Do Outcomes of Meniscal Allograft Transplantation Differ Based on Age and Sex? A Comparative Group Analysis

Rachel Frank, M.D., Ron Gilat, M.D., Eric D. Haunschild, B.S., Hailey Huddleston, M.D., Sumit Patel, M.S., Aghogho Evuarherhe Jr., B.S., Derrick M. Knapik, M.D., Justin Drager, M.D., Adam B. Yanke, M.D., Ph.D., and Brian J. Cole, M.D., M.B.A.

Purpose: To analyze the effect of patient age, sex, and associated preoperative factors on patient-reported outcome (PRO) measures and graft survival following primary meniscal allograft transplantation (MAT). **Methods:** A prospectively collected database was retrospectively reviewed to identify patients who underwent primary MAT with a minimum of 2 years of follow up between 1999 and 2017. Demographic, intraoperative, and postoperative outcome data were collected for each patient. Postoperative outcomes were stratified based on age and sex, and comparative statistical analysis was performed between sexes, both >40 and <40. **Results:** A total of 238 patients underwent primary MAT during the study period, of which 212 patients (mean age, 28.5 ± 9.0 years; range, 15.01-53.67 years) met the inclusion criteria with a mean follow-up of 5.1 ± 3.4 years (range 2.0-15.9 years). At final follow-up, patients ≥40 and <40 years of age demonstrated statistically significant improvements in nearly all PRO scores ($P < .05$ for both groups). There were no significant differences between either group for achievement of minimal clinically important difference for International Knee Documentation Committee ($P = .48$) or Knee Injury and Osteoarthritis Outcome Score symptoms ($P = .76$). Because of insufficient numbers, a statistically significant difference could not be demonstrated in reoperation rate (≥40: 1.49 ± 1.77 years, <40: 1.87 ± 1.98 years, $P = .591$), failure rate (≥40: 7/32 [21.9%], <40: 19/180 [10.6%], $P = .072$), or complication rate (≥40: 2/32 [6.3%], <40: 12/180 [6.7%], $P = .930$) based on age. Both sexes showed a significant improvement in PROs, whereas female patients were more likely to undergo revision surgery ($P = .033$), with no significant differences based on time to reoperation, failure, or complication rates. **Conclusions:** PROs similarly improved following MAT in both patients aged ≥40 and those <40 at final follow-up with no significant differences in minimal clinically important difference achievement rate, complication rate, reoperation rate, time to reoperation, or failure rate between groups. Female patients may be more likely to undergo revision surgery after MAT. **Level of Evidence:** III; therapeutic retrospective comparison study.

The meniscus serves multiple functions within the knee, including shock absorption, load transmission, decreasing the tibiofemoral contact area, increasing stability within the knee joint, and providing nourishment for the surrounding articular cartilage.[1,2] In the setting of meniscal deficiency, alterations in the knee biomechanics occur based on the amount of meniscus removed, increasing the risk for pain,

From Midwest Orthopaedics at Rush, Rush University Medical Center, Chicago, Illinois, U.S.A.

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Address correspondence to Dr. Brian J. Cole, M.D., M.B.A., Department of Orthopedics, Anatomy and Cell Biology, Cartilage Restoration Center, Rush University Medical Center, 1611 W. Harrison St., Suite 300, Chicago, IL 60612. E-mail: brian.cole@rushortho.com

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mechanical symptoms, and the initiation or progression of osteoarthritis.[3-6] In the young and active meniscal-deficient patient with persistent knee pain and preserved mechanical alignment with intact cruciate ligaments, primary meniscal allograft transplantation (MAT), either isolated or performed with concurrent procedures, represents a viable treatment option.[7-9] By restoring tibiofemoral contact pressure distribution, MAT effectively restores the biomechanical stability to the knee, improving symptoms and potentially inhibiting the onset or progression of osteoarthritis.[10-14]

Reported clinical outcomes following MAT have yielded inconsistent results when considering patient age and sex.[15] Liu et al.[16] found that patient age and sex did not significantly affect the percentage of patients achieving the minimal clinically important difference or substantial clinical benefit after MAT. In contrast, the meta-analysis performed by Fanelli et al.[17] reported that increased patient age, body mass index (BMI), and female sex were negatively correlated with patient reported-outcome measures (PROs) but not graft survival. Furthermore, the investigation by Zaffagnini et al.[18] found a negative association between outcomes in patients aged older than 50 years, with older patients possessing inferior PROs and greater failure rates when compared with younger patients. As such, the influence of patient age and sex remain largely unknown following primary MAT.

Appropriate patient selection is critical to ensure successful outcomes following MAT, warranting careful consideration to patient demographics (age and sex) and several preoperative variables. The purpose of this investigation was to analyze the effect of patient age, sex, and associated preoperative factors on PRO measures and graft survival following primary MAT. Based on previous investigations, the authors hypothesized that younger patients would possess significant improvements in PROs with fewer failures and reoperations,[17,18] whereas no significant differences in outcomes would be appreciated based on patient sex.

Methods

The prospectively collected database consisted of patients undergoing MAT (lateral, medial, or medial and lateral) performed by the senior authors (B.J.C.) between 1999 and 2017. Institutional review board approval was obtained before study initiation, after which a retrospective database review was performed to identify patients meeting inclusion/exclusion criteria by 2 authors (R.G., E.D.H.). Inclusion criteria consisted of patients undergoing primary MAT with a minimum of 2-year follow-up. Patients undergoing concomitant procedures during MAT and those who had a history of ipsilateral knee surgery (excluding previous MAT) were included. Exclusion criteria consisted of (1) patients undergoing revision MAT, (2) patients younger than 15 years of age, (3) less than 2-year follow-up, and (4) diagnosis of inflammatory arthropathy.

In the senior author's (B.J.C.) practice, indications for primary MAT include relatively young (typically age <50 years) meniscal-deficient patients with associated ipsilateral pain with or without swelling.[19] Patients with associated ligament tears requiring reconstruction or repair, articular cartilage defects necessitating repair procedures to the ipsilateral compartment, and correctable malalignment are also candidates for MAT. Contraindications to primary MAT include asymptomatic patients, presence of uncorrectable malalignment or instability, chondral damage not amendable to repair, inflammatory arthropathy, or the presence of an active infection.

The surgical technique preferred by the senior author (B.J.C.) for MAT has been previously described.[20] The bridge-in-slot technique is preferred by the senior surgeon (B.J.C.) for both lateral or medial MAT, with technique modifications as necessary based on concomitant procedures being performed. In brief, the patient is placed in the supine position while under anesthesia. Standard anteromedial and anterolateral arthroscopic portals are established and an assessment of the meniscal status, as well as ligamentous and cartilage integrity and other intra-articular pathologies. A debridement of the remaining meniscal tissue is performed until a 1- to 2-mm bleeding peripheral rim remains. An anterior longitudinal incision is performed and a mini-arthrotomy is made through the patellar tendon to facilitate graft placement. An accessory posterolateral (for lateral MAT) or posteromedial (for medial MAT) incision is made to assist with inside-out repair following allograft placement.

For tibial slot preparation, an initial reference slot is created using a 4.5-mm burr following the natural slope of the tibial plateau. A guide pin is placed distally to the reference slot and a cannulated reamer is used to overream the pin after it has been advanced to the posterior tibial cortex. A tibial slot, 8 mm wide and 10 mm deep, is then created using a box cutter.

The donor allograft can be gradually thawed in normal saline at any time during the surgery in a staging area away from the surgical field. The allograft is prepared by creating a bone bridge between the anterior and posterior horn. A single 0-polydioxanone suture is used as a traction stitch, placed in vertical mattress fashion between the middle and posterior thirds of the meniscus. The 0-polydioxanone suture attached to the allograft is shuttled through the accessory incision, the bone bridge is brought into the tibial slot and the meniscus is reduced into the compartment. A single 7×23-mm bioabsorbable interference screw is used to secure the bone bridge with the knee in flexion. The meniscus is then secured to the joint capsule using 8-10 inside-out vertical mattress sutures. Any concomitant realignment or cartilage procedure is then performed. Once all concomitant procedures are completed, incisions are closed in standard fashion.

The senior author's (B.J.C.) preferred postoperative rehabilitation protocol has the patient's knee put in a hinged knee brace locked in full extension during all activity and sleep, heel touch weight bearing with crutches, and limited range of motion (0° to 90°) when non—weight-bearing for the first 2 weeks. From weeks 2 to 8, the brace is locked from 0° to 90° and off at night. During this time, increases in range of motion are recommended as tolerated. Heel touch weight bearing with crutches is continued until week 6, after which the patient may progress to full weight-bearing. After week 8, the patient no longer needs a brace and has no restrictions with range of motion or weight bearing. Patients are able to participate in gentle recreational activities at this point and can progressively increase their exercise activities. Patients without pain or effusion are generally allowed to return to sport-specific activities 20 weeks postsurgery once cleared by the senior author (B.J.C.) following demonstration of full knee range of motion and once strength has returned to greater than 80% of contralateral leg.

