

# Systematic Review

## Meniscal Allograft Transplantation

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**Purpose:** Meniscal allograft transplantation (MAT) has become an accepted treatment option for patients undergoing meniscectomy with recalcitrant pain in the corresponding compartment. Whether MAT can oppose cartilage degeneration is unclear. Our purpose was to perform a systematic review of available literature to answer the following: (1) Does MAT prevent advancing chondrosis? (2) Who is the ideal candidate for MAT? (3) What is the survival time for allograft in a stable knee? (4) Can MAT be successful when performed with concomitant procedures? (5) Is there an outcome difference between medial and lateral meniscal allograft transplants? (6) What is the expected function of a knee that has undergone MAT? **Methods:** Two authors performed a systematic review of the literature pertaining to MAT. Included in the review are studies with at least 2 years' follow-up, studies with validated outcome measures, and studies in which the allograft meniscal horns were secured with bony fixation. **Results:** We identified 14 clinical articles that satisfied our inclusion and exclusion criteria. Thirteen of the articles provided Level IV evidence, and one article provided Level III evidence. **Conclusions:** MAT can result in alleviation of knee pain, improvement in knee function, and good patient satisfaction if performed in the optimal candidate. Improvements in both objective and subjective outcome measures were shown in relatively young patients without significant chondromalacia who underwent concomitant procedures for cartilage defects, limb malalignment, and/or knee instability. We detected no significant difference in outcomes when comparing medial and lateral meniscal allograft transplants. We detected no significant difference when comparing isolated MAT with MAT performed with concomitant procedures. **Level of Evidence:** Level IV, systematic review of Level III and IV studies.

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The meniscus plays a crucial role in maintaining and preserving normal knee function.<sup>1</sup> Its role in load distribution, shock absorption, joint lubrication, proprioception, joint congruity, and knee stabilization is well documented.<sup>2-4</sup> Conversely, absence of meniscal tissue has been shown to result in articular cartilage degeneration.<sup>5-7</sup>

With an increased understanding of meniscal function, a rationale has been provided for preserving these structures whenever possible.<sup>6</sup> Advances in the surgical treatment of meniscal tears have changed standards from complete excision to arthroscopic meniscal repairs whenever possible.<sup>8</sup> However, meniscal repair is not always possible, and even a partial meniscectomy can be functionally equivalent to a total meniscectomy.<sup>6,9</sup>

In an attempt to prevent the adverse effects observed with meniscectomy, meniscal allograft transplantation (MAT) was developed and subsequently proven to be effective in animal trials.<sup>10,11</sup> The first clinical trial was published in 1989 and reported the experimental and short-term results of the technique as a potential treatment option in a painful meniscectomized knee.<sup>12</sup> Since that time, multiple clinical, biomechanical, and review articles on MAT have been

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published.<sup>13-39</sup> The indications and techniques are continually being refined. However, the literature is replete with uncontrolled, retrospective case series involving multiple confounding variables.<sup>40</sup> The clinician has very little to guide him or her in making evidence-based decisions with regard to meniscal transplantation. No study currently exists comparing the long-term results of MAT with a meniscectomized control group receiving no treatment. We are left only with the ability to assess critically the best available studies to try to answer some basic questions about MAT.

The purpose of this study is to systematically review the literature on MAT with hopes of answering the following questions: (1) Does MAT prevent advancing chondrosis? (2) Who is the ideal candidate for MAT? (3) What is the survival time for a meniscal allograft in a stable knee? (4) Can MAT be successful when performed with concomitant procedures? (5) Is there a difference in outcome between medial and lateral meniscal allograft transplants? (6) What is the expected function of a knee that has undergone meniscal transplantation?

Our hypotheses are as follows: (1) MAT does prevent advancing chondrosis in the short term. (2) The ideal candidate for MAT is a relatively young, healthy individual with a meniscectomized knee compartment and pain that does not improve. The ideal patient has a knee with ligamentous stability, no lower extremity mechanical malalignment, and minimal chondrosis of the knee and is not overweight. (3) The survival time of meniscal allografts in an ideal environment will be approximately 5 years. (4) MAT can be successful when performed with concomitant procedures. (5) There will be no difference in outcome between MATs performed in the medial compartment and those performed in the lateral compartment. (6) It will be difficult to perform high-impact activities, but patients can expect painless knees during activities of daily living and low-impact activities.

### SEARCH STRATEGY AND CRITERIA

Two of the authors independently searched the Medline, Embase, and PubMed bibliographic databases to find relevant articles on MAT. They used the key words “meniscal transplant” and “meniscal transplantation” alone and in combination with “allograft,” “meniscus,” “clinical outcome,” and “techniques” in various combinations (using Boolean operators AND and OR). To identify additional relevant studies missed by the original literature search, the bibliogra-

phies of relevant articles were also reviewed. Included in the review were all articles reporting clinical outcomes of meniscal transplantation. Inclusion criteria included studies in which the surgical technique for meniscal allograft fixation involved the use of bony fixation methods to secure the allograft to the native tibial plateau (i.e., allograft tissue containing some form of bone attached to both the anterior and posterior meniscal horns for utilization in fixation of allograft meniscus), clinical studies with a minimum of 2 years’ follow-up, and articles written in English.

Excluded were those studies with less than a mean of 2 years’ follow-up, studies in which all of the meniscal allografts were fixed without bony fixation (soft-tissue fixation only), studies in which MAT was performed in a joint other than the knee, review articles, studies that did not define the method of allograft fixation, and studies that did not provide clinical outcomes of MAT. All inclusion and exclusion criteria were defined before the literature search was performed.

