Long-Term Survival Analysis and Outcomes of Meniscal Allograft Transplantation with Minimum 10-Year Follow-Up: A Systematic Review

ABSTRACT

Purpose: To investigate the long-term survivorship rates and functional outcomes of meniscal allograft transplantation (MAT) in patients with minimum 10-year postoperative follow-up.

Methods: Two reviewers independently searched EMBASE, MEDLINE and PubMed from database inception for literature related to MAT according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist. Data is reported in a narrative summary fashion with descriptive statistics.

Results: Eleven studies with a total of 658 patients and 688 MATs were included. Mean age of patients was 33.1 (range 14-66) years, of which 63% were male. Mean survivorship rates were 73.5% at 10-year and 60.3% at 15-year follow-up, with two studies reporting 19 and 24-year survivorship of 50% and 15.1%, respectively. Pre- and post-operative Lysholm scores ranged from 36-60.5 and 61-75, respectively. Pre- and post-operative Tegner scores ranged from 1-3 and 2.5-4.6, respectively. Post-operative KOOS subset scores were: Pain: 61.6-76.3; Symptoms: 57.9-61.8; Function in Daily Living: 68.5-79.9; Sport and Recreation: 33.9 -49.3; Quality of Life: 37.3-45.9. Post-operative IKDC scores ranged from 46-77. Regarding surgical technique, 194 MAT bone-fixation technique (53.8%) and 165 MAT suture-only fixation techniques (46.2%) were reported. The most common type of allograft used was cryopreserved (54.5% of the allografts). The most frequent concomitant procedures performed with MAT were to address chondral (20.8% of the cases) and ligament injuries (12.4% of the cases), and realignment procedures (9.4% of the cases). The most common complications observed that were not directly related to concomitant procedures were meniscal allograft partial tears (11.1%), arthrofibrosis (3.6%) and infection (2.0%). Several criteria were used among studies to define failure of MAT, the most common parameters being removal of meniscal allograft (8/11 studies) and conversion to total knee arthroplasty (TKA) (7/11 studies).

Conclusions: MAT can yield good long-term survivorship rates, with 73.5% and 60.3% of allografts remaining functional after 10 and 15 years, respectively. Functional outcomes 10 years after MAT were fair and improved compared to pre-operative scores.
INTRODUCTION

Nowadays, more than 30 years after the first meniscal transplantation was performed by Milachowski et al. in 1984, favorable clinical outcomes have been reported for short-, mid- and long-term follow-up studies. Short- and mid-term follow-up survivorship rates have been reported of 95% and 89%, respectively. However, significant heterogeneity in study population of several long-term studies has precluded a more accurate analysis of long-term results after MAT. The population in these studies is frequently composed of patients with a wide range of follow-up (from one-two years to over 10 years), thus the reported long-term outcomes of MAT may be biased by patients with shorter follow-up times. An improved understanding of the realistic long-term results after MAT is of paramount importance, given the young population that most commonly undergo this procedure. In these patients, meniscal transplants may act as a “bridging procedure” by improving symptoms and delaying the progression of OA until the patient is older and thus more appropriate for a joint replacement procedure. Additionally, in patients with a torn discoid lateral meniscus, MAT has been shown to be more cost effective than partial meniscectomy in delaying TKA.

Therefore, the purpose of this systematic review was to investigate the long-term survivorship rates and functional outcomes of MAT in patients with minimum 10-year postoperative follow-up. Based on previous MAT cases series in the literature, it was hypothesized that the survivorship rate after MAT at 10-year follow-up would be over 50% and that functional outcomes would still be improved compared to pre-operative evaluation.