Demographic (patient sex, age, BMI, traumatic etiology, athlete, worker's compensation, smoking), preoperative (Kellgren—Lawrence grade, PROs, symptom duration, recurrent effusion, range of motion, alignment, previous surgical procedures), intraoperative (laterality of transplant, concomitant procedure[s]), and postoperative data (PROs, complications, reoperation rate, time to reoperation, failure rate, procedure performed at time of reoperation, number of reoperations, and intraoperative findings at reoperation) were collected and recorded by 2 authors (R.G., E.D.H.) under the supervision of the senior author (B.J.C.). Preoperative and most recent postoperative PROs were collected using an electronic data collection service, Outcome Based Electronic Research Database (Universal Research Solutions, Columbia, MO). PROs evaluated included the International Knee Documentation Committee (IKDC), Knee Injury and Osteoarthritis Outcome Score (KOOS) symptoms, pain, daily living, sports and quality of life, KOOS for joint replacement (KOOS-JR), KOOS physical function short-form (KOOS-PS), Lysholm, Marx, Short Form—12 (SF-12) mental and physical subscales, Veterans RAND 6 (VR6D), 12-Item Health Survey (VR-12) mental subscore, and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) pain, stiffness, and function scores. PROs were collected at a minimum of 2 years following surgery (mean, 5 years; range, 2-19 years) at the time of final patient follow-up. Malalignment was defined as varus or valgus if the mechanical axis was within the medial or lateral compartment, respectively, on preoperative long axis radiographs. A traumatic etiology was defined as any knee injury in which the patient reported a definitive traumatic event occurring on a previously painless knee. A complication was defined as any unanticipated problem or deviation from the expected postoperative course, requiring medical or surgical intervention. Postoperative transplant failure was defined as revision MAT, conversion to a unilateral or total knee arthroplasty, or macroscopic graft failure at second-look arthroscopy in patients with persistent pain and effusion following MAT. Postoperative outcomes were stratified based on age and sex.

Statistical Analysis

Continuous variables are shown as mean ± standard deviation and binomial variables are presented as proportions. A power analysis for logistic regression was performed based on the failure rates published by Zaffagnini et al.,[18] who reported a failure rate of 31% in the older than 50 group and 15% in the younger than 30 group. The sample size required to detect a minimal between-groups difference in PROs using a 2-tailed *t*-test power analysis with $\alpha = 0.05$, power of 0.8 and the aforementioned difference is 26 patients in each group. A paired-samples *t*-test was used to compare change in preoperative and most recent PROs. Data were assumed to be non-normal based upon the findings of Searle et al. on a previous study conducted on meniscal allograft transplantation success.[21] The Mann—Whitney *U* test was used to compare preoperative Kellgren—Lawrence grades between both sex and age groups due to non-normal distribution in the number of patients with each grade. Sex, age, BMI, traumatic etiology, laterality of MAT, and major concomitant procedure at time of MAT were analyzed using the bivariate logistic regression model. A stepwise logistic regression model was used to analyze association between patient factors and failure. BMI was evaluated as a series of numbers and not as a group (obese vs nonobese). Survival probabilities were calculated using Kaplan—Meier survival analysis with survival defined as the absence of revision MAT, graft failure on second-look arthroscopy, or knee arthroplasty. A nonparametric distribution of time-dependent survival, comparable techniques used during operations independent of time periods and similar survival behavior between patients who did and did not meet failure criteria were assumed when analyzing data. The log-rank test was conducted to compare graft survival stratified by age, sex, and both age and sex. The minimum clinically important difference (MCID) was calculated using the distribution-based method by halving the standard deviation of the difference between preoperative and most recent postoperative PROs.[22] Cross-tabulation was used to generate odds ratios (ORs), and a 2-tailed Fisher exact probability test was conducted to determine

Table 1. Demographic and Clinical Characteristics

	Overall (N = 212)
Age at surgery, y [range]	28.5 ± 9.0 [15.01-53.67]
Sex	
Male	105 (49.5%)
Female	107 (50.5%)
Body mass index	26.0 ± 4.0
Laterality	
Right	134 (63.2%)
Left	78 (36.8%)
Smoking	
Never	180 (84.9%)
Yes	13 (6.1%)
Former	3 (1.4%)
Unknown	16 (7.5%)
Athlete	146 (68.9%)
Workers' compensation claims	19 (9.0%)
Traumatic etiology	140 (66.0%)
Symptom duration, y	4.6 ± 4.8
Recurrent effusion	88 (41.5%)
Preoperative flexion, °	133.5 ± 11.2
Preoperative extension, °	−0.1 ± 1.2
Preoperative alignment	
Neutral	154 (72.6%)
Varus	30 (14.2%)
Valgus	57 (26.9%)
Preoperative Kellgren−Lawrence Grade	
0	59 (27.8%)
1	59 (27.8%)
2	54 (25.5%)
3	24 (11.3%)
4	1 (.5%)
Unknown	15 (7.1%)
Follow-up, y	5.1 ± 3.4

NOTE. Continuous variables presented in mean ± standard deviation.

Binomial variables are presented in frequencies (proportions).

statistical significance. Statistical significance was set at *P* value <.05. Statistical analyses were performed using Stata software v.16.1 (StataCorp, College Station, TX).

Results

Review of a prospectively collected database yielded 236 patients who underwent MAT (lateral, medial, or medial and lateral) between 1999 and 2017, with a minimum of 2 years of follow-up. There were 521 patients who underwent MAT during this time but many did not complete PROs at 2-year follow-up. Of the 236 patients with greater than 2 years' follow-up, a total of 212 patients (89.8%; mean age 28.5 ± 9.0 years; range, 15.01-53.67 years; 105 male, 107 female) who underwent MAT and met inclusion criteria were included with a mean follow-up of 5.1 ± 3.4 years (range 2.0-15.9 years). Patients (n = 24) were excluded due to the following: 10 were duplicates in the original registry, 7 had their primary MAT performed at a different institution, and 7 were younger than the age of 15 years. There were 180 patients younger than 40 years old (mean age 25.7 ± 6.6 years; 85 male, 95 female) and 32 patients age 40 years old or greater (43.9 ± 3.2 years; range, 40-53.7 years; 20 male, 12 female). A total of 105 male patients (mean age 30.0 ± 9.2 years) and 107 female patients (mean age 26.9 ± 8.6 years). Demographic information on the cohort is presented in Table 1.

Patients aged ≥40 had a significantly greater rate of worker's compensation claims ($P = .033$), while patients <40 years where significantly more likely to be athletes ($P = .021$) or have had a traumatic etiology ($P = .013$). Male patients were found to possess a significantly greater BMI ($P < .0001$), smoking history ($P = .020$), and worker's compensation claims ($P < .0001$) (Table 2). Mann−Whitney *U* test showed no significant differences in preoperative Kellgren−Lawrence grades between sexes (mean grade; female: 1.22, male: 1.24; $P = .7744$) or age groups (mean grade <40: 1.20, ≥40: 1.44, $P = .2716$. All included patients had undergone at least 1 previous procedure to the index knee (Table 3), whereas concomitant surgery was performed in 156 patients during primary MAT (Table 4). Statistically significant improvements across multiple PRO measures were appreciated when accounting for all included patients when compared with preoperative values (Table 5). Of the total population, 117 (55.2%) patients completed a pre- and postoperative IKDC PRO and 129 (60.8%) patients completed a pre- and postoperative KOOS symptoms PRO. The MCID for the overall cohort was calculated as 11.2 for the IKDC PRO and 10.3 for the KOOS symptoms PRO. In the overall cohort, there were 26 (12.3%) failures with 10 (4.7%) patients converting to a total knee arthroplasty (TKA), 11 (5.2%) patients having a revision MAT, and 5 (2.4%) patients showing

Table 2. Demographic Differences Based on Age and Sex

	Age, y			Sex		
Variable	<40	≥40	*P* Value	Male	Female	*P* Value
Body mass index ± SD	25.8 ± 4.0	26.8 ± 4.2	.281	27.5 ± 4.1	24.4 ± 3.3	<.0001*
Smoking history (% of total)	11/180 (6.1%)	2/32 (6.3%)	.530	10/105 (9.5%)	3/107 (2.8%)	.020*
Workers' compensation (% of total)	15/180 (8.3%)	4/32 (25%)	.033*	17/105 (16.2%)	2/107 (1.9%)	<.0001*
Athlete classification	129/180 (71.7%)	17/32 (53.1%)	.021*			
Traumatic etiology	126/180 (70%)	14/32 (43.8%)	.013*			

SD, standard deviation.

*Statistically significant result at $P < .05$.

Table 3. Previous Surgical Procedures

	Overall
Number of patients with at least 1 previous procedure of the index knee	212 (100.0%)
Previous meniscal surgery	208 (98.1%)
Lateral meniscal repair	18 (8.5%)
Medial meniscal repair	28 (13.2%)
Lateral meniscectomy	111 (52.4%)
Medial meniscectomy	119 (56.1%)
Previous cartilage surgery	131 (61.8%)
Chondroplasty	124 (58.5%)
Microfracture	31 (14.6%)
Osteochondral autograft transplantation	3 (1.4%)
Fixation of OCD	2 (0.9%)
DeNovo (particulated juvenile allograft)	2 (0.9%)
Autologous chondrocyte implantation	2 (0.9%)
Previous nonmeniscal or cartilage surgery	76 (35.8%)
ACL reconstruction	73 (34.4%)
High tibial osteotomy	2 (0.9%)
Distal femoral osteotomy	1 (0.5%)
Tibial tuberosity osteotomy	1 (0.5%)

NOTE. Binomial variables are presented in frequencies (proportions).

ACL, anterior cruciate ligament; OCD, osteochondritis dissecans.

graft failure on second-look arthroscopy. There were 14 (6.6%) complications including 5 (2.4%) superficial wound infections, 2 (0.9%) cases of complex regional pain syndrome, 2 (0.9%) hematomas, 1 (0.5%) large effusion, 1 (0.5%) popliteal vein injury, 1 (0.5%) case of arthrofibrosis, 1 (0.5%) case of seizures, and 1 (0.5%) case of pneumonia. Thirty-three percent (n = 70) of patients underwent a subsequent reoperation.