The decision to exclude studies in which the surgical technique did not include bony fixation of the allograft meniscal horns was based on biomechanical studies showing superiority of bony fixation over suture-alone fixation. Human cadaveric studies have shown that a secure anatomic fixation with bone plugs attached to the anterior and posterior horns is essential to restore normal contact mechanics for both the lateral and medial menisci.<sup>41-44</sup> Excluding studies that use soft-tissue fixation only also effectively eliminates assessment of multiple studies with variable surgical techniques and selects only the studies using techniques supported by the biomechanical literature.

A list of relevant articles to include in the systematic review was agreed upon. Both reviewers independently assigned a Level of Evidence to each clinical study. The Levels of Evidence were subsequently compared and found to be identical. The initial search resulted in the identification of 763 articles. Fourteen clinical studies were identified as meeting the inclusion criteria.<sup>25-27,29,45-54</sup> Of the 14 articles, 2 included the utilization of more than 1 surgical technique for MAT.<sup>49,52</sup> These 2 studies included patients who underwent MAT by use of suture-only fixation for the meniscal horns but were not excluded because the number of allografts transplanted through the suture-only technique was small.<sup>49,52</sup>

Of the 14 clinical articles, 13 were assigned Level IV Evidence and 1 was assessed as Level III Evidence by both reviewers.

**TABLE 1.** Study Protocols

Author	Year Published	No. of Patients	No. of Allografts	Medial/Lateral	Patient Age [Range (Mean)] (yr)	Follow-Up [Mean (Range)] (mo)
Bhosale et al. <sup>45</sup>	2007	8	8	2/6	29-58 (42)	38 (24-72)
Cole et al. <sup>46</sup>	2006	36 (1 lost)	40	25/15	16-48 (31)	33.5 (24-57)
Farr et al. <sup>47</sup>	2007	29 (3 lost)	29	25/8	16-52 (36.9)	53 (38-68)
Graf et al. <sup>48</sup>	2004	8	8	9/0	23-42 (32.6)	115 (96-123)
Hommen et al. <sup>49</sup>	2007	22	22	13/4	17-46 (32)	141 (115-167)
Noyes et al. <sup>25</sup>	2004	38	40	20/20	14-49 (30)	40
Rath et al. <sup>26</sup>	2001	23	27	21/7	19-41 (30)	54 (24-97)
Rue et al. <sup>27</sup>	2008	30 (2 lost)	31	19/11	13.9-47.9 (29.9)	37 (1.9-5.6)
Rueff et al. <sup>50</sup>	2006	16	8	8/0	46-56 (51)	65 (60-72)
Ryu et al. <sup>51</sup>	2002	28 (3 lost)	29 (26)	5/8	15-49 (34.5)	33 (12-72)
Sekiya et al. <sup>29</sup>	2003	28	31	7/24	17-48 (35)	32 (20-66)
Sekiya et al. <sup>52</sup>	2006	32 (7 lost)	25	0/25	19-45 (30)	39 (24-72)
Stollsteimer et al. <sup>53</sup>	2000	22	23	11/12	20-42 (31)	40 (13-69)
Yoldas et al. <sup>54</sup>	2003	31	34	19/15 total, 2/9 isolated, 17/6 with ACLR	15-42 (28)	33 (24-65)
Total		323	352		33.9 (14-58)	53.8 (24-167)

Abbreviation: ACLR, anterior cruciate ligament reconstruction.

## RESULTS

No studies in this review were randomized or controlled. Rueff et al.<sup>50</sup> performed a retrospective, case-controlled study of Level III Evidence. The other 13 articles are case series (Level IV Evidence). Study characteristics are noted in Table 1.

The primary indication for MAT in this series was knee pain, specifically in the compartment of a previous meniscectomy, that had not improved after non-operative treatment. Exclusion criteria usually involved evidence of advanced arthrosis. All 14 articles classified the degree of chondral wear in the knee before MAT based on preoperative weight-bearing posteroanterior radiographs in 45° of flexion and/or Outerbridge classification.

This review excluded studies that did not fix the meniscal allograft horns to the recipient tibia with bony fixation. However, 3 articles in this review included patients who received meniscal allografts transplanted with suture alone (Table 2) with satisfactory results. However, there is evidence indicating the superiority of bony fixation (based on range of motion and International Knee Documentation Committee [IKDC] scores).<sup>52</sup> Graft preservation and sizing methods vary<sup>55-57</sup> and are noted in Table 2.

All 14 studies used validated outcome measures to report results (Table 3). Percent satisfaction ranged from 62.5% to 100% (Table 3).

Radiographic assessment of joint space narrowing in the involved compartment of the knee was

assessed in 9 of the 14 articles in this series using methods noted in Table 3. A total of 196 knees in 9 studies were assessed for joint space narrowing after MAT.

Hommen et al.<sup>49</sup> showed that patients with poor postoperative Lysholm scores had correspondingly significantly lower preoperative Lysholm scores when compared with the other patients, although both groups showed significant improvements.

Stollsteimer et al.<sup>53</sup> reported trends of better final IKDC scores if the patient had (1) body weight less than 225 lb, (2) cumulative Outerbridge scores of 5 or less, and (3) Outerbridge scores of 2 or less in any area. The articular changes had a significant effect on overall patient outcome. Patients with Outerbridge scores of 2 or less in any area had significantly improved post-treatment Lysholm and Tegner scores, whereas patients with Outerbridge grade 3 or greater in any area did not have significant improvements in post-treatment Lysholm and Tegner scores.

Results of a second-look arthroscopy procedure were described in 6 of the 14 articles; however, only a subset of the patient population in each of these studies underwent the procedure. The survival time of failed allografts, for studies that reported the data, is listed in Table 3.