MATERIALS AND METHODS

Search Strategy

Three online databases (EMBASE, MEDLINE and PubMed) were searched by two reviewers for literature related to long-term outcomes following MAT. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist and The Revised Assessment of Multiple Systematic Reviews (R-AMSTAR) criteria were used in the development of this study. The database search was conducted on January 24, 2018, and retrieved articles from database inception to the search date. The research question and individual study eligibility criteria were established a priori. Inclusion criteria were: (1) all levels of evidence, (2) human studies, (3) studies published in English, (4) studies reporting outcomes after MAT (5) studies reporting survivorship rates at minimum 10-year follow-up. Exclusion criteria were: (1) review articles, (2) biomechanical/cadaveric studies, (3) studies where outcomes for the patient population of interest (patients with minimum 10-year follow-up) could not be separated from patient outcomes at shorter time points, (4) follow-up study with same patient population (in such cases, only the more recent study was included). The following key terms were used in conjunction for the title search: (meniscus OR meniscal OR menisci) AND (transplant OR transplantation OR allograft).

Study Screening
Two reviewers (J.V.N., N.K.P.) independently screened the titles, abstracts, and full-texts of the retrieved studies. If any disagreement at the title and abstract stages, the study was included to ensure that no studies were excluded due to chance. At the full-text screening phase, discrepancies were resolved by consensus between the reviewers. If consensus could not be reached, a third reviewer was consulted to decide if the study should be included. In order to avoid the possibility of missing studies in the initial screening, references of the included articles were screened for potential inclusion of additional studies.

**Data Abstraction**

Data was collected from the included articles by four reviewers (J.V.N., N.K.P., J.L, R.V.) and recorded in a Microsoft Excel spreadsheet (version 2016; Microsoft, Redmond, WA). Extracted data included: authors, year of publication, location of study, level of evidence, study design, number of patients, number of meniscal transplants, mean age, mean follow-up, male/female ratio, medial/lateral ratio, surgical technique, graft type, survivorship rate, failure criteria, patient reported outcomes, concomitant procedures and complications.

**Quality Assessment**

To analyze the quality of the included studies, the Methodological Index for Non-Randomized Studies (MINORS) criteria was applied by four reviewers (J.V.N., N.K.P., J.L, R.V.), with two reviewers for each study. The MINORS is a validated instrument for non-randomized studies that consists of 12 items; each item is given a score from 0 to 2 with 16 being the maximum score for non-comparative studies and 24 the maximum for comparative studies. MINORS score was categorized a priori as follows: MINORS score <6 to indicate very low quality evidence; 6 ≤ MINORS score <10 to indicate low quality of evidence; 10 ≤ MINORS score <14 to indicate fair quality of evidence; and 14 ≤ MINORS score ≤16 to indicate a relatively good quality of evidence for non-comparative studies.

**Statistical Analysis**

A weighted $\kappa$ (kappa) was calculated to assess inter-reviewer agreement for each study screening phase in order to avoid elimination of studies by chance. Agreement was categorized a priori as follows: $\kappa > 0.60$ to indicate substantial agreement, $0.21 \leq \kappa \leq 0.60$ to indicate moderate agreement, and $\kappa < 0.21$ to indicate slight agreement. Descriptive statistics including means, proportions, ranges and measures of variance such as confidence intervals (CI) are presented where applicable. Considering the selection and inherent biases that exist with combining studies of low sample size and heterogeneous reporting, added to the fact that most included studies did not adjust for confounding variables, it was decided not to combine results or perform weighted mean calculations, in accordance with recent literature. Therefore, it was decided to report ranges across functional outcomes measures, derived from the included studies. Furthermore, it was intended to show the results of the functional outcomes in forest plots without summary estimates; however, since none of the outcomes had a minimum of three studies reporting the mean along with a measure of variance, it was not possible
to present data with the plots. Finally, due to high heterogeneity among studies and multiple indirect comparisons, meta-analysis was not feasible with the presented data.

RESULTS

Study Identification

The initial search of the three databases resulted in 3,826 total studies, of which 11 met final inclusion and exclusion criteria for this review (Figure 1). There was substantial agreement between reviewers at the title ($\kappa = 0.73$; 95% CI, 0.68-0.77), abstract ($\kappa = 0.66$; 95% CI, 0.55-0.77) and full-text screening ($\kappa = 0.92$; 95% CI, 0.81-1.0).