Subgroup Analysis Based on Age

At final follow-up, no statistically significant differences in complication rate ($P = .930$), reoperation rate ($P = .559$), time to reoperation ($P = .591$), or failure rate ($P = 0.072$) were appreciated between the age groups (Appendix 1, Fig 1). Significant improvements in IKDC, Lysholm, KOOS, and SF-12 physical scores were reported in both groups when compared with preoperative values ($P < .05$ for both groups), while no statistically significant improvement in postoperative Marx, SF-12 mental subscores, and VR-12 mental subscores could be demonstrated at final follow-up for either group (Appendix 2, Fig 2). Patients younger than 40 years demonstrated significant improvements in VR-12 physical and VR6D scores ($P < .05$). Patients <40 years had significantly greater overall WOMAC pain, stiffness, and function scores ($P < .05$) when compared with patients ≥40 years, whereas the older group possessed greater overall VR-12 mental subscores ($P < .05$). Regarding MCID, 12 of 22 (54.5%) patients older than 40 and 60 of 95 (63.2%) patients younger than 40 years achieved MCID for IKDC and 15/24 (62.5%) older patients and 62/105 (59.0%) younger patients achieved MCID for KOOS symptoms. There were no significant differences between either group in terms of achievement of MCID for IKDC ($P = .48$) or KOOS symptoms ($P = .76$).

Patients older than 40 were more likely to undergo a medial meniscal transplant (≥40: 27/32 [84.4%], <40:

Table 4. Surgical Details and Concomitant Procedures for Meniscal Allograft Transplantation

Meniscus transplanted	
Medial	110 (51.9%)
Lateral	101 (47.6%)
Medial and lateral	1 (0.5%)
Major concomitant procedure	
ACL reconstruction	25 (11.8%)
Osteochondral autograft	107 (50.5%)
High tibial osteotomy	15 (7.1%)
Distal femoral osteotomy	9 (4.2%)
Tibial tuberosity osteotomy	0 (0.0%)
Microfracture	22 (10.4%)
OATS	4 (1.9%)
ACI	12 (5.7%)
DeNovo Natural Tissue graft	2 (0.9%)
Bone marrow aspirate concentrate injection	3 (1.4%)

NOTE. Binomial variables are presented in frequencies (proportions).

ACI, autologous chondrocyte implantation; ACL, anterior cruciate ligament reconstruction; OATS, osteoarticular transfer system.

Table 5. Patient-Reported Outcome Scores for Overall Cohort Preoperatively and at Most Recent Follow-up

	Preoperative	Most Recent Follow-up	P Value
IKDC	43.08 ± 15.57	64.08 ± 19.95	<.0001*
Marx	5.90 ± 6.17	4.45 ± 4.69	.4889
Lysholm	48.47 ± 19.76	71.58 ± 20.56	<.0001*
KOOS Symptoms	58.44 ± 17.82	68.83 ± 18.16	<.0001*
KOOS Pain	56.54 ± 17.51	75.36 ± 18.39	<.0001*
KOOS Daily Living	71.98 ± 18.79	85.99 ± 16.10	<.0001*
KOOS Sports	32.77 ± 24.14	53.18 ± 27.00	<.0001*
KOOS QoL	25.70 ± 18.94	49.51 ± 25.52	<.0001*
KOOS JR	60.14 ± 13.47	73.35 ± 15.29	.0115*
KOOS PS	37.72 ± 10.55	25.82 ± 13.41	.0036*
WOMAC Pain	6.15 ± 3.58	26.66 ± 37.26	<.0001*
WOMAC Stiffness	3.23 ± 1.73	22.13 ± 33.19	<.0001*
WOMAC Function	18.25 ± 12.05	31.91 ± 37.70	.6059
WOMAC Overall	25.65 ± 16.32	32.54 ± 34.54	.2710
SF-12 Mental	52.09 ± 10.34	51.58 ± 9.44	.1007
SF-12 Physical	37.39 ± 7.76	47.69 ± 9.76	<.0001*
VR-12 Mental	54.46 ± 10.06	57.85 ± 8.17	.1575
VR-12 Physical	38.12 ± 8.81	49.43 ± 8.90	<.0001*
VR6D	0.65 ± 0.09	0.76 ± 0.11	.0013*

NOTE. Data are presented as mean ± standard deviation.

IKDC, International Knee Documentation Committee; JR, Joint Replacement; KOOS, Knee Injury and Osteoarthritis Outcome Score; PS, Physical Function Short Form; QoL, Quality of Life; SF-12, Short Form−12; VR6D, Veterans RAND 6D; VR-12, Veterans RAND 12 Item Health Survey; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

*Statistically significant result at $P < .05$.

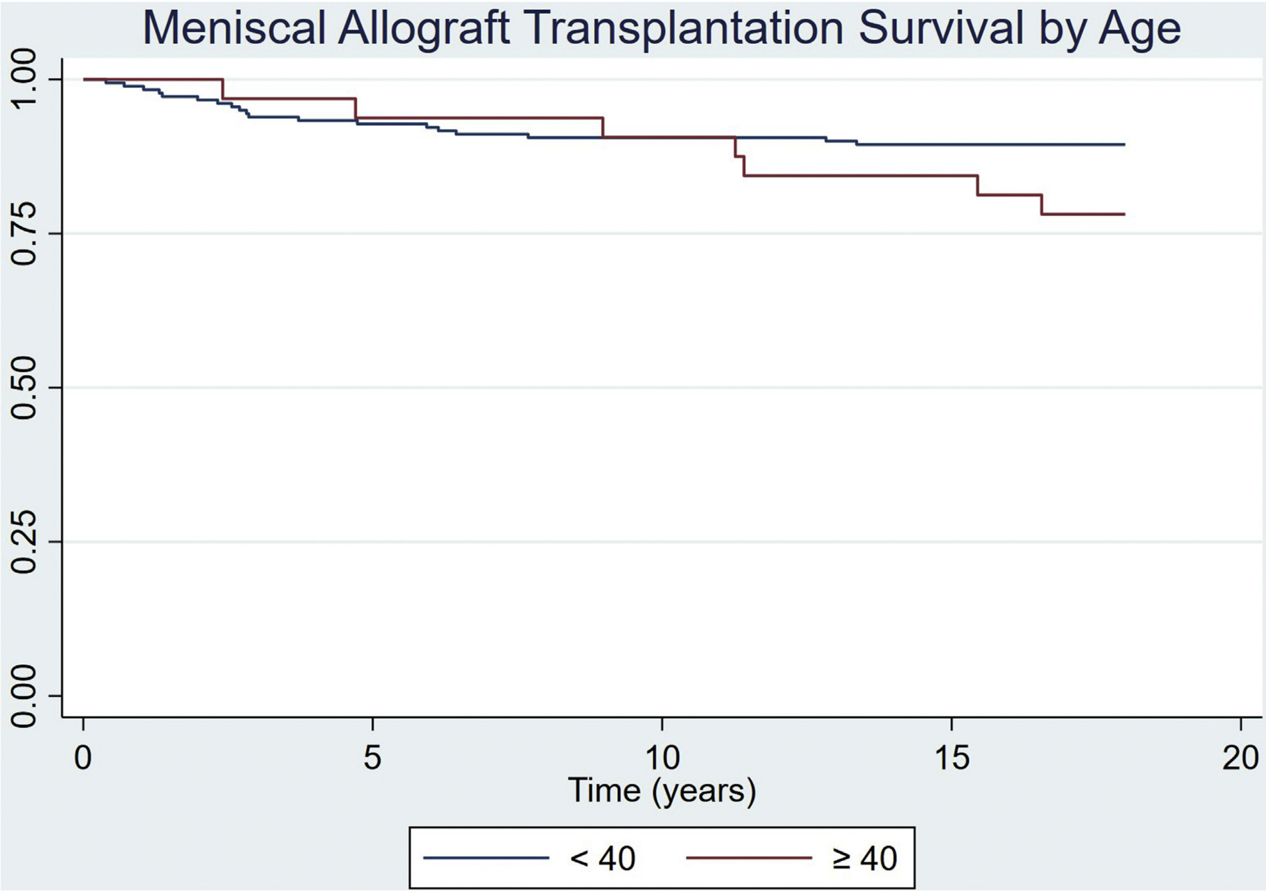

Fig 1. Kaplan−Meier survival probabilities were obtained for failed grafts, with patients aged ≥40 years demonstrating a mean time to failure of 10.11 ± 5.21 years whereas patients aged <40 years had a mean time to failure of 3.85 ± 3.80 years ($P = .018$). Survival probabilities at 1, 2, 3, 5, and 10 years, respectively, were 100.0%, 100.0%, 96.9%, 93.8%, and 90.6% for patients aged ≥40 years and 98.9%, 96.7%, 93.9%, 92.8%, and 90.6% for patients aged <40 years. The log-rank test demonstrated no significant difference in survival distributions between the groups ($P = .094$).

83/180 [46.1%], P = <.0001), whereas patients younger than 40 years were more likely to undergo a lateral meniscal transplant (≥40: 5/32 [15.6%], <40: 96/180 [53.3%], P = <.0001) (Appendix 1). There were no other significant differences in concomitant procedure or survival distributions between both groups.