Failures of the meniscal allograft that occurred at approximately 2 years or earlier were reported in the studies by Bhosale et al.<sup>45</sup> (35%), Cole et al.<sup>46</sup> (7%), Farr et al.<sup>47</sup> (12%), and Graf et al.<sup>48</sup> (11%).

TABLE 2. Graft Characteristics and Concurrent Procedures

Author	Graft Preservation	Graft Fixation Method	Sizing Method	Concurrent Procedures
Bhosale et al. <sup>45</sup>	Cryopreserved	Bone plugs	Not provided	8 ACI (6 bipolar)
Cole et al. <sup>46</sup>	>80% cryopreserved and <20% fresh frozen, nonirradiated	Medial: double bone plug Lateral: keyhole	Pollard	19 (47.5%) 3 osteochondral allograft 3 osteochondral autograft 2 microfracture 2 OCD fixation 1 ACI 1 chondral debridement 6 ligament reconstruction 1 osteotomy
Farr et al. <sup>47</sup>	Fresh frozen	Slot technique for both medial and lateral	Pollard	29 ACI (4 bipolar) 6 HTO 1 tibial tubercle medialization 1 tibial tubercle osteotomy + ACL 7 ACLR 1 anteromedialization
Graf et al. <sup>48</sup>	Cryopreserved 7/8 were irradiated	7/8 bone blocks at anterior and posterior horns	Pollard	8/8 ACLR staged or concomitant 1 had HTO 2 mo after MAT
Hommen et al. <sup>49</sup>	Cryopreserved	Medial: 3/12 by double bone plug, 8/12 by all-suture technique, 1/12 by single posterior bone plug Lateral: 2/8 by single bone plug with trough, 5/8 by suture, 1/8 by double bone plug	Pollard	Medial: 8 ACLR, 1 revision ACLR, 1 HTO, 3 lateral release, 1 loose body removal, 2 capsular plication, 2 chondroplasty of femoral condyle Lateral: 1 ACL R, 1 HTO, 2 LOA, 1 chondroplasty of femoral condyle
Noyes et al. <sup>25</sup>	Cryopreserved	Medial: double bone plug Lateral: bone block between anterior and posterior horns into bony trough	Pollard	16/40 (40%) osteochondral autografts 7 ACLR 1 MCL reconstruction 1 PCL 1 ACL/PCL
Rath et al. <sup>26</sup>	Deep frozen and cryopreserved	Medial: double bone plugs in all but 1 Lateral: bone block connecting horns in 1	Pollard radiography and Shaffer <sup>57</sup> MRI	11 ACLR (5 revisions) 3 partial meniscectomies of opposite meniscus 1 anteromedial tibial tubercle transfer
Rue et al. <sup>27</sup>	Before 2004: cryopreserved (majority) After 2004: fresh frozen	Before July 2005: Medial (14): double bone plug Lateral (4): keyhole technique After July 2005: All MAT done with bridge-in-slot technique (6 medial/7 lateral)	Not provided	16 (52%) ACI 15 (48%) osteochondral allograft 3 patients in osteochondral group also underwent additional concomitant procedure (2 hardware removals and 1 HTO)
Rueff et al. <sup>50</sup>	Cryopreserved	1 case with double bone plug 7 cases with bone bridge with tibial trough	Not provided	8 ACLR with various allograft tissues

TABLE 2. Continued

Author	Graft Preservation	Graft Fixation Method	Sizing Method	Concurrent Procedures
Ryu et al. <sup>51</sup>	Not provided	Lateral: bone bridge Medial: bone blocks	Not provided	12 ACLR
Sekiya et al. <sup>29</sup>	Cryopreserved	Lateral: bone bridge and trough Medial: horns fixed with bone tunnels through transosseous tunnels	PA and lateral radiographs described by Shaffer	19 primary ACLR 9 revision ACLR 2 lateral closing-wedge osteotomies
Sekiya et al. <sup>52</sup>	Cryopreserved	12 bone bridge with trough 8 suture-only fixation of horns 5 bone plugs	Based on lateral and PA radiograph (Pollard and Shaffer)	None
Stollsteimer et al. <sup>53</sup>	Cryopreserved	Bone plugs	AP/lateral radiograph	Not provided (no concurrent procedures mentioned but nothing stating that they were not performed)
Yoldas et al. <sup>54</sup>	Fresh frozen	Medial: bone plugs Lateral: bone plugs/bridge	PA/lateral radiographs "similar" to Pollard	11 isolated MAT 20 MAT+ ACLR (12 primary ACLR with patellar tendon autograft and 8 revision ACLR with patellar tendon allograft)

Abbreviations: ACL, autologous chondrocyte implantation; OCD, osteochondritis dissecans; HTO, high tibial osteotomy; ACLR, anterior cruciate ligament reconstruction; LOA, lysis of adhesions; MCL, medial collateral ligament; PCL, posterior cruciate ligament; PA, posterolateral; AP, anteroposterior.

Investigators who analyzed patients undergoing concomitant procedures as a subgroup generally did not detect a difference in outcome between the groups. Results from Hommen et al.<sup>49</sup> showed a trend toward greater improvement in Lysholm and pain scores for patients undergoing isolated MAT compared with MAT with 3 or more additional procedures.

Cole et al.<sup>46</sup> showed no significant difference between the mean preoperative and mean follow-up outcome scores between the medial and lateral subgroups; however, they did notice that the lateral subgroup showed a trend toward greater improvements than the medial subgroup on nearly all knee scoring scales. With regard to visual analog scale scores and IKDC scores, the authors admit that the study was under-powered to detect significant differences.