Figure 1: Flow diagram of systematic search performed based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist.

Study Characteristics and Quality
Studies included were conducted between 2002 and 2017. This included a total of 658 patients and 688 MATs. The mean age of patients was 33.1 (range, 14 to 66) years, of which 63% were male.

The characteristics of each of the included studies can be found in Table 1. Ten included studies were of level IV evidence (case series), and one study was of level III evidence (retrospective cohort). The included studies had an average MINORS score of 10.1 ± 1.9 out of 16, which indicates a fair quality of evidence for non-comparative studies (Table 1).

### Table 1. Characteristics of Included Studies

<table>
<thead>
<tr>
<th>Primary Authors</th>
<th>Year</th>
<th>Country</th>
<th>Study Design</th>
<th>LOE</th>
<th>Patients</th>
<th>MATs</th>
<th>Medial/ Lateral</th>
<th>Average F/U (years)</th>
<th>Mean Age (years)</th>
<th>Male (%)</th>
<th>Male</th>
<th>Mean MINORS Score</th>
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<tbody>
<tr>
<td>Binnet et al.19</td>
<td>2011</td>
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<td>49</td>
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<td>6.8</td>
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<td>60.4</td>
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<td>Hommen et al.3</td>
<td>2007</td>
<td>USA</td>
<td>Case series</td>
<td>IV</td>
<td>12</td>
<td>12</td>
<td>12/0</td>
<td>12.2</td>
<td>30</td>
<td>75.0</td>
<td>13</td>
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<tr>
<td>Noyes et al.5</td>
<td>2016</td>
<td>USA</td>
<td>Case series</td>
<td>IV</td>
<td>69</td>
<td>72</td>
<td>41/31</td>
<td>11.2</td>
<td>30</td>
<td>47.8</td>
<td>11</td>
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<td>Ogura et al.20</td>
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<td>Case series</td>
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<td>18</td>
<td>1/17</td>
<td>7.9</td>
<td>31.7</td>
<td>52.9</td>
<td>12</td>
<td></td>
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<td>Kim et al.*12</td>
<td>2017</td>
<td>Korea</td>
<td>Case series</td>
<td>IV</td>
<td>47</td>
<td>49</td>
<td>18/31</td>
<td>11.1</td>
<td>30.4</td>
<td>78.7</td>
<td>9</td>
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<tr>
<td>Van der Straeten et al.*21</td>
<td>2016</td>
<td>Belgium</td>
<td>Case series</td>
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<td>329</td>
<td>119/210</td>
<td>6.8</td>
<td>33</td>
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<td>9</td>
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<td>Case series</td>
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<td>39.4</td>
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<td>Verdonk et al.24</td>
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<td>Case series</td>
<td>IV</td>
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<td>25/13</td>
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<td>35.2</td>
<td>85</td>
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<tr>
<td>Vundelinckx et al.*6</td>
<td>2014</td>
<td>Belgium</td>
<td>Case series</td>
<td>IV</td>
<td>27</td>
<td>30</td>
<td>11/19</td>
<td>12.7</td>
<td>33</td>
<td>50</td>
<td>8</td>
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<tr>
<td>Wirth et al.25</td>
<td>2002</td>
<td>Germany</td>
<td>Retrospective Cohort</td>
<td>III</td>
<td>28</td>
<td>23</td>
<td>23/0</td>
<td>14</td>
<td>29.6</td>
<td>87</td>
<td>10</td>
<td></td>
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</tbody>
</table>

- * Studies that also included patients with less than 10-year follow-up. These studies were not considered for functional outcomes in order to homogenize the cohort to only report long-term results.
- LOE: Level of Evidence; MAT: Meniscal Allograft Transplantation; F/U: follow-up

