Prospective Clinical and Radiographic Outcomes After Concomitant Anterior Cruciate Ligament Reconstruction and Meniscal Allograft Transplantation at a Mean 5-Year Follow-up

Bryan M. Saltzman,*† MD, Maximilian A. Meyer,† BS, Alexander E. Weber,† MD, Sarah G. Poland,† BS, Adam B. Yanke,† MD, and Brian J. Cole,† MD, MBA
Investigation performed at Rush University Medical Center, Chicago, Illinois, USA

Background: Concomitant anterior cruciate ligament reconstruction and meniscal allograft transplantation (ACLR/MAT) has demonstrated short-term success in small, retrospective cohort studies. Patient- and disease-specific predictors of success after ACLR/MAT are largely unknown.

Purpose: To (1) prospectively evaluate the subjective and objective clinical and radiographic outcomes after ACLR/MAT and (2) conduct a subgroup analysis to identify patient- or disease-related factors that correlate with failure.

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

Methods: Patient-reported outcomes (PROs) were prospectively collected on 40 patients undergoing concomitant ACLR/MAT. Nineteen athletes responded to return-to-sport data. Clinical data (physical examination including Lachman and pivot-shift testing and KT-1000 arthrometer testing) were obtained on 28 patients who returned for an evaluation, while 24 of those patients additionally had radiographic data (progression of Kellgren-Lawrence [KL] grade and joint-space narrowing) evaluated. Reoperations and failures were documented for all patients at their final follow-up.

Results: The overall cohort of 40 patients had a mean age of 30.3 $\pm$ 9.6 years (range, 16.0-54.0 years) and a mean body mass index of 27.7 $\pm$ 4.2 kg/m^2. The mean follow-up time was 5.7 $\pm$ 3.2 years (range, 1.7-16.5 years). There were 33 (83%) medial meniscal transplants performed compared with 7 (17%) lateral meniscal transplants. Patients underwent a mean of 2.9 $\pm$ 1.9 prior surgical procedures. Nineteen patients underwent concomitant procedures, including, most commonly, 9 hardware removals and 9 osteochondral allografts. There were significant improvements in 12 of 15 PRO measures as well as a 50% return-to-sport rate. Knee stability significantly improved in 28 patients who returned for a physical examination, and KT-1000 arthrometer testing indicated no differences between the affected and unaffected sides at final follow-up (mean, 0.9 $\pm$ 1.5 mm [range, –2 to 4 mm] in comparison to contralateral knee at 30 lb of testing; mean, 0.9 $\pm$ 1.9 mm [range, –4 to 4 mm] in comparison to contralateral knee at maximum manual strength). Significant improvements were seen in patients with Lachman grade $\geq$2A at final follow-up (18% vs 97%, respectively; $P < .01$) and with pivot shift $\geq$1+ at final follow-up (36% vs 94%, respectively; $P < .01$) compared with preoperatively. For the 24 patients with radiographic data, no significant joint-space decrease was recorded in the medial compartment for medial MAT–treated patients or the lateral compartment for lateral MAT–treated patients. The mean KL grade increased from 0.7 $\pm$ 0.8 to 1.6 $\pm$ 0.9 at final follow-up ($P < .01$). There were no major (0%) and 2 minor (5%) complications, which constituted early postoperative drainage treated successfully with oral antibiotics. While 35% of patients underwent reoperations, the majority of these were simple arthroscopic debridements and occurred after nearly 4 years from the index surgery. The overall survival rate at final follow-up was 80%. Failures occurred at a mean of 7.3 years, and those who converted to arthroplasty did so at a mean of 8.3 years from the time of index ACLR/MAT. Patients with failed grafts were more frequently associated with workers' compensation claims (38% vs 13%, respectively) and less frequently self-identified as athletes (13% vs 56%, respectively) compared with patients with intact grafts.

Conclusion: Concomitant ACLR/MAT can provide significant improvements in clinical outcomes and enhancement in objective knee stability and was associated with an insignificant degree of radiographic joint-space narrowing changes with a 5-year survivorship of more than 80% for those with data available. Athlete status may be a preoperative predictor of midterm survival.

Keywords: meniscal allograft transplantation; MAT; anterior cruciate ligament reconstruction; ACLR

The meniscus provides an important role for the knee joint in terms of load transmission, stability, lubrication, proprioception, and shock absorption[10,17,35]; these functions are

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magnified in an anterior cruciate ligament (ACL)–deficient knee because of the resultant destabilization and altered transmission of loads across the joint.[1,17,18] In the setting of meniscal injuries, meniscal repair or partial meniscectomy is commonly utilized in lieu of total meniscectomy in an effort to maintain meniscal function. However, in the presence of complex tears, especially in the avascular zone of the meniscus, subtotal partial meniscectomy may be the only surgical treatment option available. The absence of the meniscus can lead to the progressive deterioration of articular cartilage and radiographic joint-space narrowing.[2,3,7,29] Meniscal allograft transplantation (MAT) has emerged in recent decades as a viable option for meniscal deficiency in young patients.[22]

MAT is indicated for patients ideally younger than 50 years with persistent pain in the meniscectomized compartment but is not appropriate in patients with diffuse arthritic changes, substantial joint-space narrowing, inflammatory arthritis, or marked obesity.[12,16,19] Additionally, coronal malalignment, cruciate ligament insufficiency, and/or focal chondral defects must be addressed either concomitantly or via staged procedures to provide a biomechanically sound knee for successful MAT.[12,16,19] In indicated patients, isolated MAT has demonstrated promising clinical and radiographic results from the short to long term,[8,15,27,33] with successful improvement in function, quality of life, and return to athletic competition.[28]

The available evidence indicates that associated procedures do not worsen the results of MAT.[28] Specifically, ACL reconstruction (ACLR) performed concomitantly with MAT has been the focus of several prior publications, with results suggesting good clinical outcomes, improved joint stability, and similar findings to historical results of ACLR or MAT performed in isolation.[5,9,26,30,35] However, these previous studies have had design limitations, including heterogeneous patient populations and surgical procedures, short-term follow-ups, small cohort sizes, incomplete standardization of outcome evaluations, and outdated surgical techniques.

The purpose of this study was to prospectively evaluate the subjective and objective clinical and radiographic outcomes after concomitant ACLR (primary or revision) and MAT. A secondary goal was to conduct a subgroup analysis of successful versus failed ACLR/MAT in an attempt to identify patient- or disease-related factors that correlate with failure of the procedure. Our primary hypothesis was that combined ACLR/MAT can be safely performed and lead to improvements in patient-reported outcomes (PROs) and objective functional outcomes and limit the progression of degenerative radiographic parameters in the short term to midterm. We also hypothesized that the subgroup analysis of successful versus failed ACLR/MAT would demonstrate no significant differences in patient- or disease-related factors.

METHODS

After institutional review board approval, all patients were selected from a database of prospectively collected data, and those requiring additional follow-up data returned to the clinic. Between 1999 and 2014, a total of 53 patients underwent concomitant ACLR/MAT by a single surgeon at a single academic medical center. Three patients had no preoperative, intraoperative, or postoperative data available because of the transition to an electronic medical record and so were excluded from this study. Of the remaining 50 patients available for inclusion, a cohort of 40 patients (80% follow-up) had completed clinical outcome surveys at a minimum 1.7-year follow-up. Twenty-eight of these patients returned for a clinical and radiographic follow-up appointment at a minimum of 1.7 years. Twelve patients were unable to return to the clinic but completed PRO surveys online.