Subgroup Analysis Based on Sex

Both male and female patients demonstrated significant improvement in IKDC, Lysholm, KOOS (Symptoms, Pain, Daily Living, Sports and Quality of Life), SF-12 and VR-12 physical subscores and VR6D (P<.05) (Appendix 3, Fig 3). Female patients also showed a significant improvement in KOOS JR and PS ($P < .05$). Between the 2 sexes, female patients had greater postoperative IKDC, pre- and postoperative Lysholm, preoperative KOOS QoL, postoperative KOOS scores (other than KOOS symptoms [$P = .055$]), preoperative WOMAC total scores, preoperative SF-12 physical subscores and postoperative VR6D scores than male patients ($P < .05$). In terms of MCID, 42/60 (70.0%) female and 30/57 (52.6%) male patients achieved MCID for IKDC and 41 of 67 (61.2%) female and 36 of 62 (58.1%) male patients achieved MCID for KOOS symptoms. No significant differences were noted between either group in terms of achievement of MCID for IKDC ($P = .055$) or KOOS symptoms ($P = .720$).

Female patients were more likely to have had a previous lateral meniscectomy before meniscal transplant (males: 45/105 [42.9%], females: 66/107 [61.7%], $P = .003$). Male patients were more likely to undergo a concomitant high tibial osteotomy (males: 12/105 [11.4%], females 3/107 [2.8%], $P = .014$). In terms of revision transplant, female patients were statistically more likely to undergo revision (males: 2/105 [1.9%], females: 9/107 [8.4%], $P = .033$ No statistically significant differences could be demonstrated in the rate of complications (males: 8/105 [7.6%], females: 6/107 [5.6%], $P = .555$) or time to failure between the sexes (males: 5.48 ± 4.89 years, females: 5.39 ± 5.07 years, $P = .966$) (Fig 4).

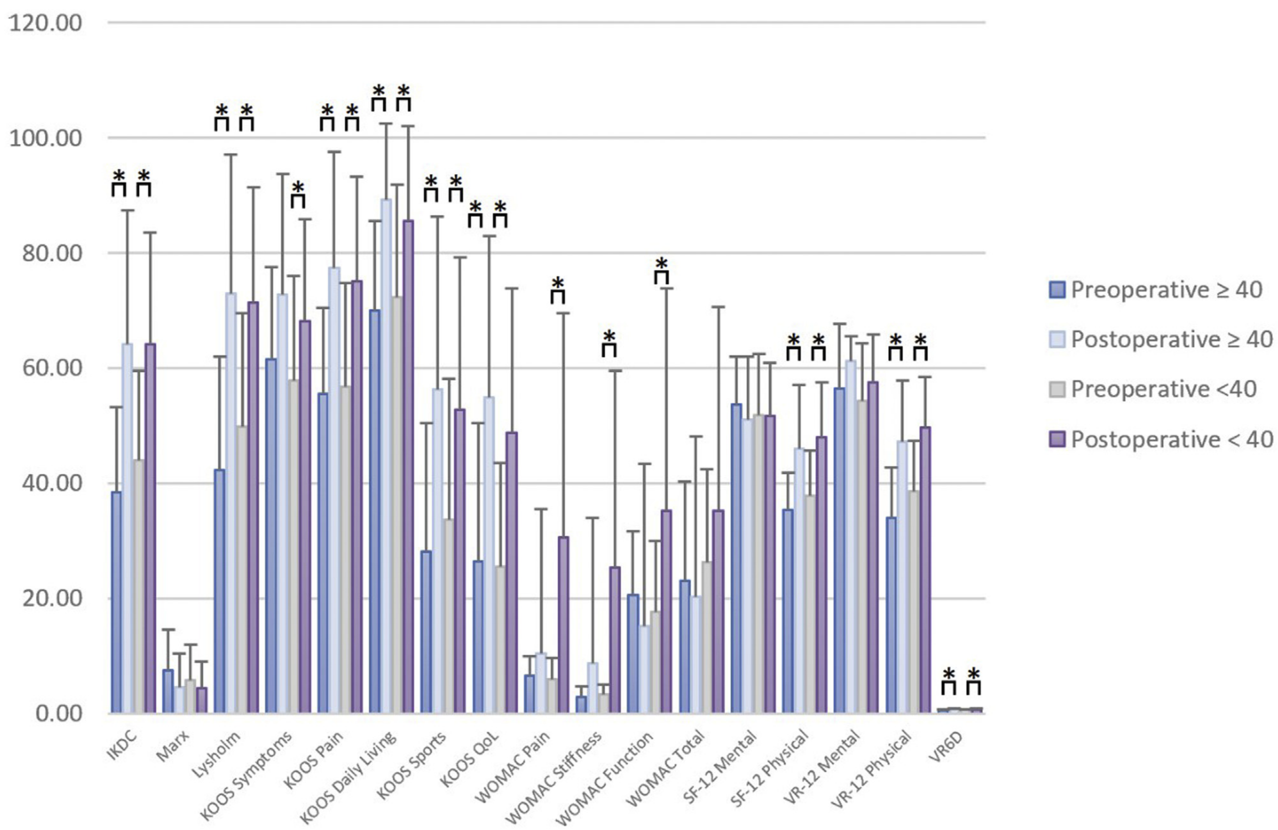

Fig 2. Summary of patient-reported outcome scores pre- and postoperatively stratified by age with a mean follow-up time of 5.1 ± 3.4 years. Patients in both age groups demonstrated significant improvements in International Knee Documentation Committee (IKDC), Lysholm and Knee Injury and Osteoarthritis Outcome Score (KOOS, other than KOOS symptoms [$P = .053$]), Short Form−12 (SF-12) physical scores, Veterans RAND-12 (VR-12) physical scores, and Veterans RAND 6D scores as compared with preoperative values ($P < .05$ for both groups). The younger patient group had significant improvements in Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores as well ($P < .05$). Postoperative Marx, SF-12 mental subscores, and VR-12 mental subscores were not significantly improved at final follow-up for either group ($P \geq .05$ for both groups). The patient-reported outcome scores marked with asterisks showed a significant improvement in scores ($P < .05$). Data shown as mean ± standard deviation.

Subgroup Analysis Based on Age and Sex

When stratifying by both age and sex, the younger male group was more likely to undergo concomitant high tibial osteotomy (males <40 year: 9/85 [10.6%], females <40 years: 3/95 [3.2%], $P = .046$) (Appendix 4). The younger female group was found to have failed previous lateral meniscectomy more so than the younger male group (males <40 years: 40/85 [47.1%], females <40 years: 61/95 [64.2%], $P = .009$). All 4 groups had a statistically significant improvement in IKDC, Lysholm, KOOS (Symptoms, Pain, and Daily Living), and SF-12 physical subscores ($P < .05$) (Appendix 5, Fig 5). The older male group is the only group to not have a statistically significant improvement in KOOS Sports and Quality of living ($P \geq .05$). The younger male and female groups both VR-12 physical subscores and VR6D, and younger female patients also showed improvement in VR-12 mental subscores ($P < .05$). There were no significant differences in the rate of complications (≥40, $P = .163$; <40, $P = .843$), reoperation (≥40, $P = .721$; <40, $P = .902$), failure (≥40, $P = .278$; <40, $P = .144$), or time to failure ($P = .072$) between the sexes when stratified by age (Fig 6).

Logistic Regression

A logistic regression model using sex, age, BMI, traumatic etiology, laterality of MAT, and major concomitant procedure at time of MAT was used to assess risk factors predictive of failure. The results of this model are found in Appendix 6. When using logistic regression to test each risk factor for failure independently, traumatic etiology was found to have a protective effect and led to less failure (OR 0.347; 95% confidence interval [CI] 0.139-0.866; $P = .023$). Furthermore, univariate analysis revealed that patients with increased age (OR 1.115; 95% CI 1.037-1.200; $P = .003$), BMI (OR 1.164; 95% CI 1.011-1.340; $P = .035$), and those undergoing concomitant anterior cruciate ligament reconstruction (ACLR; OR, 5.714; 95% CI