Farr et al.<sup>47</sup> also found that both medial and lateral subgroups showed significant improvements in the Browne Modified Cincinnati, Lysholm, visual analog scale, and maximum pain and satisfaction scores. However, there was a significant difference between the 2 subgroups in the change in Lysholm score only: the lateral group improved by only 1.13 points, whereas the medial group improved by 27.29 points. The lateral group had much higher preoperative Lysholm scores and had a trend toward more pain at the latest follow-up.

Rue et al.<sup>27</sup> showed no statistical difference in any outcome measure used when comparing medial MAT with concomitant autologous chondrocyte implantation and lateral MAT with autologous chondrocyte implantation. Ryu et al.,<sup>51</sup> Stollsteimer et al.,<sup>53</sup> and Yoldas et al.<sup>54</sup> all showed no significant difference in outcome between medial and lateral meniscal allografts.

Functional outcomes (e.g., participation in sports and activity level) were generally good where reported, as detailed in Table 3.

## DISCUSSION

The question of greatest import is whether MAT can preserve cartilage in the knee. Studies have shown osteoarthritis to be inevitable in a meniscectomized knee. MAT attempts to re-create some of the load-distributing properties of the native meniscus to prevent or slow the process of cartilage degeneration. Whether an allograft achieves this is uncertain—one needs objective criteria to arrive at a conclusive answer. To achieve Level I Evidence, the progression of chondromalacia in a meniscectomized knee would be compared with the progression of chondromalacia, or

TABLE 3. Outcomes

Author	Outcome Measures	Radiographic Assessment of OA	Satisfaction	Isolated MAT v Concomitant Procedure Subgroup	Complication	Failures	Failure Time
Bhosale et al. <sup>45</sup>	Lysholm, MRI, second-look arthroscopy at 1 yr	Not provided	5/8 (62.5%) Lysholm mean from 49 to 63.6 at latest follow-up		Aseptic synovitis in 2/8	3/8	35% in first 2 yr
Cole et al. <sup>46</sup>	Lysholm, Tegner, IKDC, KOOS, Noyes, SF-12, VAS	Not provided	77.5% completely/mostly satisfied 90% normal/nearly normal IKDC	No significant difference in outcomes	None	7/43 (16%)	3/7 in first year (7% of total patients)
Farr et al. <sup>47</sup>	Browne patient/clinician Cincinnati, Lysholm, VAS, satisfaction	Not provided	13/33 (39.4%) good to excellent by Lysholm; this includes the 4 early failures	No significant difference in outcomes	68% of nonfailures <2 yr required at least 1 additional procedure	56% fair/poor by use of Lysholm	4/33 (12%) early failures (<2 yr)
Graf et al. <sup>48</sup>	IKDC, 6/8 second-look arthroscopy, return to recreational sports, satisfaction	6/8 with progressive joint space narrowing on AP WB Mean narrowing, 0.38 mm	7/8 returned to recreational sports 8/8 satisfied 1/8 success ("near normal") from overall IKDC score (poor results of IKDC largely because of radiographic scores)	No control group (all 8 patients had concomitant ACLR)	1 patient had ACLR with allograft and required revision 6 mo postoperatively because of trauma	1/9 not included in long-term study: removed at 4 mo	1/9 (11%) in first 2 yr
Hommen et al. <sup>49</sup>	Lysholm, modified pain score, subjective assessment form, Tegner, IKDC, SF-12, radiography in 15/22, MRI in 7/22 at follow-up only	15 radiography at follow-up (WB PA 45°) 10 had narrowing (5.15 mm to 4 mm) correlated with lower mean postoperative Lysholm scores	Overall mean Lysholm score increased from 53 to 75 6/20 (30%) excellent/good at follow-up 2 scores worsened at follow-up (both lateral grafts)	No significant difference in outcomes but trend observed toward greater improvement in Lysholm and pain scores for isolated MAT compared with MAT plus 3 procedures	40 subsequent procedures Other than subsequent meniscal procedures, 17 complications	4/8 (50%) lateral 3/12 (25%) medial 7/20 (35%) total 85% underwent subsequent procedures	Failure rates are at mean follow-up of 11.8 yr
Noyes et al. <sup>25</sup>	29/40 (73%) analyzed by MRI, Cincinnati knee scale, pain and function score, examination, arthroscopy in symptomatic knees (13)	Preoperative and postoperative 45° WB PA radiography 3 knees went on to narrowing of tibial/femoral joint space	89% of knees improved 76% returned to light low-impact sports 11% had pain with ADLs at follow-up compared with 79% preoperatively	No significant difference in outcomes	Limited flexion requiring manipulation (4) 4 allografts failed and were removed between 8 wk and 18 mo	11 (28%) failed 12 (30%) altered characteristics based on MRI, second-look arthroscopy, and clinical examination	Lateral allografts failed at a mean of 53 mo Medial allografts at a mean of 25 mo