The mean duration of follow-up for the 40 patients included in the final analysis was 5.7 ± 3.2 years (range, 1.7-16.5 years). There were 21 (53%) male and 19 (47%) female patients. At the time of the index surgery, patients had a mean age of 30.3 ± 9.6 years and a mean body mass index (BMI) of 27.7 ± 4.2 kg/m^2. There were 22 (55%) procedures on the right knee and 18 (45%) procedures on the left knee. There were 33 (83%) medial meniscal transplants performed compared with 7 (17%) lateral meniscal transplants. A total of 7 patients were under workers' compensation claims. Ten patients (25%) identified as competitive athletes at the time of the index surgery (1 professional, 5 college, 4 high school). Nine other patients (23%) self-identified as recreational athletes and also answered questions on return to sport. The most common sports played were soccer (n = 5) and football (n = 3) (Figure 1).

All patients except for 1 (3%) had a history of a single, discrete knee injury and subsequent operation. There was a mean duration of 9.1 ± 6.6 years between the initial knee injury and combined ACLR/MAT. In this interim time, patients had a mean of 2.9 ± 1.9 surgical procedures before the index surgery. On average, for those patients with a surgical intervention before the ACLR/MAT procedure, the intervention immediately preceding the index surgery was performed a mean 3.1 ± 3.7 years prior. In total, 32 patients (80%) underwent a previous ACLR procedure that had failed, necessitating revision ACLR at the time of the concurrent ACLR/MAT procedure. Patients had a mean of 1.4 ± 1.0 arthroscopic meniscal debridements and 1.4 ± 0.9 ACLRs. Ten patients (25%) also

*Address correspondence to Bryan M. Saltzman, MD, Department of Orthopedic Surgery, Rush University Medical Center, 1611 West Harrison Street, Suite 300, Chicago, IL 60612, USA (email: bryan.m.saltzman@gmail.com).

†Department of Orthopedic Surgery, Rush University Medical Center, Chicago, Illinois, USA.

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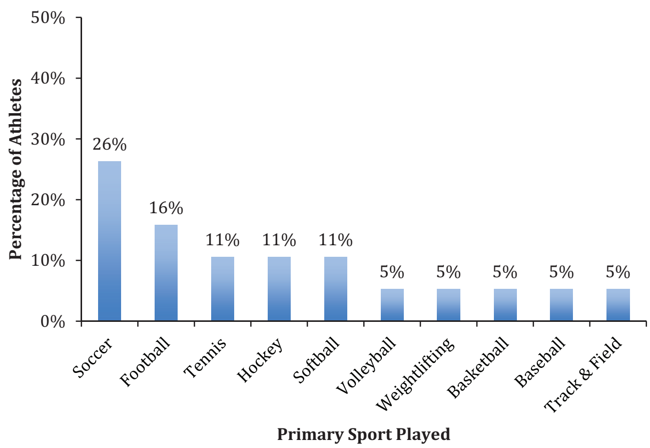

Figure 1. Primary sports played by both competitive and recreational athletes undergoing concomitant anterior cruciate ligament reconstruction and meniscal allograft transplantation.

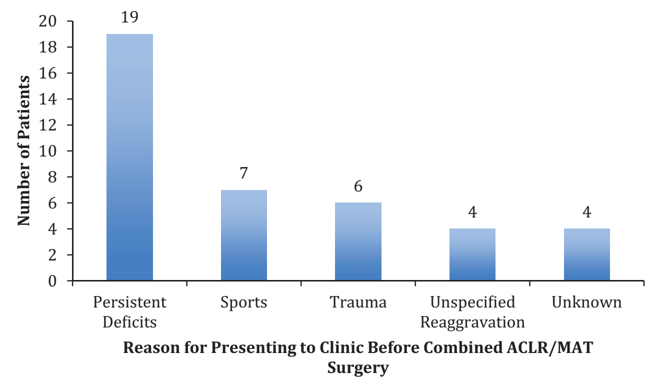

Figure 2. Reasons that patients presented to the attending surgeon before undergoing combined anterior cruciate ligament reconstruction and meniscal allograft transplantation (ACLR/MAT).

underwent staging diagnostic arthroscopic surgery with the senior surgeon at a mean of 0.34 ± 0.2 years before the index ACLR/MAT surgery. Nearly half the cohort (17 patients; 43%) experienced acute reaggravation of a prior knee injury that led to a clinical evaluation by the senior surgeon and subsequent combined ACLR/MAT surgery (Figure 2), whereas 19 patients (48%) complained of chronic, persistent knee deficits before ACLR/MAT. Of those patients who experienced acute reaggravation, there was a mean duration of 1.3 ± 1.1 years between reaggravation and combined ACLR/MAT surgery.

Indications for ACLR/MAT

Patients appropriate for the ACLR/MAT procedure were those with subjective complaints (including persistent joint-line pain and instability due to an ACL injury or failed previous ACLR) or objective findings (including meniscal deficiency and joint instability). Advanced age was not used as an absolute contraindication; however, indicated patients were typically young, active adults. All patients had persistence of unicompartmental or joint-line pain as well as recurrent episodes of knee instability with activities of daily living or athletics. Despite evidence to suggest that meniscal deficiency is associated with increased ACL strain,[17] the senior author (B.J.C.) did not generally recommend MAT simply because a patient has a history of functional meniscectomy in the setting of primary or revision ACLR in the absence of pain. The historical symptoms were documented at a preoperative visit, and a full physical examination was conducted to confirm joint-line pain, presence of an effusion, and instability on Lachman and pivot-shift testing. Lachman test grading was per the standard technique (grade 1, 3-5 mm of translation; grade 2, 5-10 mm of translation [AQ: 1]; and grade 3, >10 mm of translation), with A (firm endpoint) and B (no endpoint) modifiers. Pivot-shift testing was graded as follows: grade 1, abnormal movement only when the tibia is held in maximal internal rotation and absent in neutral or external rotation; grade 2, positive in the neutral position as well as in internal rotation but negative when the tibia is held in a position of definite external rotation; and grade 3, abnormal movement with a pronounced clunk when the tibia is held in neutral or moderate external rotation.

Patient-Reported Outcomes

At the time of the preoperative visit, PROs were collected including the following: Lysholm knee score[32]; International Knee Documentation Committee (IKDC) score[13]; Knee injury and Osteoarthritis Outcome Score (KOOS) subscales for pain, symptoms, activities of daily living (ADL), sport, and quality of life (QOL)[25]; Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) subscales for pain, stiffness, and function[4]; Overall Knee Function score[14]; and Short Form (SF)–12 subscales for physical and mental health.[20]

Radiographic Evaluation

Preoperatively, patients had anteroposterior (AP), lateral, 45° flexion weightbearing, and Merchant view plain radiographs. Preoperative Kellgren-Lawrence (KL) grades (0-4), minimum vertical joint-space measurements (in millimeters), and IKDC radiographic scores by compartment were determined from these radiographs when available. Standing alignment radiographs were frequently obtained to assess for underlying varus/valgus coronal abnormalities that may need to be addressed concomitantly at the time of surgery. Joint-space narrowing greater than 2 mm compared with the contralateral side was used as a general contraindication to MAT. Grade 4 KL changes were also used as a contraindication to MAT.

