Minimally clinically important difference (MCID) is a low bar. *Arthroscopy*. 2023;39(2):139-141. doi:10.1016/j.arthro.2022.11.001
26. Saltzman BM, Bajaj S, Salata M, et al. Prospective long-term evaluation of meniscal allograft transplantation procedure: a minimum of 7-year follow-up. *J Knee Surg*. 2012;25(2):165-175. doi:10.1055/S-0032-1313738
27. Saltzman BM, Griffin JW, Wetters N, Meyer MA, Cole BJ, Yanke AB. Concomitant arthroscopic meniscal allograft transplantation and anterior cruciate ligament reconstruction. *Arthrosc Tech*. 2016;5(5):e1161. doi:10.1016/J.EATS.2016.07.002
28. Serdar M, Burak B, Kaya A. Lyophilised medial meniscus transplantations in ACL-deficient knees: a 19-year follow-up. *Knee Surg Sports Traumatol Arthrosc*. 2012;20(1):109-113. doi:10.1007/s00167-011-1556-3
29. Southworth TM, Naveen NB, Tauro TM, Chahla J, Cole BJ. Meniscal allograft transplants. *Clin Sports Med*. 2020;39(1):93-123. doi:10.1016/J.CSM.2019.08.013
30. Van Der Straeten C, Byttebier P, Eeckhoudt A, Victor J. Meniscal allograft transplantation does not prevent or delay progression of knee osteoarthritis. *PLoS One*. 2016;11(5):e0156183. doi:10.1371/JOURNAL.PONE.0156183
31. van der Wal RJP, Nieuwenhuijse MJ, Spek RWA, Thomassen BJW, van Arkel ERA, Nelissen RGHH. Meniscal allograft transplantation in The Netherlands: long-term survival, patient-reported outcomes, and their association with preoperative complaints and interventions. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(11):3551-3560. doi:10.1007/S00167-020-06276-Y

32. Vundelinckx B, Vanlauwe J, Bellemans J. Long-term subjective, clinical, and radiographic outcome evaluation of meniscal allograft transplantation in the knee. *Am J Sports Med*. 2014;42(7):1592-1599. doi:10.1177/0363546514530092
33. Wang DY, Lee CA, Li YZ, et al. Prognostic factors to determine survivorship of meniscal allograft transplant: a systematic review. *Orthop J Sports Med*. 2021;9(6):23259671211007215. doi:10.1177/23259671211007215
34. Waterman BR, Rensing N, Cameron KL, Owens BD, Pallis M. Survivorship of meniscal allograft transplantation in an athletic patient population. *Am J Sports Med*. 2016;44(5):1237-1242. doi:10.1177/0363546515626184
35. Wirth CJ, Peters G, Milachowski KA, Weismeier KG, Kohn D. Long-term results of meniscal allograft transplantation. *Am J Sports Med*. 2002;30(2):174-181. doi:10.1177/03635465020300020501