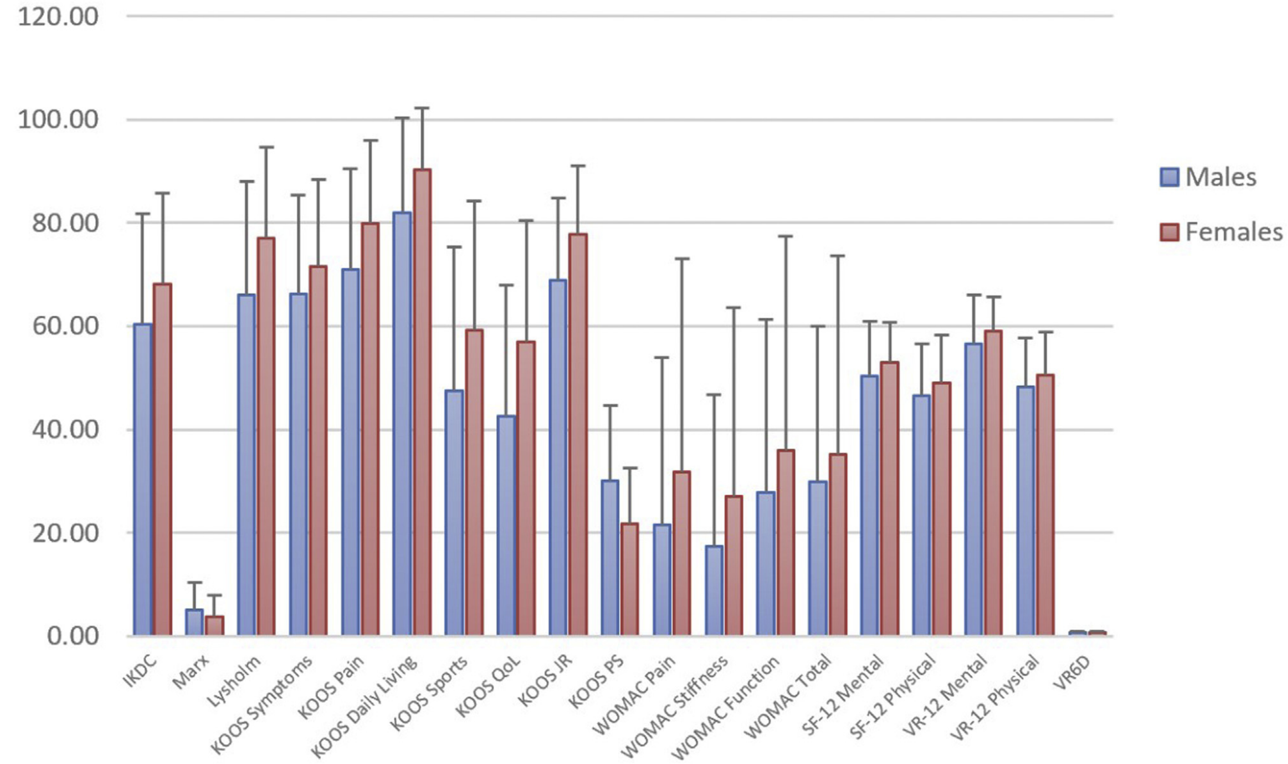

Fig 3. Most recent patient-reported outcome scores stratified by sex at a mean follow-up of 5.1 ± 3.4 years. Both groups showed a significant improvement in International Knee Documentation Committee (IKDC), Lysholm, Knee Injury and Osteoarthritis Outcome Score (KOOS; Symptoms, Pain, Daily Living, Sports, and Quality of Life), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) Pain and stiffness, Short Form−12 (SF-12) and Veterans RAND-12 (VR-12) physical subscores, and VR6D ($P < .05$). Female patients also showed a significant improvement in VR-12 mental subscores, WOMAC function and overall, and KOOS JR and PS ($P < .05$). Between the 2 sexes, female patients had greater postoperative IKDC, pre- and postoperative Lysholm, preoperative KOOS QoL, postoperative KOOS scores (other than KOOS symptoms [$P = .055$]), preoperative WOMAC total scores, preoperative SF-12 physical subscores, and postoperative VR6D scores than male patients ($P < .05$). Data shown as mean ± standard deviation.

1.491-21.899; $P = .011$) were more likely to undergo total knee arthroplasty post meniscal transplant. Patients with traumatic etiologies (OR 0.125; 95% CI 0.031-0.506; $P = .004$) were less likely to undergo revision meniscal transplant. Male patients <40 years demonstrated a mean time to failure of 2.95 ± 1.89 years, while female patients <40 years showed a mean time to failure of 4.21 ± 4.32 years ($P = .364$).

Discussion

The principal findings from this investigation were that nearly all evaluated PROs were significantly improved in both patients aged ≥40 years and those <40 years following primary MAT at final follow-up, with no significant differences in complication rate, reoperation rate, time to reoperation, and failure rate between age groups, disproving our hypothesis. When analyzed based on patient sex, both male and female patients demonstrated significant improvement in most PROs, whereas female patients were more likely to undergo revision surgery, while no significant differences in complication rate, time to reoperation, or failure rates were observed. Male patients aged <40 years were significantly more likely to undergo concomitant high tibial osteotomy while a traumatic etiology was found to be protective, leading to lower transplantation failure rates and fewer revision surgeries. Patients of older age, increasing BMI, or requiring concomitant ACLR were more likely to require total knee arthroplasty following MAT.

When evaluating patients based on age (≥40 vs those <40 years), we found significant improvements in multiple outcome scores were reported in both groups when compared with preoperative values. Concern regarding MAT outcomes and graft survival have been raised in older patients, especially those older than 50-55 years due to greater likelihood of degenerative changes to the chondral surface with resultant axial malalignment.[20,23,24] These characteristics have been shown to be more amendable to total joint replacement versus MAT.[7,24-26] As such, the increasing incidence and degree of osteoarthritis seen in patients with

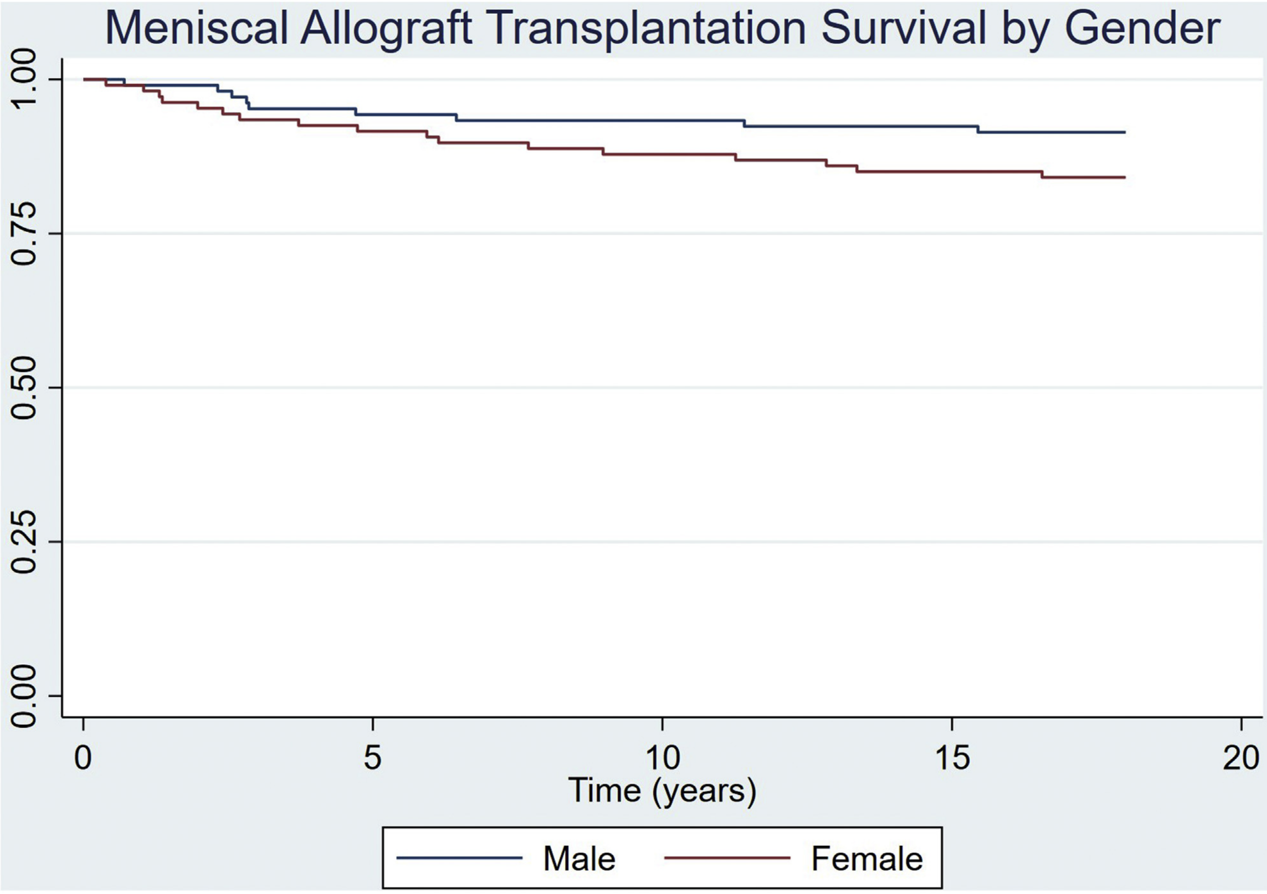

Fig 4. Kaplan–Meier survival probabilities were obtained for failed grafts, with male patients demonstrating a mean time to failure of 5.48 ± 4.89 years whereas female patients had a mean time to failure of 5.39 ± 5.07 years (P = .966). Survival probabilities at 1, 2, 3, 5, and 10 years, respectively, were 99.1%, 99.1%, 95.2%, 94.3%, and 93.3% for male and 99.1%, 95.3%, 93.5%, 91.6%, and 87.9% for female patients. The log-rank test demonstrated no significant difference in survival distributions between the groups (P = .106).

increasing age, secondary to a cumulative exposure of various risk factors and age-related changes within the joint, likely account for the greater rate of older patients requiring TKA following MAT in our investigation.[27] The influence of associated arthritic changes on MAT outcomes was further demonstrated by Saltzman et al.[28] in their evaluation of 60 magnetic resonance imaging scans in patients undergoing isolated MAT with a mean follow-up of 4.9 ± 2.3 years. The authors reported that increasing severity and size of preoperative tibial subchondral bone marrow lesions were associated with worse postoperative pain and activity ratings. Investigations have disputed the impact of increasing patient age as a negative predictor for outcomes following MAT. Recently, Song et al.[29] analyzed the relationship between age and MAT survivorship. In a cohort of 264 patients, they found MAT survivorship was more affected by age-related prognostic factors, such as cartilage status and time from previous meniscectomy, rather than age itself. However, their study differs from the present study by several factors including the use of bone plugs for lateral MAT and a minimum 6 months' follow-up. The meta-analysis by De Bruycker et al.[30] of 65 articles comprising 2977 patients with a mean age of 33 years (range 9-51 years) with a mean follow-up of 5.4 years found that patient age was not found to be a determinant variable at final follow-up associated with outcome scores or graft survival.