**TABLE 3.** *Continued*

Author	Outcome Measures	Radiographic Assessment of OA	Satisfaction	Isolated MAT v Concomitant Procedure Subgroup	Complication	Failures	Failure Time
Rath et al. <sup>26</sup>	SF-36 IKDC at follow-up only Histology of torn allograft menisci	WB PA radiography in 45° of flexion in 11/22 showed 5.2 mm preoperatively and 4.5 mm at follow-up, showing no significant difference on average	Mean IKDC score postoperatively of 54 (35-82) 21/22 (95%) had significant improvement in SF-36	No significant difference in mean SF-36 but greater improvement in role-physical category in MAT + ACLR group	10 patients: repeat arthroscopy for 1 case of arthrofibrosis, 8 cases of retearing, and 1 case of patellofemoral pain	8/22 (36%) tore requiring 2 total and 6 partial meniscectomies 1 patient had a decrease in SF-36	Mean, 31 mo
Rue et al. <sup>27</sup>	IKDC, Noyes symptom rating and sports activity, SF-12, KOOS, Lysholm, Tegner	Not provided	22/29 (76%) completely/ mostly satisfied 90% would have surgery again IKDC defined 48% as normal/near normal at follow-up		None	2/29 (6.9%) defined as failures	2 failures occurred at 2.4 and 3 yr
Rueff et al. <sup>50</sup>	IKDC, Lysholm, VAS	Not provided	7/8 (87.5%) would have procedure again IKDC increased from 60.8 to 90.3—only activity level and kneeling showed no significant improvement Lysholm scores improved significantly except swelling		None	None reported	
Ryu et al. <sup>51</sup>	VAS, Lysholm-II, Tegner, IKDC, satisfaction	8/25 available for comparison with 2 yr follow-up No change in 5 patients, 1-2 mm change in 2 patients and 4 mm of narrowing in 1 patient	17/25 (68%) normal/near normal activity level (78% grade II/III v 43% grade IV)	No significant difference in outcomes	6 effusions (resolved) 10 repeat arthroscopies 1 motion loss requiring manipulation + LOA	None reported	

TABLE 3. Outcomes (Continued)

Author	Outcome Measures	Radiographic Assessment of OA	Satisfaction	Isolated MAT v Concomitant Procedure Subgroup	Complication	Failures	Failure Time
Sekiya et al. <sup>29</sup>	Lysholm, KOS, SF-36, ADLs, physical examination	Preoperative and follow-up PA WB radiography in 45° of flexion: no significant difference in joint space	26/28 patients (93%) were greatly/somewhat improved 20/28 (71%) participate in moderate or strenuous sports		None reported	1 patient felt he was made worse by procedure	
Sekiya et al. <sup>52</sup>	Lysholm, KOS, SF-36, IKDC subjective evaluation	20 patients with PA WB radiography in 45° of flexion: preoperative mean space of 3.70 mm compared with 3.65 mm at follow-up Mean of 0.17 mm of narrowing	96% felt function and activity level improved SF-36 scores higher than age- and sex-matched US controls 20/25 (80%) with normal or near-normal activity		None reported	Not defined 1/25 unsatisfied	
Stollsteimer et al. <sup>53</sup>	IKDC, Lysholm, Tegner (independent assessor)	Standing AP radiographs: mean loss of joint space of 0.882 mm (range, 0-3 mm) 12 had no loss, 4 lost 1 mm, 5 lost 2 mm, and 1 lost 3 mm (infection)	18/23 (78%) had pain improvement Mean Lysholm score increased from 47.2 to 75.6 Patients with OB ≤2 had significantly improved Lysholm and Tegner but no improvement if ≥3 in any area Trend toward better IKDC with weight <225 lb, COB ≤5, and OB ≤2 in any area		1 infection 1 case of hemarthrosis 2 cases of synovitis requiring synovectomy 1 loosened bone plug 6 meniscal tears requiring surgery (5 partial meniscectomies and 1 repair)	Failure not specifically defined 1 infection requiring graft removal	

TABLE 3. Continued

Author	Outcome Measures	Radiographic Assessment of OA	Satisfaction	Isolated MAT v Concomitant Procedure Subgroup	Complication	Failures	Failure Time
Yoldas et al. <sup>54</sup>	Lysholm, KOS, SF-36, physical examination, KT-1000, functional strength	PA WB radiography in 45° of flexion Increased joint space in both medial and lateral, though no statistical significance	94% no pain with ADLs Functional strength: 85% of uninvolved leg 22/31 "greatly improved" (71%) 8/31 "somewhat improved" (26%) In 30/31 knee function and level of activity were normal or nearly normal 61% participate in moderate or strenuous sports without pain	No significant difference in outcomes	No clinical evidence of re-tear	No failures requiring removal of graft However, 1 patient reported no subjective improvement as a result of surgery	

Abbreviations: OA, osteoarthritis; KOOS, Knee Injury and Osteoarthritis Outcome Score; SF, Short Form; VAS, visual analog scale; AP, anteroposterior; WB, weight bearing; LOA, lysis of adhesions; ADLs, activities of daily living; PA, posteroanterior; OB, Outerbridge; COB, cumulative Outerbridge.

lack thereof, in a meniscectomized knee that received MAT, with a follow-up of more than 10 years.

Second-look arthroscopy was performed in 62 patients in the studies reviewed. Very few authors performing this procedure commented on the amount of chondrosis at follow-up compared with preoperative chondrosis. Some authors attributed their failures to advancement of chondromalacia in the involved compartment. These studies showed a trend of advancing chondrosis correlating with failure of MAT, even when addressed with a cartilage-preserving procedure. Because of the strict inclusion and exclusion criteria, this systematic review contains only the more recent studies, written by authors who have recognized the poor outcome predictors (malalignment, advanced chondromalacia, knee instability) associated with previous studies on MAT.<sup>32,58</sup>

Many of the second-look arthroscopies were for mechanical meniscal symptoms and resulted in partial or total meniscectomies. Overall failures of MAT in this review ranged from 0% to 37.5% (although the majority of articles did not provide a strict definition of failure). If we exclude the study performed by Bhosale et al.,<sup>45</sup> which included a slightly older patient population and patients with bipolar arthrosis, the mean early failure rate ( $\leq 2$  years) is approximately 10%. Potential factors explaining the early failures were not always provided, but the few that were described were usually associated with a greater degree of chondrosis.