Donor-Recipient Matching

Patient donor meniscal measurements were obtained according to preoperative lateral and AP radiographs as previously described.[23,31] We used a single tissue bank

(AlloSource) for all meniscal and ACL allografts included in the study. All allografts were sterilely harvested and cryopreserved without the use of radiation. Grafts were stored at −80°C before their surgical use.

Surgical Technique

The surgical procedure was performed under general endotracheal anesthesia in the supine position. The foot of the bed was flexed to greater than 90°, and the operative leg was placed in an ACL leg holder, while the nonoperative leg was well padded and placed in the lithotomy position. Examination under anesthesia was routinely performed to confirm ACL deficiency and to rule out additional cruciate, collateral, or soft tissue deficiency. Diagnostic arthroscopic surgery was then performed to evaluate the medial, lateral, and patellofemoral compartments for chondral damage and for concomitant injuries that needed to be addressed. In our patient cohort, diagnostic arthroscopic surgery at the beginning of the index procedure identified 11 patients (28%) with a grade 4 cartilage defect [AQ: 2] in the affected meniscal compartment. The mean cartilage defect area among grade 4 compartments was 225 ± 135 mm^2. All cartilage defects encountered during diagnostic arthroscopic surgery were focal in nature, were within the weightbearing region of the femoral condyle in the affected meniscal compartment, and were therefore considered amenable to cartilage restoration procedures (osteochondral allograft or microfracture), as diffuse arthritic disease was considered a contraindication to meniscal transplantation. Two patients (5%) were found to have grade 3 defects, and 7 patients (18%) had grade 2 defects. Regarding chondral damage in the unaffected meniscal compartment, 3 patients (8%) had grade 3 damage.

The notch was debrided with notchplasty when necessary to allow for visualization. The femoral tunnel was drilled first with the knee in a hyperflexed position through the anteromedial portal at the location of the native ACL femoral footprint. The remaining meniscus was debrided to a bleeding peripheral rim of tissue, being careful to not violate the posterior or anterior horns, which provide landmarks for preparation of the meniscal tibial bone slot. In the setting of medial MAT, the tibial bone slot position was shifted 1 to 2 mm more medially to preserve the bony location that would become the ACL tibial tunnel site. The slot was created with a bur and reamer, finally using a box cutter and rasp to remove remaining bony debris. Recently, the technique has evolved in which the MAT tibial slot is created first to preserve the central bony wall and then the tibial and femoral sockets are drilled arthroscopically for ACLR. Before 2011, the senior author (B.J.C.) had drilled the femoral tunnel through a transtibial approach; after that time, in both isolated and concurrent ACLR situations, the senior author switched to an anteromedial portal technique for drilling the femoral tunnel. The graft choice was typically an Achilles tendon allograft to avoid bony impingement between the meniscal bone bridge and the ACL graft. This is because the Achilles tendon allograft has only a single bone plug (destined for the femoral tunnel), and thus, at the tibial tunnel, there is only soft tissue at the graft-tunnel interface, avoiding bone-on-bone impingement concerns.

The ACL and meniscal grafts were prepared on the back table. Attention was turned back to the patient, and an ACL tibial tunnel was drilled, taking care to preserve the site of the tibial bone slot for MAT placement. The ACL graft was subsequently passed through the tibial tunnel and secured on the femoral side with a 7 × 20–mm metal interference screw. The meniscal allograft was inserted into the prepared bone slot through anterior transpatellar mini-arthrotomy. An inside-out technique was used to place 8 to 10 vertical mattress sutures to secure the meniscal allograft in position. Finally, an interference screw secured the ACL graft at the tibial tunnel with the knee between full extension and 15° of flexion depending on graft isometry.

The mean meniscal transplant was 4.3 ± 0.5 cm in anterior-posterior length and 3.1 ± 0.3 cm in medial-lateral width. With regard to ACLR, the leading ACL graft utilized was an Achilles allograft (n = 27; 68%), followed by a bone–patellar tendon–bone allograft (n = 6; 15%), a bone–patellar tendon–bone autograft (n = 2; 5%), and a hamstring allograft (n = 1; 2%). A tibialis anterior allograft was utilized in 1 patient (2%), while the graft type was unable to be found in the remaining 3 patients (8%). Often, a bone–patellar tendon–bone autograft is not available because this graft has frequently been utilized in primary ACLR (and many of these cases included revision ACLR); however, while a bone–patellar tendon–bone allograft is an option with a bone-bone interface for healing, it risks bony impingement of the tibial-sided bone block in medial MAT [AQ: 3]. The use of an Achilles allograft is therefore an often preferred alternative for several reasons: (1) it circumnavigates the issue of bony impingement between grafts, (2) it still allows for bony integration on the femoral side and interference fixation into bone on the femur, and (3) it is strong and can be tailored to any size necessary for the given patient. Nearly half of the patients (n = 19; 48%) underwent concomitant surgery in addition to ACLR/MAT, including 9 osteochondral allografts, 9 ACL hardware removals, 2 microfractures, and 1 saphenous neuroma excision. The mean total tourniquet time for the procedure was 116 ± 19 minutes.

Postoperative Rehabilitation

The patient's knee was placed into a hinged knee brace locked in extension. The brace could be removed after postoperative day 1 to allow passive range of motion exercises without weightbearing. Patients were allowed 50% partial weightbearing for 4 to 6 weeks with the assistance of crutches, utilized through the fourth postoperative week. Early active range of motion was restricted for the first 6 weeks to protect the MAT site, and subsequently, at 6 weeks in the rehabilitation process, full range of motion and mobilization were permitted, including quadriceps sets, heel slides, and straight-leg raises. Physical therapy exercises for quadriceps and hamstring strengthening and range of motion persisted for 2 to 3 months; patients were able to return to running at 5 to 6 months, with a full return to sporting activities after 6 to 9 months.

Follow-up Evaluation

Intraoperative and postoperative complications were documented. Patients who identified as athletes preoperatively were questioned about returning to sport (timing and level of competition). Revision procedures, reoperations, and conversions to arthroplasty (total or unicompartmental knee arthroplasty), including the timing of such procedures, were recorded. Postoperative 3-view radiographs (lateral, 45° flexion weightbearing, and Merchant view plain radiographs) were obtained to identify KL grades, IKDC radiographic scores, and minimum vertical joint-space measurements (in millimeters); these were measured on a picture archiving and communication system (PACS), and radiographic measurement/grading was performed by an orthopaedic sports medicine fellow. The same postoperative scores were obtained as those preoperatively (Lysholm, IKDC, KOOS with subscales, WOMAC with subscales, Overall Knee Function, SF-12 with subscales), with the addition of the Tegner activity scale and Marx activity rating scale to assess activity at final follow-up. The physical examination included an assessment of range of motion (flexion and extension from hand measurements by the senior surgeon or his trained physician assistants), motor strength (standard scale with a maximum score of 5 to evaluate gross motor deficits), joint-line tenderness to palpation, patellar tenderness to palpation, presence of an effusion, knee crepitus, the McMurray test, the Thessaly test, the Lachman test, the anterior/posterior drawer test, the pivot-shift test, and valgus/varus instability. A single-leg hop for distance was recorded as a percentage of the nonoperative lower extremity. KT-1000 arthrometer testing was performed as an objective measure of ACL laxity.

Survivorship and Clinical Failures

Survivorship was calculated based on the status of the index concomitant ACLR/MAT procedure at final follow-up. Clinical failures were defined as an additional ACLR procedure, revision MAT, or conversion to unicompartmental or tricompartmental total knee arthroplasty.