Similarly, this investigation did not demonstrate significant differences in complication rate, reoperation rates, time to reoperation, or failure rates between age groups. In their assessment of 60 patients undergoing MAT at a mean age of 35.6 ± 7.5 years and mean follow-up of 3.4 ± 1.6 years, Searle et al.[21] found on binary multiple logistic regression that increasing patient age was not significantly associated with an increased risk for surgical (P = .077) or clinical failure (P = .243) postoperatively. The influence of patient age on MAT outcomes remains unclear, however this is likely related to presence of osteoarthritic changes. We found a 90.6% 10-year survival rate in both the ≥40

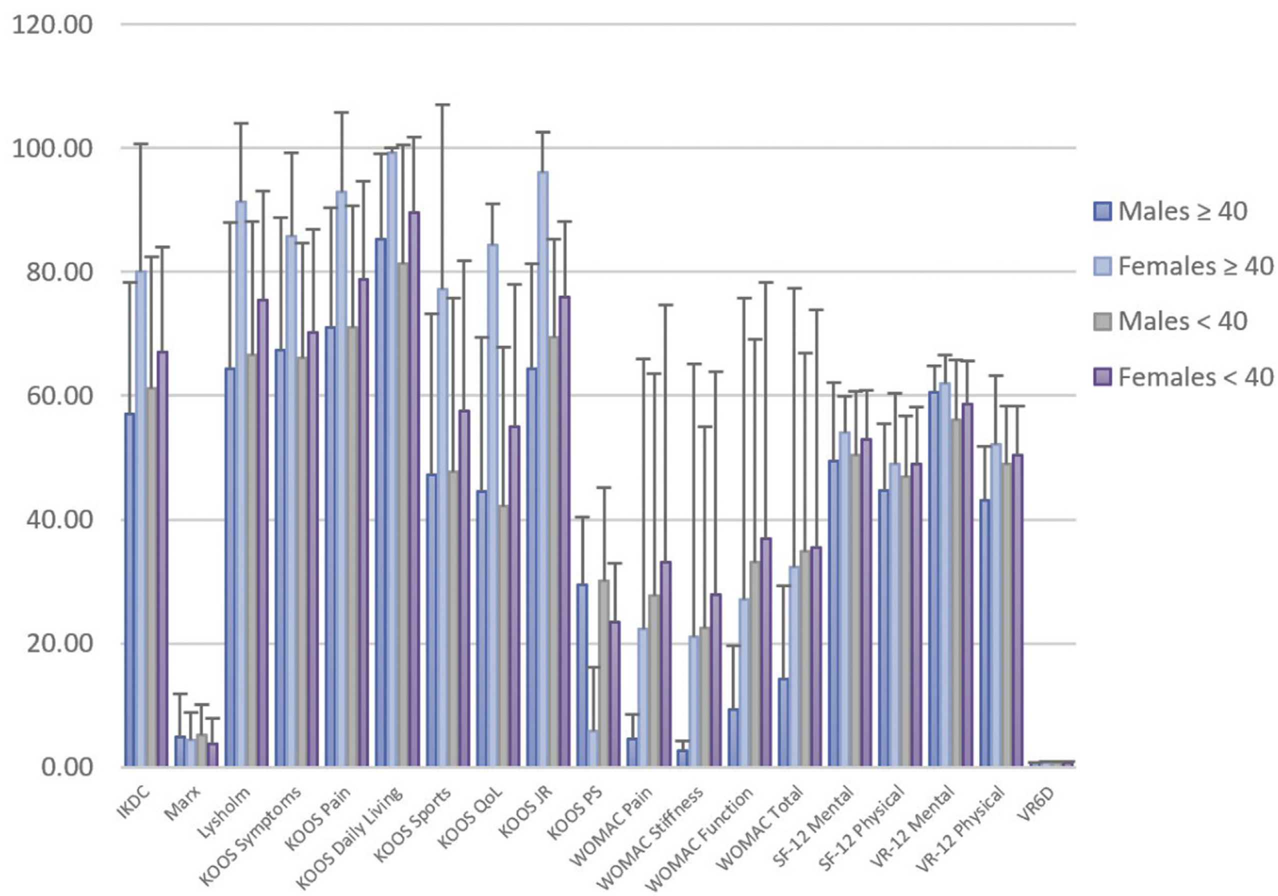

Fig 5. Final patient-reported outcome scores at a mean follow-up of 5.08 ± 3.84 years for male patients aged ≥40 years, 6.20 ± 2.97 years for female patients aged ≥40 years, 5.03 ± 3.17 years for male patients aged <40 years, and 4.46 ± 2.53 years for female patients aged <40 years. All 4 groups had a statistically significant improvement in International Knee Documentation Committee (IKDC), Lysholm, Knee Injury and Osteoarthritis Outcome Score (KOOS; Symptoms, Pain, and Daily Living), and SF-12 physical subscores ($P < .05$). The older male group is the only group to not have a statistically significant improvement in KOOS Sports and Quality of living ($P \geq .05$). The younger male and female groups both have a significant improvement in WOMAC pain and stiffness, VR-12 physical subscores and VR6D, and younger female patients also showed improvement in WOMAC function and VR-12 mental subscores ($P < .05$). Data shown as mean ± standard deviation.

years group and <40 years group. As such, in the appropriately indicated patient without severe cartilage degeneration and osteoarthritic changes with concurrent joint malalignment, MAT appears safe in patients ≥40 years with comparable improvements in outcomes when compared with patients <40 years of age.

When analyzed based on sex, female patients were found to report greater PROs in multiple categories when compared with male patients. Of the few previous studies that have separately analyzed differences in outcomes between male and female patients, conflicting results have been reported. In their analysis of 57 patients (n = 40 males, n = 17 females) undergoing 63 cryopreserved MATs with a minimum follow up of 9 years, van der Wal et al.[31] found that male patients were found to report significantly greater Lysholm ($P =$ .001), IKDC ($P = .002$), and 3 subgroups of the KOOS score (pain, symptoms, function in activities daily living; $P = .014$).[31] The authors were unable to explain the reasons behind these findings, whereas no separate subgroup analysis based on sex was performed when evaluating the incidence of graft failure and time to failure. Meanwhile, Liu et al.[16] found in their study of 50 male and 48 female patients undergoing MAT that when analyzing patient achievement of minimal clinically important difference (MCID) and patient acceptable symptomatic state, sex was not found to be associated with greater odds of achieving either MCID or patient acceptable symptomatic state. In addition, the meta-analysis by De Bruycker et al.,[30] including 1982 male and 898 female patients found no correlation when examining outcomes based on patient sex. The reasons for the differences in outcome score between male and female patients are beyond the scope of our investigation; however, the inherent differences between sexes in the dimensions of the distal femur,

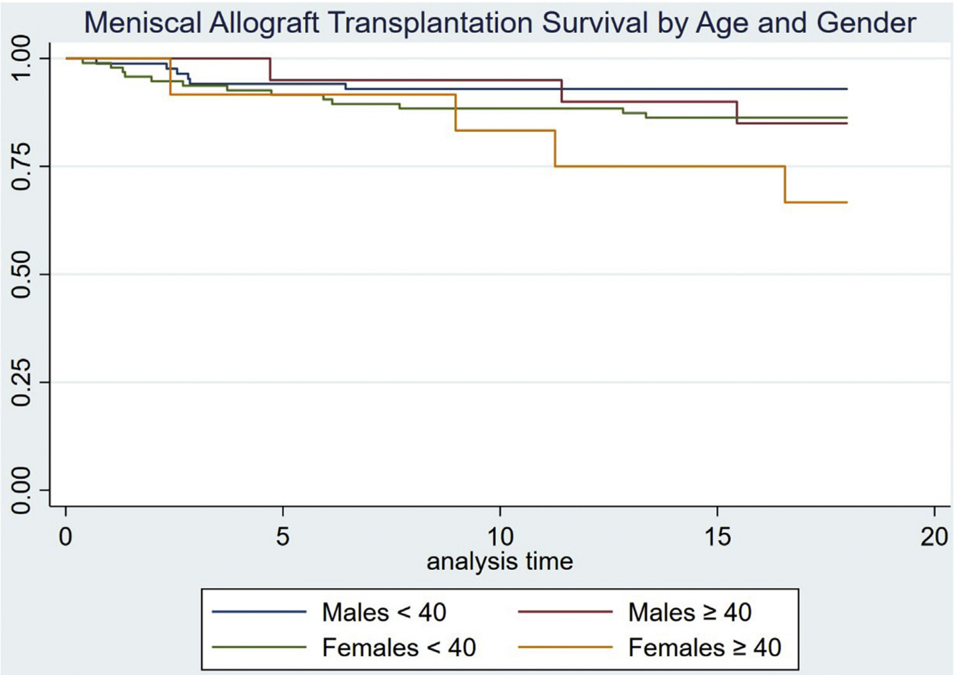

Fig 6. Kaplan–Meier survival probabilities were obtained for failed grafts, with male patients ≥40 years demonstrating a mean time to failure of 10.52 ± 5.43 years whereas female patients ≥40 years had a mean time to failure of 9.80 ± 5.86 years (P = .873). Male patients <40 years demonstrated a mean time to failure of 2.95 ± 1.89 years, whereas female patients <40 years showed a mean time to failure of 4.21 ± 4.32 years (P = .364). Survival probabilities at 1, 2, 3, 5, and 10 years for male patients ≥40 years were 100.0%, 100.0%, 100.0%, 95.0%, and 95.0%, and 100.0% and 100.0%, 91.7%, 91.7%, and 83.3% for female patients ≥40 years. Survival probabilities at 1, 2, 3, 5, and 10 years for male patients <40 years were 98.8%, 98.8%, 94.1%, 94.1% and 92.9%, and 99.0%, 94.7%, 93.7%, 91.6%, and 88.4% for female patients <40 years. The log-rank test demonstrated no significant difference in survival distributions between the groups (P = .0716).

proximal tibia, and patella, as well as differences in surgical technique, graft size, and graft selection across studies likely account for the heterogeneity of findings in the present literature.[32]

Female patients also were found to undergo MAT revision at a greater rate when compared with male patients. This finding conflicts with the results reported in the cohort study by Parkinson et al.[33] of 124 patients (n = 86 male, n = 39 female) undergoing MAT, in which the authors found that patient sex was not predictive of graft survival or the need for revision surgery (P = .48). However, despite a comparable mean age at the time of surgery (male, 31 years; female, 28.5 years) with our investigation, these findings may be explained by the shorter mean follow-up in the study by Parkinson et al.[33] (3 years) when compared with our investigation (5.1 years). As such, further investigations examining long-term outcomes and graft survival rates following MAT between male and female patients are warranted.