Some but not all of the studies reviewed radiographically measured the tibiofemoral distance preoperatively and at follow-up, in an attempt to quantify the effectiveness of a meniscal allograft in preventing osteoarthritis. Although this measurement does not always correlate with patient satisfaction, we believe this is a useful tool and one to be used by all clinicians researching the topic. There are some potential problems with this method, however. First, many of the measurements are less than 1 mm, raising questions regarding accuracy and reproducibility. Second, other than Sekiya et al.,<sup>29</sup> who provided radiographic data based on IKDC criteria, nonvalidated criteria ("mild narrowing" and so on) were used to grade arthrosis.

Several authors performed magnetic resonance imaging (MRI) evaluation of the meniscal allograft at follow-up, though with unclear and nonuniform parameters for success. Universal MRI parameters specifically defining failure and success are needed.<sup>59</sup> We believe that MRI can be a useful objective parameter to define allograft signal, extrusion, and tears, as well

as to determine the long-term chondroprotective effect of the transplanted meniscus.

The mean age in this series was 33.9 years. Other than Rueff et al.,<sup>50</sup> who specifically looked at a patient population older than the age that has historically been indicated for MAT, most of the remainder of the patients were aged less than 50 years. None of the articles specifically analyzed patient age as a potential factor affecting the outcome of MAT, and Rueff et al. showed outcomes in their older population equivalent to the other studies with younger patient groups. Therefore no definitive conclusion can be reached about the ideal age of a patient indicated for MAT based on the available literature.

Only a small number of the articles specifically assessed function of the knee at follow-up. The percentage of patients who rated their postoperative activity level at follow-up as normal to nearly normal ranged from 68% to 89%. In addition, 61% to 88% could return to some level of sports, and Yoldas et al.<sup>54</sup> showed 85% functional strength of the involved leg when compared with the contralateral leg. These articles show that greater than 60% of patients who undergo MAT can be expected to return to some level of sports. The level of sporting activity was not always specified, and the long-term consequences of engaging in sports are unknown. On the basis of these studies, the goal and expected outcome should be a painless knee during activities of daily living. The expectation of returning to sports should be very guarded, and given the relatively high meniscal tear rate, restrictions on high-impact activities with cutting or pivoting are warranted.

A potential weakness of this review is the possible overlap of patients among different studies. Of the 14 articles, 4 included J. K. Sekiya as the primary author or a coauthor. When we analyze the time periods of when MAT was performed among the 4 studies, it becomes evident that there are many years of overlap. The total number of patients and allografts may actually be smaller than what is reported in this systematic review. Another limitation of this review is its exclusion of soft-tissue fixation techniques, which necessarily decreased the amount of data from which to draw conclusions.

Using our strict inclusion/exclusion criteria, we believe that we have minimized certain variables that can have an important effect on outcome and have thus selected the articles that provide the most valid results of MAT. Most studies published continue to be Level IV Evidence. However, if the researchers use strict indications, several objective and subjective val-

idated outcome measures, and preoperative and follow-up radiographs and MRI; diligently record the state of the meniscal allograft and cartilage surfaces when performing a second-look arthroscopy; and describe failures in detail, then future clinicians will have a clearer understanding of outcomes of MAT.

Ideally, multicenter randomized, controlled trials would provide us with answers to many of the questions surrounding this topic. Until that time, systematic reviews such as this one can help guide the present-day clinician.

From this review, we conclude that good early and midterm results of cryopreserved or fresh-frozen, non-irradiated MAT can be achieved in a relatively young patient with only mild chondromalacia (lower than Outerbridge grade 3) who is not overweight and has a stable, mechanically aligned lower extremity, if the allograft is sized radiographically by use of anteroposterior and lateral films and the allograft meniscal horns have bony attachments and are fixed by bony techniques. Similar results can be expected if the transplant is performed alone or with a concomitant cartilage repair procedure; however, significant cartilage defects (Outerbridge grade 2 or greater) on both the femoral and tibial sides in the same compartment (“kissing lesions”) requiring autologous cartilage implantation result in a high failure rate. Good outcomes of MAT can be expected when performing a concomitant ligament reconstruction or malalignment procedure on the knee, unless greater than 3 concomitant procedures are performed. There is no significant difference in outcome between medial and lateral MAT. Patients who undergo MAT should be warned of the likelihood of a repeat procedure on their knee, most likely for treatment of a meniscal allograft tear.

Despite a growing body of knowledge on the topic, there remains a lack of consensus regarding optimal allograft sizing technique, allograft fixation techniques, tissue processing, indications, and long-term efficacy. The question remains: Does implantation of a meniscal allograft slow or stop cartilage degeneration in a meniscus-deficient knee? Moreover, the answer remains: Without a prospective, randomized trial comparing MAT in a meniscectomized knee with a control group, we will continue to lack an evidence-based answer for our patients.

Many surgeons continue to report their case series, each providing a small piece of the puzzle. A systematic review can put some of these pieces together to help us make informed clinical decisions. As more modern techniques evolve and as awareness of some of the important factors in maximizing patient out-

come grows, the group of relevant clinical studies from which we can draw conclusions about MAT will also grow.

## CONCLUSIONS

MAT can result in alleviation of knee pain, improvement in knee function, and good patient satisfaction if performed in the optimal candidate. Improvements in both objective and subjective outcome measures were shown in relatively young patients without significant chondromalacia, who underwent concomitant procedures for cartilage defects, limb malalignment, and/or knee instability. We detected no significant difference in outcomes when comparing medial and lateral meniscal allograft transplants. We detected no significant difference when comparing isolated MAT with MAT performed with concomitant procedures.