### Definition of MAT Failure

Several different criteria were used among all studies to define failure of MAT. The most common parameters were: removal of meniscal allograft (8/11 studies)5, 6, 12, 19-23 and conversion to TKA (7/11 studies)5, 6, 12, 20, 21, 23, 24. Other criteria considered as failure were: low patient reported outcomes (PROs) scores3, 12, no improvement in pain score3, signs of allograft failure (signal intensity, more than
50% of meniscal width extrusion) on magnetic resonance imaging (MRI)\textsuperscript{3, 5, 25}, signs of meniscal tear on clinical examination\textsuperscript{5}, loss of joint space in the involved tibiofemoral compartment on 45° weight-bearing PA radiographs (International Knee Documentation Committee [IKDC] grade D)\textsuperscript{5} and development of new defects elsewhere in the same knee necessitating additional surgery (disease progression)\textsuperscript{20}.

**Survivorship Rates**

Six studies\textsuperscript{5, 6, 12, 20, 23, 24} (249 patients, 257 MATs) reported survivorship rate at 10 years, with an overall survivorship rate of 73.5%. Four studies\textsuperscript{5, 6, 12, 25} (169 patients, 174 MATs) reported survivorship at 15 years on 174 MATs, with 60.3% of the transplants remaining functional. Other specific time points of survivorship were additionally reported by single studies: survivorship of 75%, at 12 years\textsuperscript{3} (12 patients, 12 MATs), 52.5% at 16 years\textsuperscript{22} (57 patients, 63 MATs), 50% at 19 years\textsuperscript{19} (4 patients, 4 MATs) and 15.1% at 24 years\textsuperscript{21} (313 patients, 329 MATs) after MAT. Figure 2 shows a scatter plot of the MAT survivorship rates with a line of best fit.

**Functional Outcomes**

For assessment of functional outcomes, five studies\textsuperscript{3, 19, 22, 24, 25} (134 patients, 141 MATs) in which all patients had been followed for a minimum of 10 years were used (Table 2). Four studies\textsuperscript{3, 19, 22, 25} (96 patients, 98 MATs) evaluated pre- and post-operative Lysholm. Pre-operative Lysholm ranged from 36 to 60.5 while post-operative Lysholm ranged from 61 to 75. Three studies\textsuperscript{3, 19, 25} (39 patients, 39 MATs) reported post-operative Tegner, while two\textsuperscript{19, 25} (27 patients, 27 MATs) of those also reported pre-operative Tegner. Pre-operative Tegner ranged from 1 to 3 while the post-operative Tegner ranged from 2.5 to 4.6. Two studies\textsuperscript{22, 24} (95 patients, 102 MATs) reported post-operative KOOS, with the range of scores of the five categories being: Pain: 61.6 to 76.3; Symptoms: 57.9 to 61.8; Function in Daily Living: 68.5 to 79.9; Sport and Recreation: 33.9 to 49.3; Quality of Life: 37.3 to 45.9. Two studies\textsuperscript{3, 22}
(69 patients, 75 MATs) reported post-operative IKDC, that ranged from 46 to 77. Other parameters utilized in single studies were: Knee Society Score\textsuperscript{19}, Pain Score\textsuperscript{3} and SF-12 Score\textsuperscript{3}.