The necessity of performing a major concomitant procedure during MAT, primarily osteochondral allograft and ACLR, was not found to cause significant difference in outcome score or graft survival compared with those undergoing only MAT. Several previous investigations have demonstrated improved outcomes in which MAT is performed in knees with concurrent ligamentous instability, malalignment, or focal cartilage wear, whereas failure to address these issues has been shown to result in inferior outcomes.[25,26,34,35] In their systematic review and meta-analysis, Lee et al.[36] reported that in 4 studies comparing isolated MAT with MAT + ACL in patients with ACL insufficiency, no significant differences were appreciated when evaluating Lysholm score.[35-39] Meanwhile, several other investigations have reported improved allograft survival when MAT is performed with ACLR.[40,41] The greater rate of TKA in patients undergoing MAT with concurrent ACLR may likely be related to the greater prevalence of pre-existing chondral injuries in the ACL and meniscal deficit joint, shown to result in inferior outcomes with deterioration of outcome scores compared to patients with stable knees.[42-44]

Meanwhile, in their investigation on 100 patients undergoing osteochondral allograft with or without MAT, Frank et al.[45] found significant improvements in Lysholm, IKDC, KOOS, WOMAC, and SF-12 physical scores when compared with preoperative values, with no significant differences in reoperation rates, time to reoperation, failure rates, or improvements in PROs between groups. Meanwhile, the systematic review by Harris et al.[46] of 6 studies in 110 patients undergoing combined MAT with cartilage repair or restoration reported a failure rate of 12%, while Getgood et al.[25] found a 10-year survivorship of 69% for MAT and 68% for cartilage repair in their retrospective review of 48 patients. In our investigation, male patients were found to undergo high tibial osteotomy at a greater rate compared with female patients. As such, despite the increased risk of concomitant surgery secondary to increased surgical time and rehabilitation time, performance of appropriate indicated concurrent procedures can improve outcomes without increasing the risk for failure or reoperation.

Patients with a reported traumatic mechanism of injury were less likely to require revision MAT when compared with patients experiencing a degeneration meniscal lesion. When compared with traumatic lesions, the presence of degenerative meniscal lesions is considered an early indicator for osteoarthritic development and representative of a decrease in the overall health of the knee joint, especially in middle-aged patient.[47-52] Due to the slowly degenerative process occurring over several years responsible for the development of degenerative meniscal tears, continued hoop and shear stresses on the degenerative meniscus results in gross failure, with resultant simultaneous pathology to the articular surface within the knee joint and joint malalignment.[53,54]

Limitations

This study has limitations. This study involved a retrospective review of a prospectively collected database spanning 18 years, introducing the potential for reporting bias and other confounders inherent to a retrospective review. Data are also limited to the accuracy of the inputted information, as multiple examiners collected and recorded preoperative, intraoperative, and postoperative data. Due to the duration of study data collection, changes and advancement in technology and instrumentation, as well as the surgical expertise of the senior author, have occurred, potentially confounding the reported outcomes in patients with the passage of time. There was also a significant difference in the number of patients in the older and younger group. A power analysis for failure rates found that 43 patients would be needed in each group to find a significant difference, but although our study represents one of the largest MAT cohorts available in the literature, we were only able to include 32 patients in the ≥40 years group, increasing the risk of a beta error.[18] Also, it was not possible to match patients in a 1:1 format between the 2 groups based on other demographic characteristics, such as BMI, worker's compensation status, smoking status, athlete status, and type of previous surgery. While we accounted for a variety of variables between patients based on sex and age, there is likely additional factors such as alignment that were not accounted for that may confound the data presented in the present investigation. Due to the time period in which study data were collected, some PRO measures were not available or collected during the entirety of the study period. A total of 73.6% (n = 156) of patients underwent a concomitant procedure, as such contribution of MAT to changes in postoperative outcomes are unknown.

Conclusions

PROs similarly improved following MAT in both patients aged ≥40 years and those <40 years at final follow-up with no significant differences in MCID achievement rate, complication rate, reoperation rate, time to reoperation, or failure rate between groups. Female patients may be more likely to undergo revision surgery after MAT.

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Appendix

Appendix 1. Transplant Side, Major Concomitant Procedures, and Outcomes Based on Age

	<40 years	≥40 years	*P* value
Transplant side			<.0001*
Medial	83 (39.2%)	27 (12.7%)	
Lateral	96 (45.3%)	5 (2.4%)	
Medial and lateral	1 (0.5%)	0 (0%)	
Any concomitant procedure	128 (71.1%)	28 (87.5%)	.053
OCA	87 (48.33%)	20 (62.5%)	.140
Ligament repair/reconstruction	20 (11.1%)	5 (15.6%)	.466
HTO	12 (6.7%)	3 (9.4%)	.582
DFO	9 (5.0%)	0 (0%)	.196
Complication rate, %	12/180 (6.7%)	2/32 (6.3%)	.930
Reoperation rate, %	58/180 (32.2%)	12/32 (37.5%)	.559
Time to reoperation, y ± SD	1.87 ± 1.98	1.49 ± 1.77	.591
Failure rate, %	19/180 (10.6%)	7/32 (21.9%)	.072

NOTE. Data are shown as n (%).

DFO, distal femoral osteotomy; HTO, high tibial osteotomy; MAT, meniscus allograft transplantation; OCA, osteochondral allograft; SD, standard deviation.

*Statistically significant result $P < .05$.

Appendix 2. Patient-Reported Outcome Scores by Age Group Preoperatively and at Most Recent Follow-up

	<40 Years			≥40 Years		
	Preoperative	Postoperative	*P* Value	Preoperative	Postoperative	*P* Value
IKDC	42.87 ± 15.36	62.39 ± 20.13	<.0001*	37.63 ± 13.33	63.06 ± 23.11	.0017*
Marx	5.57 ± 6.13	4.56 ± 4.76	.7186	4.61 ± 5.30	4.56 ± 4.76	.2783
Lysholm	48.91 ± 19.66	70.30 ± 20.08	<.0001*	41.95 ± 18.98	73.28 ± 23.95	.0010*
KOOS Symptoms	58.33 ± 18.41	67.28 ± 17.93	<.0001*	58.92 ± 16.73	73.85 ± 20.69	.0147*
KOOS Pain	56.16 ± 17.59	74.10 ± 18.61	<.0001*	53.92 ± 15.17	76.79 ± 20.04	.0003*
KOOS Daily Living	71.48 ± 19.76	84.89 ± 16.95	<.0001*	68.82 ± 14.97	86.66 ± 15.44	.0067*
KOOS Sports	32.49 ± 24.29	51.52 ± 27.03	<.0001*	29.05 ± 20.95	55.50 ± 31.39	.0312*
KOOS QoL	26.11 ± 18.26	47.83 ± 25.24	<.0001*	27.72 ± 21.96	54.17 ± 27.87	.0075*
KOOS JR	58.90 ± 14.42	71.98 ± 14.42	.0115*	57.14 ± 0.00	77.63 ± 19.94	–
KOOS PS	38.36 ± 10.37	27.49 ± 13.43	.0036*	–	20.64 ± 16.71	–
WOMAC Pain	6.23 ± 3.56	30.20 ± 37.69	.1982	7.30 ± 3.17	9.00 ± 21.82	.7860
WOMAC Stiffness	3.22 ± 1.67	25.16 ± 33.62	.1742	3.09 ± 1.81	6.95 ± 21.40	.4521
WOMAC Function	17.90 ± 12.39	35.09 ± 37.73	.9170	21.39 ± 10.60	16.06 ± 25.07	.4514
WOMAC Overall	26.80 ± 16.00	35.58 ± 33.39	.2690	26.95 ± 16.87	23.13 ± 26.96	.7443
SF-12 Mental	51.62 ± 11.15	51.73 ± 9.30	.3700	54.42 ± 8.00	49.77 ± 12.32	.0577
SF-12 Physical	38.15 ± 8.12	47.26 ± 9.66	<.0001*	35.38 ± 6.18	46.72 ± 10.62	.0027*
VR-12 Mental	53.82 ± 10.35	57.38 ± 8.40	.2273	56.40 ± 11.30	59.94 ± 7.82	.5145
VR-12 Physical	38.69 ± 9.08	48.86 ± 8.85	<.0001*	34.05 ± 8.68	47.56 ± 10.01	.9112
VR6D	0.66 ± 0.09	0.75 ± 0.11	.0018*	0.63 ± 0.07	0.77 ± 0.12	.5232

NOTE. Data presented as mean ± standard deviation.