## REFERENCES

- Swenson TM, Harner CD. Knee ligament and meniscal injuries. Current concepts. *Orthop Clin North Am* 1995;26:529-546.
- Henning CE, Lynch MA. Current concepts of meniscal function and pathology. *Clin Sports Med* 1985;4:259-265.
- Levy IM, Torzilli PA, Gould JD, Warren RF. The effect of lateral meniscectomy on motion of the knee. *J Bone Joint Surg Am* 1989;71:401-406.
- Levy IM, Torzilli PA, Warren RF. The effect of medial meniscectomy on anterior-posterior motion of the knee. *J Bone Joint Surg Am* 1982;64:883-888.
- Alford JW, Lewis P, Kang RW, Cole BJ. Rapid progression of chondral disease in the lateral compartment of the knee following meniscectomy. *Arthroscopy* 2005;21:1505-1509.
- Lee SJ, Aadalen KJ, Malaviya P, et al. Tibiofemoral contact mechanics after serial medial meniscectomies in the human cadaveric knee. *Am J Sports Med* 2006;34:1334-1344.
- Shelbourne KD, Dickens JF. Digital radiographic evaluation of medial joint space narrowing after partial meniscectomy of bucket-handle medial meniscus tears in anterior cruciate ligament-intact knees. *Am J Sports Med* 2006;34:1648-1655.
- Diment MT, DeHaven KE, Sebastianelli WJ. Current concepts in meniscal repair. *Orthopedics* 1993;16:973-977.
- Kline AJ, Miller MD. Complications in meniscal surgery. *Oper Tech Sports Med* 2003;11:134-143.
- Canham W, Stanish W. A study of the biological behavior of the meniscus as a transplant in the medial compartment of a dog's knee. *Am J Sports Med* 1986;14:376-379.
- McNickle AG, Wang VM, Shewman EF, Cole BJ, Williams JM. Performance of a sterile meniscal allograft in an ovine model. *Clin Orthop Relat Res* 2009;467:1868-1876.
- Milachowski KA, Weismeier K, Wirth CJ. Homologous meniscus transplantation. Experimental and clinical results. *Int Orthop* 1989;13:1-11.
- Alhalki MM, Hull ML, Howell SM. Contact mechanics of the medial tibial plateau after implantation of a medial meniscal allograft. A human cadaveric study. *Am J Sports Med* 2000;28:370-376.
- Carter T. Meniscal allograft: Keyhole technique. *Oper Tech Sports Med* 2002;10:144-149.
- Chang HC, Teh KL, Leong KL, Mak SL, Karim SA. Clinical evaluation of arthroscopic-assisted allograft meniscal transplantation. *Ann Acad Med Singapore* 2008;37:266-272.
- Cole BJ, Carter TR, Rodeo SA. Allograft meniscal transplantation: Background, techniques, and results. *Instr Course Lect* 2003;52:383-396.
- DiStefano VJ. Function, post-traumatic sequelae and current concepts of management of knee meniscus injuries: A review article. *Clin Orthop Relat Res* 1980:143-146.
- Fox J, Lee S, Cole B. Bone plug technique for meniscal transplantation. *Oper Tech Sports Med* 2003;11:161-169.
- Garrett JC, Steensen RN. Meniscal transplantation in the human knee: A preliminary report. *Arthroscopy* 1991;7:57-62.
- Hunt S, Kaplan K, Ishak C, Kummer FJ, Meislin R. Bone plug versus suture fixation of the posterior horn in medial meniscal allograft transplantation: A biomechanical study. *Bull NYU Hosp Jt Dis* 2008;66:22-26.
- Kawamura S, Lotito K, Rodeo S. Biomechanics and healing response of the meniscus. *Oper Tech Sports Med* 2003;11:68-76.
- Lubowitz JH, Verdonk PC, Reid JB III, Verdonk R. Meniscus allograft transplantation: A current concepts review. *Knee Surg Sports Traumatol Arthrosc* 2007;15:476-492.
- Matava MJ. Meniscal allograft transplantation: A systematic review. *Clin Orthop Relat Res* 2007;455:142-157.
- McDermott ID, Lie DT, Edwards A, Bull AM, Amis AA. The effects of lateral meniscal allograft transplantation techniques on tibio-femoral contact pressures. *Knee Surg Sports Traumatol Arthrosc* 2008;16:553-560.
- Noyes FR, Barber-Westin SD, Rankin M. Meniscal transplantation in symptomatic patients less than fifty years old. *J Bone Joint Surg Am* 2004;86:1392-1404.
- Rath E, Richmond JC, Yassir W, Albright JD, Gundogan F. Meniscal allograft transplantation. Two- to eight-year results. *Am J Sports Med* 2001;29:410-414.
- Rue JP, Yanke AB, Busam ML, McNickle AG, Cole BJ. Prospective evaluation of concurrent meniscus transplantation and articular cartilage repair: Minimum 2-year follow-up. *Am J Sports Med* 2008;36:1770-1778.
- Sekiya JK, Elkousy HA, Harner CD. Meniscal transplant combined with anterior cruciate ligament reconstruction. *Oper Tech Sports Med* 2002;10:157-164.
- Sekiya JK, Giffin JR, Irrgang JJ, Fu FH, Harner CD. Clinical outcomes after combined meniscal allograft transplantation and anterior cruciate ligament reconstruction. *Am J Sports Med* 2003;31:896-906.
- Sohn DH, Toth AP. Meniscus transplantation: Current concepts. *J Knee Surg* 2008;21:163-172.
- Stone KR, Walgenbach AW, Turek TJ, Freyer A, Hill MD. Meniscus allograft survival in patients with moderate to severe unicompartamental arthritis: A 2- to 7-year follow-up. *Arthroscopy* 2006;22:469-478.
- van Arkel ER, de Boer HH. Human meniscal transplantation. Preliminary results at 2 to 5-year follow-up. *J Bone Joint Surg Br* 1995;77:589-595.
- van Arkel ER, de Boer HH. Survival analysis of human meniscal transplantations. *J Bone Joint Surg Br* 2002;84:227-231.
- Verdonk PC, Demurie A, Almqvist KF, Veys EM, Verbruggen G, Verdonk R. Transplantation of viable meniscal allograft. Survivorship analysis and clinical outcome of one hundred cases. *J Bone Joint Surg Am* 2005;87:715-724.
- Verdonk PC, Demurie A, Almqvist KF, Veys EM, Verbruggen G, Verdonk R. Transplantation of viable meniscal allograft.