Subgroup Analysis

A subgroup analysis was performed to evaluate for patient- or disease-related factors affecting clinical outcomes and survivorship, including medial or lateral meniscal transplantation. The cohort was divided based on failure status. Preoperative and intraoperative variables were examined as independent predictors of clinical outcomes. Postoperative outcomes were compared between the 2 subgroups.

Statistical Analysis

Descriptive statistics were calculated for all variables, including frequencies and mean values. Preoperative and postoperative subjective outcomes and objective clinical findings were compared using 2-tailed Student t tests for quantitative data and chi-square tests for qualitative data. A Kaplan-Meier survival curve was created to examine the longevity of combined ACLR/MAT. Further subgroup analysis was performed based on laterality of the transplant, primary versus revision ACLR, and survival at final follow-up. All statistical computations were performed using SPSS software (IBM Corp). Statistical significance was set at $P < .05$ for all testing.

RESULTS

Subjective Outcomes and Return to Sport

Patients (n = 40) reported statistically significant improvements in all PRO measures except for the WOMAC stiffness and Tegner scores (Table 1). The WOMAC stiffness scores improved; however, the improvement did not reach statistical significance. The mean Tegner score statistically significantly declined 1.7 points; however, this was at a mean of 5.7 years after combined ACLR/MAT. In addition, the final follow-up Marx scores ranged from 0, indicating very infrequent activity, to a maximum score of 16, indicating that running, cutting, decelerating, and pivoting are performed several times per week. The magnitude of change in the PROs was most pronounced for the IKDC subjective score and KOOS QOL score.

Of the initial 19 self-identifying athletes, 18 recently returned to the clinic to answer questions about returning to sport and their current activity level. Of these patients, 9 (50%) were able to return to sport, and 7 (39%) returned to the same level of play. Among the 10 patients involved in competitive sports, 5 (50%) were able to return to sport, and all reported that they returned to the same level of play. The mean duration from the index surgery to return to play was 9.1 ± 4.2 months. Of the 11 (58%) patients who either did not return to sport or who returned to play at a lower level, the leading limitations cited were fear of reinjuries (n = 7; 37%) and pain (n = 7; 37%) (patients were allowed to give more than one reason for not returning to play) (Figure 3).

Objective Results

Knee-Specific Physical Examination. Twenty-eight patients returned to the clinic for a postoperative examination at a mean final follow-up of 5.9 ± 3.3 years. During the physical examination, patients did not exhibit any significant differences in strength or range of motion when compared with the contralateral leg (Table 2). Over one-third of patients exhibited tenderness to palpation on the joint line specific to their meniscal transplant, and approximately another third demonstrated knee crepitus. Patellar tenderness to palpation was rare. Two-thirds of patients evaluated for functional testing had single-hop test results of $\geq$75% of the contralateral leg. None had the presence of a knee joint effusion.

ACL Examination. An additional ACL-specific physical examination and objective testing yielded marked improvements in knee stability (Table 3). The Lachman and pivot-shift test results both significantly improved from preoperatively to final follow-up ($P < .01$ for both). KT-1000 arthrometer testing was conducted on all patients

TABLE 1
Comparison of Patient-Reported Outcomes Before Index ACLR/MAT Surgery and at Final Follow-up[a]

	Preoperative	Final Follow-up	*P* Value
Lysholm	44 ± 16	67 ± 22	**<.01**
IKDC subjective	37 ± 14	60 ± 22	**<.01**
KOOS			
Pain	59 ± 17	74 ± 21	**<.01**
Symptoms	59 ± 17	68 ± 18	**.04**
ADL	72 ± 19	85 ± 16	**<.01**
Sport	24 ± 18	48 ± 28	**<.01**
QOL	20 ± 16	45 ± 25	**<.01**
WOMAC			
Pain	6.9 ± 3.5	4.0 ± 4.1	**<.01**
Stiffness	3.4 ± 1.9	2.8 ± 2.1	.22
Function	19.0 ± 13.0	9.9 ± 11.0	**<.01**
Total	30.0 ± 18.0	17.0 ± 17.0	**<.01**
Overall Knee Function	3.5 ± 1.2	7.6 ± 7.3	**<.01**
Tegner	6.3 ± 2.3[b]	4.6 ± 2.5	**.02**
Marx	N/A	3.6 ± 4.7	N/A
SF-12 physical	41.0 ± 7.4	43.0 ± 6.5	.28
SF-12 mental	49.0 ± 13.0	54.0 ± 9.6	.14

[a]Data are reported as mean ± SD. Bolded *P* values indicate statistically significant between-group difference ($P < .05$). ACLR/MAT, anterior cruciate ligament reconstruction/meniscal allograft transplantation; ADL, activities of daily living; IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; N/A, not applicable; QOL, quality of life; SF-12, Short Form–12; VAS, visual analog scale; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index. [AQ: 4]

[b]Preinjury Tegner score.

returning for follow-up, and results revealed no significant differences in ligament stability when compared with the contralateral knee at both 30 lb and maximum manual strength (*P* = .09 and .13, respectively).

Radiographic Evaluation. A total of 28 preoperative radiographs were available for review. Of the 28 patients returning to the clinic, 24 received 3-view radiographs of the affected knee and were evaluated for the progression of osteoarthritis compared with their preoperative radiographs. Compartment joint-space height and KL grading were used to evaluate the progression of arthrosis (Table 4). Overall, the mean medial joint-space height decreased from 5.2 ± 1.1 mm preoperatively to 4.5 ± 0.8 mm at final follow-up (*P* = .02) [AQ: 6]. Similarly, the mean lateral joint-space height decreased from 5.7 ± 1.2 mm preoperatively to 4.3 ± 0.9 mm at final follow-up ($P < .01$). However, when evaluating the medial joint space in the medial MAT–treated patients, there was no statistically significant joint-space change in the medial compartment between preoperative and postoperative radiographs. Likewise, when evaluating the lateral joint space in the lateral MAT–treated patients, there was no statistically significant joint-space change between preoperative and postoperative radiographs. No patient had KL grade 4 changes preoperatively or postoperatively (Figure 4). The mean KL grade increased from 0.7 ± 0.8 preoperatively to 1.6 ± 0.9 at final follow-up ($P < .01$). The percentage of patients with KL grade 0 to 1

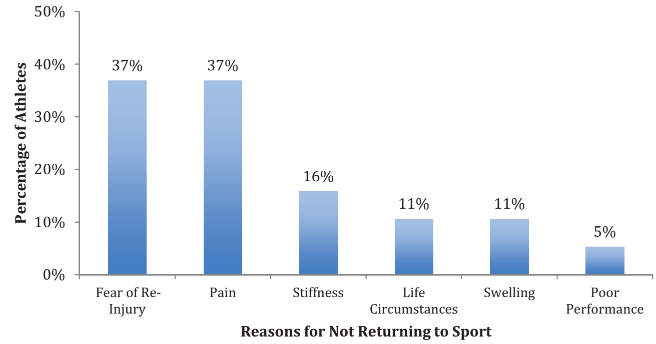

Figure 3. Reasons for either not returning to sport or not returning to the same level of play. Note that patients were allowed to list multiple reasons.