**Table 2. Functional Outcomes Reported in Studies with All Patients with Minimum 10-year Follow-Up**

<table>
<thead>
<tr>
<th>Studies</th>
<th>Pre-Operative Lysholm</th>
<th>Post-Operative Lysholm</th>
<th>Pre-Operative Tegner</th>
<th>Post-Operative Tegner</th>
<th>Post-Operative IKDC</th>
<th>Post-Operative KOOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binnet et al.\textsuperscript{19}</td>
<td>60.5</td>
<td>62.5</td>
<td>3</td>
<td>2.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hommen et al.\textsuperscript{3}</td>
<td>53</td>
<td>75</td>
<td>-</td>
<td>4.3</td>
<td>77</td>
<td>-</td>
</tr>
<tr>
<td>Van der Wal et al.\textsuperscript{22}</td>
<td>36</td>
<td>61</td>
<td>-</td>
<td>-</td>
<td>46</td>
<td>Pain:61.6; Symptoms:57.9; Function in Daily Living:68.5; Sport and Recreation:33.9; Quality of Life:37.3</td>
</tr>
<tr>
<td>Verdonk et al.\textsuperscript{24}</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Pain: 76.3; Symptoms: 61.8; Function in Daily Living: 79.9; Sport and Recreation: 49.3; Quality of Life: 45.9</td>
</tr>
<tr>
<td>Wirth et al.\textsuperscript{25}</td>
<td>59</td>
<td>75</td>
<td>1</td>
<td>4.6</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Surgical Technique**

Ten studies\textsuperscript{3, 5, 6, 12, 19, 20, 22-25} (345 patients, 359 MATs) reported which surgical technique was performed for fixation of meniscal allograft. One study\textsuperscript{21} (313 patients, 329 MATs) did not specify the fixation technique. Four studies\textsuperscript{5, 12, 20, 23} (181 patients, 188 MATs) used MAT bone fixation technique, four studies\textsuperscript{19, 22, 24, 25} (122 patients, 129 MATs) used MAT suture-only fixation technique and two studies\textsuperscript{3, 6} (42 patients, 42 MATs) performed both techniques. In total, 194 MAT bone-fixation technique (53.8%) and 165 MAT suture-only fixation (46.2%) were reported.

**Graft Preparation Technique**

The most common type of allograft used was cryopreserved, used exclusively in four studies\textsuperscript{3, 5, 6, 22} (168 patients, 177 MATs) and along with fresh-frozen allograft in another 2 studies\textsuperscript{12, 20} (64 patients, 67 MATs) (Table 3). Fresh allografts were used exclusively in two studies\textsuperscript{23, 24} (86 patients, 88 MATs) and in one study\textsuperscript{21} (313 patients, 329 MATs) that also used fresh-frozen grafts. Lyophilized allografts were transplanted in one study\textsuperscript{19} (12 patients, 12 MATs) exclusively and in another study\textsuperscript{25} (23 patients, 23 MATs) that also transplanted fresh-frozen allografts.

**Table 3. Graft Preparation Technique Reported in the Included Studies**

<table>
<thead>
<tr>
<th>Studies</th>
<th>Graft Preparation Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binnet et al.\textsuperscript{19}</td>
<td>Lyophilized</td>
</tr>
<tr>
<td>Getgood et al.\textsuperscript{23}</td>
<td>Fresh</td>
</tr>
</tbody>
</table>
Concomitant Procedures

Among 688 MATs included in this study, in 296 transplantations a concomitant procedure was performed. The procedures most commonly performed with MAT were: osteochondral graft transfer (autograft and allograft, medial and femoral condyles, and unipolar and bipolar grafting – N=73 – 10.6% of the cases), ACL reconstruction or revision ACLR (N=66 – 9.6% of the cases), high tibial osteotomy (HTO – N=64 – 9.3% of the cases), and microfracture (N=52 – 7.6% of the cases). Other concomitant procedures reported were: medial collateral ligament (MCL) femoral advancement (N=19), autologous chondrocyte implantation (ACI – N=18), femoral varus osteotomy (N=7) and lateral retinaculum release (N=3).

Complications

Across all 11 studies, the following complications were reported in either isolated or concomitant MAT: arthrofibrosis in three studies (15 cases in 419 MATs - 3.6%), infection in two studies (8 cases in 401 MATs – 2.0%), meniscal allograft partial tears in one study (2 cases in 18 MATs – 11.1%), algoneurodystrophy in one study (2 cases in 329 MATs – 0.6%), deep vein thrombosis in one study (1 case in 329 MATs – 0.3%) and compartment syndrome in one study (1 case in 18 MATs – 5.5%). Complications related to concomitant procedures were: autologous chondrocyte implantation (ACI) graft hypertrophy in one study (4 cases in 18 MATs – 22.2%), complications related to HTO in one study (3 non unions, 1 case of osteomyelitis in 329 MATs – 1.2%) and painful hardware in one study (2 cases in 18 MATs – 11.1%).