- Surgical technique. *J Bone Joint Surg Am* 2006;88:109-118 (suppl 1, pt 1).
36. Verdonk R, Almqvist KF, Huysse W, Verdonk PC. Meniscal allografts: Indications and outcomes. *Sports Med Arthrosc* 2007;15:121-125.
  37. von Lewinski G, Kohn D, Wirth CJ, Lazovic D. The influence of nonanatomical insertion and incongruence of meniscal transplants on the articular cartilage in an ovine model. *Am J Sports Med* 2008;36:841-850.
  38. von Lewinski G, Milachowski KA, Weismeier K, Kohn D, Wirth CJ. Twenty-year results of combined meniscal allograft transplantation, anterior cruciate ligament reconstruction and advancement of the medial collateral ligament. *Knee Surg Sports Traumatol Arthrosc* 2007;15:1072-1082.
  39. Wirth CJ, Peters G, Milachowski KA, Weismeier KG, Kohn D. Long-term results of meniscal allograft transplantation. *Am J Sports Med* 2002;30:174-181.
  40. Rodeo SA. Meniscal allografts—Where do we stand? *Am J Sports Med* 2001;29:246-261.
  41. Alhalki MM, Howell SM, Hull ML. How three methods for fixing a medial meniscal autograft affect tibial contact mechanics. *Am J Sports Med* 1999;27:320-328.
  42. Chen MI, Branch TP, Hutton WC. Is it important to secure the horns during lateral meniscal transplantation? A cadaveric study. *Arthroscopy* 1996;12:174-181.
  43. Paletta GA Jr, Manning T, Snell E, Parker R, Bergfeld J. The effect of allograft meniscal replacement on intraarticular contact area and pressures in the human knee. A biomechanical study. *Am J Sports Med* 1997;25:692-698.
  44. Rijk PC. Meniscal allograft transplantation—Part I: Background, results, graft selection and preservation, and surgical considerations. *Arthroscopy* 2004;20:728-743.
  45. Bhosale AM, Myint P, Roberts S, et al. Combined autologous chondrocyte implantation and allogenic meniscus transplantation: A biological knee replacement. *Knee* 2007;14:361-368.
  46. Cole BJ, Dennis MG, Lee SJ, et al. Prospective evaluation of allograft meniscus transplantation: A minimum 2-year follow-up. *Am J Sports Med* 2006;34:919-927.
  47. Farr J, Rawal A, Marberry KM. Concomitant meniscal allograft transplantation and autologous chondrocyte implantation: Minimum 2-year follow-up. *Am J Sports Med* 2007;35:1459-1466.
  48. Graf KW Jr, Sekiya JK, Wojtys EM. Long-term results after combined medial meniscal allograft transplantation and anterior cruciate ligament reconstruction: Minimum 8.5-year follow-up study. *Arthroscopy* 2004;20:129-140.
  49. Hommen JP, Applegate GR, Del Pizzo W. Meniscus allograft transplantation: Ten-year results of cryopreserved allografts. *Arthroscopy* 2007;23:388-393.
  50. Rueff D, Nyland J, Kocabey Y, Chang HC, Caborn DN. Self-reported patient outcomes at a minimum of 5 years after allograft anterior cruciate ligament reconstruction with or without medial meniscus transplantation: An age-, sex-, and activity level-matched comparison in patients aged approximately 50 years. *Arthroscopy* 2006;22:1053-1062.
  51. Ryu RK, Dunbar VW, Morse GG. Meniscal allograft replacement: A 1-year to 6-year experience. *Arthroscopy* 2002;18:989-994.
  52. Sekiya JK, West RV, Groff YJ, Irrgang JJ, Fu FH, Harner CD. Clinical outcomes following isolated lateral meniscal allograft transplantation. *Arthroscopy* 2006;22:771-780.
  53. Stollsteimer GT, Shelton WR, Dukes A, Bomboy AL. Meniscal allograft transplantation: A 1- to 5-year follow-up of 22 patients. *Arthroscopy* 2000;16:343-347.
  54. Yoldas EA, Sekiya JK, Irrgang JJ, Fu FH, Harner CD. Arthroscopically assisted meniscal allograft transplantation with and without combined anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2003;11:173-182.
  55. McAllister DR, Joyce MJ, Mann BJ, Vangsness CT Jr. Allograft update: The current status of tissue regulation, procurement, processing, and sterilization. *Am J Sports Med* 2007;35:2148-2158.
  56. Pollard ME, Kang Q, Berg EE. Radiographic sizing for meniscal transplantation. *Arthroscopy* 1995;11:684-687.
  57. Shaffer B, Kennedy S, Klimkiewicz J, Yao L. Preoperative sizing of meniscal allografts in meniscus transplantation. *Am J Sports Med* 2000;28:524-533.
  58. Cameron JC, Saha S. Meniscal allograft transplantation for unicompartmental arthritis of the knee. *Clin Orthop Relat Res* 1997:164-171.
  59. Verdonk PC, Verstraete KL, Almqvist KF, et al. Meniscal allograft transplantation: Long-term clinical results with radiological and magnetic resonance imaging correlations. *Knee Surg Sports Traumatol Arthrosc* 2006;14:694-706.