IKDC, International Knee Documentation Committee; JR, Joint Replacement; KOOS, Knee Injury and Osteoarthritis Outcome Score; QoL, Quality of Life; PS, Physical Function Short Form; SF-12, Short Form—12; VR6D, Veterans RAND 6D; VR-12, Veterans RAND 12 Item Health Survey; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

*Statistically significant result at $P < .05$.

Appendix 3. Patient-Reported Outcome Scores by Sex Preoperatively and at Most Recent Follow-up

	Male			Female		
	Preoperative	Postoperative	*P* Value	Preoperative	Postoperative	*P* Value
IKDC	41.68 ± 15.57	59.47 ± 21.64	<.0001*	42.12 ± 15.80	65.59 ± 19.02	<.0001*
Marx	5.23 ± 6.45	5.19 ± 5.30	.6159	6.10 ± 5.97	4.03 ± 4.31	.0872
Lysholm	45.06 ± 20.39	66.55 ± 22.00	<.0001*	50.10 ± 18.68	74.79 ± 18.80	<.0001*
KOOS Symptoms	57.67 ± 18.96	66.51 ± 19.72	.0002*	59.12 ± 17.32	70.04 ± 17.13	<.0001*
KOOS Pain	53.96 ± 19.28	70.69 ± 20.05	<.0001*	57.37 ± 15.06	78.16 ± 16.86	<.0001*
KOOS Daily Living	68.68 ± 18.80	81.19 ± 19.21	<.0001*	73.01 ± 18.97	88.90 ± 12.95	<.0001*
KOOS Sports	32.16 ± 24.03	47.74 ± 28.56	.0032*	31.66 ± 23.59	56.36 ± 26.29	<.0001*
KOOS QoL	22.79 ± 17.83	42.27 ± 25.51	<.0001*	29.67 ± 19.30	55.13 ± 24.35	<.0001*
KOOS JR	50.80 ± 31.88	69.02 ± 15.95	.1430	60.22 ± 10.59	76.17 ± 13.98	.0200*
KOOS PS	43.07 ± 16.40	30.38 ± 15.40	.1455	36.95 ± 8.60	23.14 ± 11.77	.0070*
WOMAC Pain	6.80 ± 3.76	20.54 ± 31.46	.7478	6.16 ± 3.20	29.63 ± 38.92	.2177
WOMAC Stiffness	3.29 ± 1.83	16.45 ± 28.38	.7548	3.08 ± 1.57	24.82 ± 34.73	.1273
WOMAC Function	20.46 ± 12.02	27.70 ± 32.41	.1909	17.11 ± 11.90	27.70 ± 39.27	.8110
WOMAC Overall	30.61 ± 17.08	30.46 ± 29.61	.0520	23.30 ± 14.44	35.24 ± 36.17	.8724
SF-12 Mental	53.33 ± 10.90	50.24 ± 10.96	.110	51.09 ± 10.52	52.55 ± 8.53	.9485
SF-12 Physical	35.90 ± 7.47	46.12 ± 9.96	<.0001*	39.12 ± 7.95	48.19 ± 9.58	<.0001*
VR-12 Mental	56.19 ± 10.50	56.60 ± 9.55	.4798	52.43 ± 10.10	58.68 ± 7.03	.2316
VR-12 Physical	37.79 ± 8.75	47.95 ± 9.26	.0186*	38.64 ± 9.43	49.36 ± 8.74	.0026*
VR6D	0.66 ± 0.08	0.73 ± 0.11	.0155*	0.65 ± 0.10	0.76 ± 0.10	.0400*

NOTE. Data presented as mean ± standard deviation.

IKDC, International Knee Documentation Committee; JR, Joint Replacement; KOOS, Knee Injury and Osteoarthritis Outcome Score; QoL, Quality of Life; PS, Physical Function Short Form; SF-12, Short Form−12; VR6D, Veterans RAND 6D; VR-12, Veterans RAND 12 Item Health Survey; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

*Statistically significant result at $P < .05$.

Appendix 4. Transplant Side and Major Concomitant Procedures Based on Age and Sex

	< 40 Years			≥40 Years		
	Male	Female	*P* Value	Male	Female	*P* Value
Transplant side			.247			.900
Medial	44 (20.8%)	39 (18.4%)		17 (8%)	10 (4.7%)	
Lateral	41 (19.3%)	55 (25.9%)		3 (1.4%)	2 (0.9%)	
Bilateral	0 (0%)	1 (0.5%)		0 (0%)	0 (0%)	
Any concomitant procedure			.608			.098
Yes	62 (29.2%)	66 (31.1%)		16 (7.5%)	12 (5.7%)	
No	23 (10.8%)	29 (13.7%)		4 (1.9%)	0 (0%)	
OCA			.534			.258
Yes	39 (18.4%)	48 (22.6%)		11 (5.2%)	9 (4.2%)	
No	46 (21.7%)	47 (22.2%)		9 (4.2%)	3 (1.4%)	
Ligament repair/reconstruction			.225			.900
Yes	12 (5.7%)	8 (3.8%)		3 (1.4%)	2 (0.9%)	
No	73 (34.4%)	87 (41%)		17 (8.0%)	10 (4.7%)	
HTO			.046*			.159
Yes	9 (4.2%)	3 (1.4%)		3 (1.4%)	0 (0%)	
No	76 (35.8%)	92 (43.4%)		17 (8.0%)	12 (5.7%)	
DFO			.864			
Yes	4 (1.9%)	5 (2.4%)		0 (0%)	0 (0%)	
No	81 (38.2%)	90 (42.5%)		20 (9.4%)	12 (5.7%)	

NOTE. Data are shown as n (%).

DFO, distal femoral osteotomy; HTO, high tibial osteotomy; MAT, meniscus allograft transplantation; OCA, osteochondral allograft.

*Statistically significant result $P < .05$.

Appendix 5. Patient-Reported Outcomes by Age and Sex at Final Follow-up

	<40 Years			≥40 Years		
	Male	Female	*P* Value	Male	Female	*P* Value
IKDC	61.13 ± 21.37	67.06 ± 16.98	.063	57.12 ± 21.23	80.09 ± 20.64	.167
Marx	5.15 ± 5.02	3.78 ± 4.09	.120	4.86 ± 7.01	4.33 ± 4.50	.874
Lysholm	66.56 ± 21.64	75.50 ± 17.53	.013*	64.40 ± 23.65	91.29 ± 12.72	.003*
KOOS Symptoms	66.07 ± 18.58	70.26 ± 16.66	.141	67.44 ± 21.39	85.71 ± 13.52	.022*
KOOS Pain	71.02 ± 19.59	78.75 ± 15.96	.008*	71.08 ± 19.27	92.86 ± 12.91	.005*
KOOS Daily Living	81.26 ± 19.19	89.56 ± 12.16	.002*	85.29 ± 13.77	99.27 ± 0.81	.002*
KOOS Sports	47.67 ± 28.16	57.56 ± 24.17	.021*	47.19 ± 26.07	77.14 ± 29.84	.044*
KOOS QoL	42.08 ± 25.76	54.92 ± 23.00	.001*	44.49 ± 24.99	84.38 ± 6.56	<.001*
KOOS JR	69.47 ± 15.86	75.89 ± 12.30	.020*	64.31 ± 17.08	96.10 ± 6.48	<.001*
KOOS PS	30.16 ± 15.01	23.40 ± 9.52	.006*	29.49 ± 10.96	5.90 ± 10.21	.002*
WOMAC Pain	27.68 ± 35.92	33.15 ± 41.51	.583	4.50 ± 4.01	22.40 ± 43.49	.410
WOMAC Stiffness	22.52 ± 32.49	27.88 ± 35.97	.540	2.60 ± 1.65	21.00 ± 44.19	.405
WOMAC Function	33.12 ± 35.93	36.98 ± 41.26	.698	9.25 ± 10.32	27.00 ± 48.81	.522
WOMAC Overall	34.78 ± 32.19	35.50 ± 38.42	.939	14.25 ± 15.11	32.25 ± 45.17	.489
SF-12 Mental	50.42 ± 10.28	52.86 ± 7.95	.112	49.46 ± 12.69	54.10 ± 5.74	.231
SF-12 Physical	46.86 ± 9.92	48.99 ± 9.12	.179	44.62 ± 10.88	48.89 ± 11.44	.396
VR-12 Mental	56.11 ± 9.73	58.67 ± 6.92	.116	60.53 ± 4.34	61.90 ± 4.74	.602
VR-12 Physical	48.93 ± 9.45	50.37 ± 7.99	.388	43.12 ± 8.75	52.07 ± 11.16	.145
VR6D	0.74 ± 0.12	0.77 ± 0.10	.147	0.72 ± 0.08	0.83 ± 0.13	.107

NOTE. Data presented as mean ± standard deviation.

IKDC, International Knee Documentation Committee; JR, Joint Replacement; KOOS, Knee Injury and Osteoarthritis Outcome Score; PS, Physical Function Short Form; SF-12, Short Form—12; VR6D, Veterans RAND 6D; VR-12, Veterans RAND 12 Item Health Survey; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

*Statistically significant result at $P < .05$.

Appendix 6. Binary Multivariate Logistic Regression for Failure

	Odds Ratio	*P* Value	95% CI
Age	0.999	0.971	0.939-1.062
Sex (female vs male)	2.556	0.095	0.848-7.697
BMI	1.063	0.367	0.931-1.212
Traumatic etiology	0.387	0.077	0.135-1.107
Lateral vs medial MAT	0.840	0.734	0.308-2.297
Major concomitant procedure	2.316	0.229	0.589-9.106

BMI, body mass index; CI, confidence interval; MAT, meniscal allograft transplantation.