TABLE 2
Knee-Specific Physical Examination Findings at Final Follow-up

	Values
Range of motion, deg, mean ± SD (range)	
Flexion	133 ± 8 (115 to 15)
Loss of flexion[a]	4 ± 5 (0 to 16)
Extension	1 ± 2 (–4 to 3)
Loss of extension[a]	1 ± 1 (0 to 5)
Motor strength (1-5 scale, with 5 = xxx)	
Quadriceps	5 (all 28 patients)
Hamstring	5 (all 28 patients)
Tenderness to palpation, No. of patients (%)	
On joint line of transplanted meniscus	11 (39)
On patella	2 (7)
Knee crepitus	8 (29)
Single-hop testing for distance, No. of patients[b] (%)	
>90% of contralateral leg	5 (33)
75%-90% of contralateral leg	5 (33)
50%-75% of contralateral leg	5 (33)

[a]Loss of flexion and extension both reported in comparison to the contralateral leg. [AQ: 5]

[b]Fifteen patients underwent single-hop testing for distance. Single-hop testing was not performed on the remaining 13 patients.

changed from 86% preoperatively to 46% postoperatively, and the percentage of patients with KL grade 2 to 3 changed from 14% preoperatively to 54% postoperatively ($P < .01$ for both). With respect to IKDC radiographic grading, preoperatively, the medial compartment included 57.1% of patients with grade A changes, 35.7% grade B, 7.1% grade C, and 0% grade D. Postoperatively, 16.7% of patients showed grade A findings, 54.2% grade B, 29.2% grade C, and 0% grade D. For the lateral compartment, preoperatively, radiographs demonstrated 64.3% grade A findings, 32.1% grade B, 3.6% grade C, and 0% grade D, and postoperatively, 37.5% of patients had grade A findings, 45.8% grade B, 16.7% grade C, and 0% grade D (Figures 5 and 6).

TABLE 3
Comparison of Ligament-Specific Physical Examination Findings Before Index ACLR/MAT Surgery and at Final Follow-up[a]

	Preoperative (n = 35)[b]	Final Follow-up (n = 28)	*P* Value
Lachman grade ≥2A, n (%)	34 (97)	5 (18)	**<.01**
Pivot shift ≥1+, n (%)	33 (94)	10 (36)	**<.01**
Positive McMurray test result, n (%)	2 (6)	1 (4)	.69
Positive Thessaly test result at 30° of flexion, n (%)	N/A	2 (7)	
KT-1000 arthrometer testing,[c] mm, mean ± SD (range)			
At 30 lb	0.9 ± 1.5 (–2 to 4)		.09
Maximum manual strength	0.9 ± 1.9 (–4 to 4)		.13

[a]Bolded *P* values indicate statistically significant between-group difference ($P < .05$). ACLR/MAT, anterior cruciate ligament reconstruction/meniscal allograft transplantation; N/A, not available.
[b]Preoperative clinical examination records were unavailable for 5 patients because of the transition to an electronic medical record.
[c]Results are reported in millimeters of anterior tibial translation in comparison to the contralateral knee.

TABLE 4
Comparison of Radiographic Findings Before Index ACLR/MAT Surgery and at Final Follow-up[a]

Joint-Space Height, mm	Preoperative (n = 28)	Final Follow-up (n = 24)	*P* Value
Medial transplants			
Affected medial compartment	5.3 ± 1.3	4.5 ± 0.8	.08
Unaffected lateral compartment	5.9 ± 1.2	4.3 ± 0.8	**<.01**
Lateral transplants			
Affected lateral compartment	5.0 ± 0.7	4.5 ± 1.2	.44
Unaffected medial compartment	5.0 ± 0.1	4.5 ± 0.8	.22

[a]Data are reported as mean ± SD. Bolded *P* value indicates statistically significant between-group difference ($P < .05$). ACLR/MAT, anterior cruciate ligament reconstruction/meniscal allograft transplantation.

Complications and Reoperations

There were no major complications in this study cohort. However, 2 minor complications (5%) were encountered. In both cases, there was surgical drainage from the operative incision in the early postoperative period. Both knees were treated with oral antibiotic therapy and dry dressing changes. Neither patient required a return to the operating room or a deviation in postoperative rehabilitation.

Fourteen patients (35%) underwent subsequent reoperations after the index ACLR/MAT procedure (Figure 7). The subsequent reoperations occurred at a mean of 3.8 ± 4.2 years after the index procedure. The leading subsequent operation was debridement (8 patients; 20%), followed by partial meniscectomy (4 patients; 10%). Six patients (15%) underwent 2 subsequent reoperations after the index procedure. The second subsequent reoperation occurred at a mean of 5.6 ± 4.3 years after the index procedure. The leading second subsequent reoperation was total knee arthroplasty (4 patients; 10%), followed by 1 patient (3%) who underwent combined high tibial osteotomy and revision meniscal transplant and 1 patient (3%) who underwent partial meniscectomy.

Clinical Failures and Survivorship

Survivorship of the index ACLR/MAT procedure is illustrated on the Kaplan-Meier curve demonstrating cumulative survival for the 40-patient cohort (Figure 8). Overall, there were 8 clinical failures (20%) in this cohort, including 6 patients (15%) progressing to total knee arthroplasty, 1 patient (3%) requiring revision meniscal transplant, and 1 patient (3%) requiring revision concomitant ACLR/MAT. The patient undergoing revision ACLR/MAT was contacted 4 years after the revision procedure and has reported positive subjective outcomes in regards to knee pain and function.

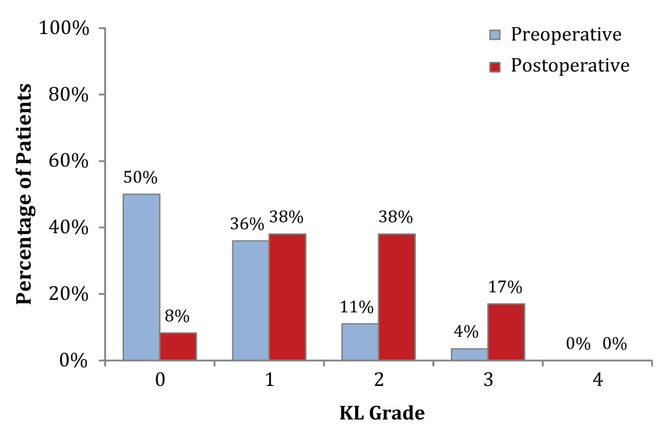

Figure 4. Kellgren-Lawrence (KL) grade distribution before index anterior cruciate ligament reconstruction/meniscal allograft transplantation surgery and at final follow-up.

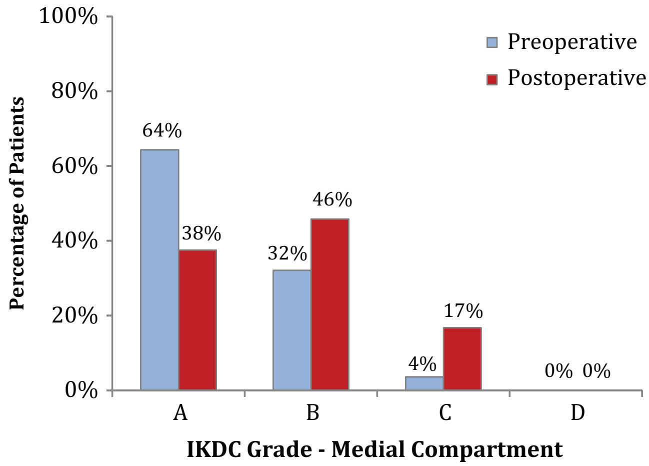

Figure 5. International Knee Documentation Committee (IKDC) grade distribution for the medial tibiofemoral compartment before index anterior cruciate ligament reconstruction/meniscal allograft transplantation surgery and at final follow-up.

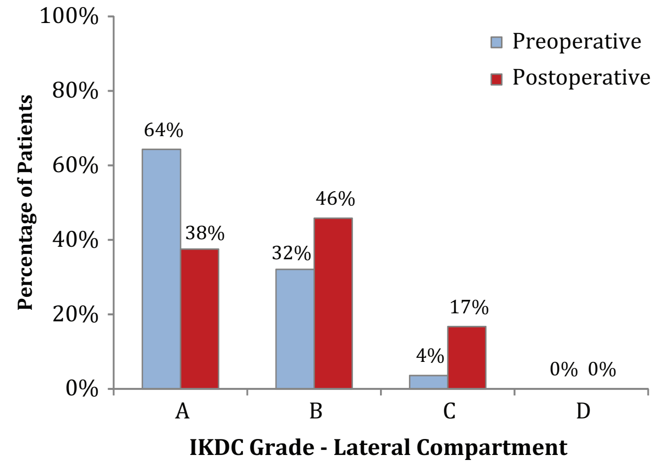

Figure 6. International Knee Documentation Committee (IKDC) grade distribution for the lateral tibiofemoral compartment before index anterior cruciate ligament reconstruction/meniscal allograft transplantation surgery and at final follow-up.[AQ: 8]

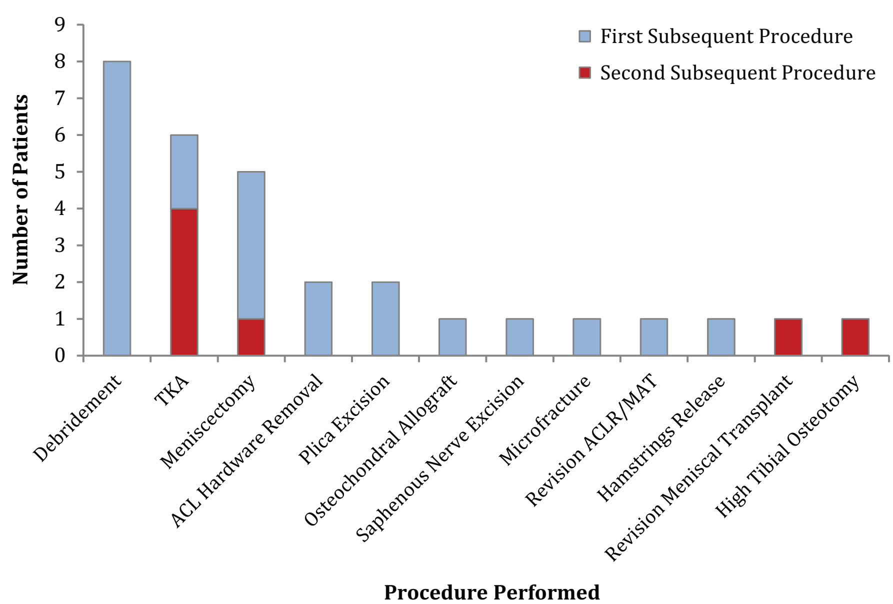

Figure 7. Reoperations after index anterior cruciate ligament reconstruction/meniscal allograft transplantation (ACLR/MAT). The frequency was recorded based on the type of surgery performed. TKA, total knee arthroplasty.

At a minimum of 1.7-year follow-up, the survival rate was 98% (1 failure). The survival rate at 5 years was 84% (21/25), and the survival rate at 10 years was 45% (5/11). The mean time to failure for the 8 clinical failures was 7.3 ± 4.5 years, while the mean time to arthroplasty for the 6 patients requiring it was 8.3 ± 4.0 years.

Subgroup Analysis

Subgroup analysis was performed based on the survival status of the index ACLR/MAT procedure (Table 5). In terms of preoperative differences, patients with intact grafts from the index ACLR/MAT procedure at final follow-up were more likely to be self-identified athletes with higher preoperative PROs and lower KL grades (P = .026, P = .03, P = .04, P = .03, and $P < .01$, respectively [AQ: 7]). Additional preoperative differences included a trend of patients surviving ACLR/MAT being younger, with a lower BMI and less proportion of workers' compensation claims at the time of the index surgery. There were no significant differences between the groups in terms of cartilage damage, ACL graft type, tourniquet time, or percentage of primary ACLR versus revision ACLR. At final follow-up, patients with intact grafts from the index

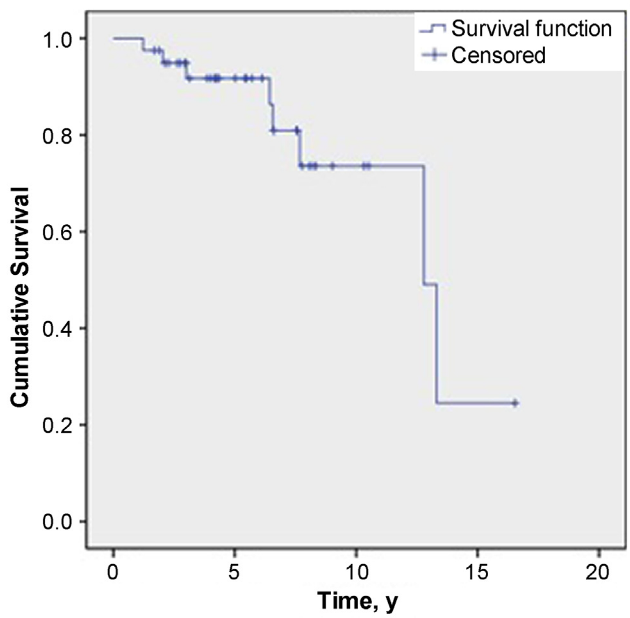

Figure 8. Kaplan-Meier curve showing cumulative survival of index anterior cruciate ligament reconstruction/meniscal allograft transplantation surgery in 40 patients. In this graph, patients become ''censored'' after being lost to follow-up.

ACLR/MAT surgery had significantly greater PROs in 11 of 14 [AQ: 9] recorded parameters, with WOMAC stiffness, Overall Knee Function, and SF-12 mental scores being the exceptions (Table 5). Patients with failed index procedures underwent significantly more reoperations ($P < .01$). If subsequent surgery was necessary, the intact graft cohort had it performed almost 2 years sooner than the failed cohort (mean, 2.8 years vs 4.6 years, respectively), although this trend was not statistically significant.

Subgroup analysis based on transplant laterality revealed that patients receiving lateral meniscal transplants had a significantly longer duration between prior surgery and index ACLR/MAT surgery (Table 6). There were no intraoperative differences between the groups. After the index surgery, patients receiving lateral meniscal transplants reported significantly better subjective outcomes in knee function and quality of life. Athletes receiving lateral menical transplants trended toward higher rates of return to play (57% vs 15%, respectively) compared with those receiving medial transplants, although this finding was not statistically significant. There were no cases of reoperation or failure in the lateral meniscal transplant group.

DISCUSSION

Combined ACLR/MAT for symptomatic ACL deficiency in the setting of subtotal or total meniscal loss is a technically challenging surgical procedure in a difficult-to-treat patient population. The results of the current study suggest that when the correct indications are used and surgery is performed well, patients have significant improvements in subjective and objective clinical parameters at a mean of 5.7 years' follow-up. We found statistically significant improvements in PROs in 12 of 15 outcome scores and a 50% return-to-sport rate. The physical examination and radiographic findings were as promising as the subjective findings. Knee stability significantly improved in all tested patients, and KT-1000 arthrometer testing indicated that there were no significant differences between the affected and unaffected sides at final follow-up. Radiographically, joint-space narrowing and an increase in KL grades occurred as well as an increase from preoperative to postoperative results in the proportion of patients with grade B to C versus grade A IKDC radiographic grades; however, the joint space in the compartment treated with MAT did not significantly decrease between the preoperative and postoperative time points. This may have been affected by the reduced cohort number available for radiographic review, which could have affected the power of this parameter finding, and thus, the trends toward reduced joint space should not be ignored. While 35% of patients underwent reoperations, the majority of these were simple arthroscopic debridements and occurred after nearly 4 years from the index surgery. Notably, at a minimum of 1.7-year follow-up, the survival rate was 98% (1 failure). The survival rate at 5 years was 84% (21/25), and the survival rate at 10 years was 45% (5/11). Failures occurred at a mean of 7.3 years, and those who converted to arthroplasty did so at a mean of 8.3 years from the time of the index ACLR/MAT procedure.

All but 1 of the 19 self-identified athletes returned for follow-up. Half of these patients as a whole returned to sport, and half of the high-level competitive athletes returned to their same level of sport. Interestingly, a majority of patients not returning to sport indicated a fear of reinjuries as a leading reason, 4 of whom also had pain with sport. This finding affirms the powerful and commonly suggested role of psychological factors during an athlete's recovery process. In the absence of these psychological factors, our findings indicate excellent pain and functional outcomes, allowing the return to high-level competition at a mean of 9.1 months postoperatively.

In comparison to those patients with intact grafts at the time of final follow-up, patients with failed ACLR/MAT during the study period had significantly greater preoperative KL grades, lower Lysholm scores, lower KOOS pain scores, and higher WOMAC pain scores. In addition, patients with failed grafts were more frequently associated with workers' compensation claims and being less frequently self-identified as athletes. While not statistically significant, patients who failed were also older (mean age, 35.4 vs 29.0 years, respectively) than those who did not fail. Lastly, patients with ACLR/MAT that went on to failure during the study period underwent significantly more reoperations on the affected knee; however, the duration of time before the first reoperation was approximately 2 years greater than the reoperations for those patients with intact grafts from ACLR/MAT at final follow-up.

Through subgroup analysis, our cohort findings suggest significantly superior results after lateral MAT as compared with medial MAT when combined with ACLR. Postoperative

TABLE 5
Differences in Preoperative, Intraoperative, and Postoperative Data Between Patients With Failure and Patients With Intact Grafts at Final Follow-up[a]

	Failure (n = 8)	Intact Grafts (n = 32)	*P* Value
Preoperative			
Age at surgery, y	35.4 ± 8.2	29.0 ± 9.7	.09
BMI, kg/m^2	28.6 ± 4.4	27.5 ± 4.2	.58
Self-identified as athlete, n (%)	1 (13)	18 (56)	**.026**
Workers' compensation, n (%)	3 (38)	4 (13)	.10
Failed prior ACL surgery, n (%)	5 (63)	27 (84)	.42
Mean KL grade	2.5	0.5	**<.01**
Patient-reported outcomes			
Lysholm	31 ± 13	48 ± 15	**.03**
KOOS pain	45 ± 18	62 ± 16	**.04**
WOMAC pain	9.8 ± 3.4	6.2 ± 3.2	**.03**
Intraoperative			
Prevalence of ICRS grade 4 cartilage damage, n (%)	2 (25)	9 (28)	.86
Transplant side, n			
Medial	8	25	.15
Lateral	0	7	
Leading ACL graft utilized, n (%)			
Achilles allograft	2 (25)	25 (78)	.08
Bone–patellar tendon–bone allograft	3 (38)	3 (9)	
Tourniquet time, h:min	2:11 ± 0:33	1:53 ± 0:13	.09
Postoperative			
No. of reoperations	1.6 ± 0.5	0.6 ± 0.7	**<.01**
Time to reoperation, y	4.6 ± 4.9	2.8 ± 3.0	.44
Patient-reported outcomes			
Lysholm	42 ± 16	72 ± 20	**<.01**
IKDC subjective	36 ± 7	64 ± 21	**.01**
KOOS pain	48 ± 21	78 ± 17	**<.01**
KOOS symptoms	49 ± 12	72 ± 17	**<.01**
KOOS ADL	68 ± 16	88 ± 15	**.01**
KOOS sport	21 ± 12	52 ± 27	**.03**
KOOS QOL	49 ± 25	25 ± 13	**.04**
WOMAC pain	9.3 ± 4.3	3.2 ± 3.5	**<.01**
WOMAC stiffness	4.3 ± 1.7	2.6 ± 2.0	.13
WOMAC function	22 ± 13	14 ± 14	**.01**
WOMAC total	35 ± 18	14 ± 14	**.01**
Overall Knee Function	2.8 ± 0.5	8.2 ± 7.6	.16
SF-12 physical	35.0 ± 3.6	44.0 ± 6.1	**.01**
SF-12 mental	55.0 ± 8.7	47.0 ± 14.0	.16

[a]Data are reported as mean ± SD unless otherwise indicated. Bolded *P* values indicate statistically significant between-group difference ($P < .05$). ACL, anterior cruciate ligament; ADL, activities of daily living; BMI, body mass index; ICRS, International Cartilage Repair Society; IKDC, International Knee Documentation Committee; KL, Kellgren-Lawrence; KOOS, Knee injury and Osteoarthritis Outcome Score; QOL, quality of life; SF-12, Short Form–12; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

IKDC, KOOS ADL, and KOOS QOL scores are significantly better with the lateral MAT subgroup. This is in contrast to prior literature on meniscal transplantation, which has suggested that patients undergoing medial compartment transplantation report superior improvements than their counterparts.[27] While the rates of failure were not statistically significant between medial MAT and lateral MAT, the failure rate of 24% versus 0%, respectively, is clinically relevant ($P = .15$), and the mean number of reoperations was in fact significant (1.1 vs 0.0, respectively; $P < .01$). However, medial MAT–treated patients had significantly greater WOMAC function and total scores, while the KOOS ADL and QOL scores were significantly greater after lateral MAT. These findings suggest that a younger, athletic patient with less radiographic arthritis and relatively higher preoperative clinical scores who undergoes lateral MAT with ACLR would be the best demographic to have success with combined ACLR/MAT. Of note, our subgroup analysis failed to reveal any significant differences in the preoperative or postoperative outcomes after the index surgery between primary and revision ACLR, aside from the expected decrease in the number of prior surgeries before the index ACLR/MAT procedure [AQ: 10].

Interestingly, there was a mean 9.1 years between the initial knee injury for these patients and the index procedure, with patients undergoing, on average, 2.9 surgeries before combined ACLR/MAT. While our patient cohort precludes us from such an analysis, future studies could

TABLE 6
Differences in Preoperative, Intraoperative, and Postoperative Data Between Patients With Medial and Lateral Meniscal Transplants[a]

	Medial Transplants (n = 33)	Lateral Transplants (n = 7)	*P* Value
Preoperative			
Age at surgery, y	31.5 ± 9.9	24.4 ± 5.8	.07
BMI, kg/m^2	27.9 ± 4.3	26.5 ± 3.6	.51
Self-identified as athlete, n (%)	14 (42)	5 (71)	.16
Workers' compensation, n (%)	7 (21)	0 (0)	.179
Time between previous and index surgery, y	2.5 ± 2.2	6.2 ± 7.8	**.04**
Medial JSH, mm	5.3 ± 1.3	5.0 ± 0.1	.63
Lateral JSH, mm	5.9 ± 1.2	5.0 ± 0.7	.13
Mean KL grade	0.7 ± 0.8	0.7 ± 0.8	.96
Patient-reported outcomes	No significant differences		
Intraoperative	No significant differences		
Postoperative			
No. of reoperations	1.1 ± 0.8	0.0 ± 0.0	<**.01**
Time to reoperation, y	3.8 ± 4.2	N/A	N/A
Athletes who returned to play, n (%)	5 (15)	4 (57)	.68
Graft failure, n (%)	8 (24)	0 (0)	.15
Patient-reported outcomes			
IKDC subjective	56 ± 22	75 ± 14	.06
KOOS ADL	80 ± 21	98 ± 4	**.05**
KOOS sport	44 ± 28	67 ± 17	.07
KOOS QOL	40 ± 24	70 ± 14	<**.01**
WOMAC function	11.0 ± 11.0	1.3 ± 2.8	**.03**
WOMAC total	20.0 ± 16.0	4.8 ± 6.2	**.04**

[a]Data are reported as mean ± SD unless otherwise indicated. Bolded *P* values indicate statistically significant between-group difference ($P < .05$). ADL, activities of daily living; BMI, body mass index; IKDC, International Knee Documentation Committee; JSH, joint-space height; KL, Kellgren-Lawrence; KOOS, Knee injury and Osteoarthritis Outcome Score; N/A, not applicable; QOL, quality of life; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

provide value by an assessment of patients in which ACLR/MAT is used earlier in the course of the patient's treatment to see if it improves on results.

While several studies evaluating MAT have included patients with concurrent ACLR,[6,11,22,24,35,36] relatively few studies with relatively low patient numbers, many of which were retrospective cohort reviews, have performed a focused evaluation on concomitant ACLR/MAT, and the results have not often included both subjective and objective clinical outcomes.[5,9,26,30,34] Graf et al[9] reviewed a small cohort of 8 patients (mean age, 32.6 years) who underwent concurrent medial MAT/ACLR at a minimum of 8.5 years of follow-up; they reported normal IKDC symptoms in 2 patients and normal IKDC function in 5 patients. Six of the 8 patients were involved in recreational sport and were pleased with the functional level of the knee, and the authors concluded that the combined MAT/ACLR procedure resulted in adequate functional results and good satisfaction in the long term.[9] Binnet et al[5] reported 19-year follow-up of 4 patients (mean age, 24.5 years) who underwent lyophilized medial MAT and ACLR; the authors found a median Tegner score decrease from 3 to 2.5, a median Lysholm score increase from 60.5 to 62.5, and a median total Knee Society score decrease from 60.5 to 59.5. While no patients demonstrated instability, all had Outerbridge grade IV osteoarthritis at final follow-up.[5]

Rueff et al[26] compared 8 patients who underwent ACLR with medial MAT (mean age, 51.0 years) to 8 patients who underwent ACLR without MAT (either repair or partial meniscectomy) at a minimum of 5 years postoperatively. The authors reported comparable improvements in pain, subjective IKDC scores, and Lysholm scores between the cohorts, with higher improvement in swelling and rates of subjective success (100% vs 87%, respectively) in those without MAT versus those with MAT.[26] Wirth et al,[34] in a larger prospective cohort review of 23 patients at 14 years postoperatively, reported a Lysholm score of 75 points and good preservation of deep-frozen MATs in 6 patients on magnetic resonance imaging and second-look arthroscopic surgery in comparison to the lyophilized MATs used in 17 of the 23 patients.

In the largest prior cohort review to date, Sekiya et al[30] retrospectively reviewed 28 patients (mean age, 35 years) who underwent combined ACLR/MAT at an average of 2.8 years (range, 1.8-5.6 years) postoperatively. At final follow-up, they reported normal or nearly normal IKDC scores in 86% of their cohort, SF-36 physical and mental component summary scores at higher levels than age- and sex-matched populations, 90% with normal or nearly normal Lachman and pivot-shift test scores, and no significant difference in joint-space narrowing on plain radiographs compared with the nonoperative knee.[30] Despite an average increase in 1.5 mm of anterior translation by KT-1000 arthrometer testing, the authors concluded that combined ACLR/MAT can be a beneficial procedure to re-establish meniscal function, provide chondral protection, and improve stability of the knee joint.[30]

Overall, the current study corroborates the conclusions of Sekiya et al[30] while presenting the largest patient cohort (n = 40) with a midterm follow-up duration (nearly 6 years postoperatively) to date. The mean patient age (30.3 years) and patient demographics from the current study are comparable with the average age and associated demographics of the available studies published on the topic.[5,9,26,30] However, the prospective data and completeness of PROs, objective outcomes, and radiographic follow-up are unique to the current study. In addition, there is some concern that earlier results of combined ACLR/MAT may not be generalizable to the current patient population because of modern adaptations of MAT surgical techniques that were not employed in previous studies but exist in our patient review.[9,26,34]

An evaluation of the recent long-term follow-up literature on MAT performed in isolation shows that the combined ACLR/MAT procedure performs well by comparison. Noyes and Barber-Westin[21] reported an estimated probability of survival of 85% at 2 years, 77% at 5 years, and 45% at 10 years postoperatively in their 69 MAT-treated patients; these are similar to our findings of 98% survival at 1.7 years, 84% at 5 years, and 45% at 10 years for those with available data. Our overall reoperation rate was actually less at 35% than their cohort in which 37 patients (53.6%) required further surgery.[21] However, our cohort findings of overall reduced symptoms and improved function mirror those of the isolated MAT cohort.

Our study is not without limitations. This analysis of concurrent ACLR/MAT does not provide a comparison to a cohort of either isolated ACLR or isolated MAT. Thus, while we present the results of this complicated patient cohort with a concomitant procedure, we do not have a means for comparison and are unable to conclude with certainty that the combined procedure results in superior outcomes to either procedure in isolation. Our overall follow-up rate for those patients with surgical dates more than 1.7 years before study completion was 80%, which is lower than we had hoped to have, but this is not unexpected given the relatively long follow-up and potential transient nature of the young patient population that underwent the procedure. Some patients underwent additional concomitant procedures at the time of ACLR/MAT surgery, which can provide confounding variables for the resultant data. A physical examination of range of motion was not performed with a goniometer, and motor strength grading was on a gross motor deficit scale rather than with quantifiable data (such as with Cybex testing). Finally, while our mean follow-up of nearly 6 years provides valuable information on the durability and success of combined ACLR/MAT, future prospective randomized studies with a longer term follow-up will be helpful to further elucidate the benefits of ACLR/MAT in appropriately indicated patients.

CONCLUSION

Concomitant ACLR/MAT can provide significant improvements in clinical outcomes and enhancement in objective knee stability and was associated with an insignificant degree of radiographic joint-space narrowing changes with a 5-year survivorship of greater than 80% for those with data available. Athlete status may be a preoperative predictor of midterm survival.

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