DISCUSSION

The primary findings of this systematic review are that MAT yields good long-term survivorship rates, with 73.5% and 60.3% of allografts being viable after 10 and 15 years of index procedure, respectively. Survivorship rates from the present study were lower than mid-term survivorship rates.
(85.8% for medial MAT, 89.2% for lateral MAT) shown by a meta-analysis comparing medial and lateral
MAT, but higher than long-term (> 10 years) survival rates (52.6% for medial MAT and 56.6% for lateral
MAT) of the meta-analysis2. The higher 10-year survivorship rates in the present study compared to
long-term rates reported by Bin et al. may be due to the fact that the latter grouped all studies with more
than 10 years of follow-up, which may lower the rate since, as it is shown in the present review, longer
follow-ups (123, 155, 6, 12, 25, 1622, 1919 and 2421 years) have lower rates than the 10-year follow-up
studies5, 6, 12, 20, 23, 24. Additionally, the results of long-term survivorship of this study are expectedly lower
than the results of a short-term study, that observed a 94% of survival rate with a minimum 3-year
follow-up27. As shown in this review, the mean age of patients who undergo MAT is relatively young
(33.1 years), and other treatment options for these symptomatic patients following meniscectomies
(UKA, HTO, TKA) may not be well suited or indicated at this age. Although UKA and TKA result in
excellent long-term survival rates, with reported 92.8% survival 10-years after TKA28-33, these
procedures are typically performed on older and less active patients, usually after 50 years of age34, 35.
When these procedures are performed in younger patients, a lower rate of survivorship and patient
satisfaction is expected34, 35, which can lead to the need for revision of these procedures at a relatively
young age. Therefore, the survivorship results in this review highlights the capacity of MATs to at least
serve as a “bridging procedure” for this population, helping to avoid premature joint replacement
procedures while preventing long periods of debilitation and poor quality of life.

The second main finding of this review is that functional outcomes after a minimum of 10 years
following MAT were overall fair and improved compared to pre-operative scores. Among included
studies, Lysholm scores improved up to 25 points at long-term follow up22, while Tegner scores
improved up to 3.6 points25. A recent study addressing the differences between clinical and statistical
significance reported that one of the measures of clinical relevance, the minimum detectable change
(MDC), has been established for both Lysholm (MDC: 8.9) and Tegner (MDC: 1) scores36. Therefore,
the achievement of clinically significant improvements in Lysholm and Tegner scores after MAT that
were sustained at long-term follow-up provides further support for the utility and indication of MAT, and
can help management of patients’ expectations. We excluded studies in which outcomes of patients
with greater than 10-years of follow-up could not be discerned from those with less than 10-years of
follow-up, since we believe that an inclusion of short- and mid-term follow-up outcomes could
inaccurately bias long-term results. Unfortunately, this was the scenario in several long-term outcomes
studies investigating MAT4, 8-11. Many of these studies did have a significant number of patients with
long-term follow-up, 10, 15 even 20 years, but pooled outcomes with patients of even less than one-
year follow-up21. One study with a mean follow up of 7.9 years (range 2-16) observed significant
improvement in functional and pain scores after two-year and final follow-up compared to pre-operative
scores20, in agreement with the findings of the present review of better post-operative scores. However,
while the study with the largest number of patients and procedures included in this review (313 patients
and 329 MATs) had patients with up to 24 years of follow-up, it had a mean follow-up of only 6.8 years
and the least amount of follow-up being only 2 months21. This highlights the importance of the
suggestion presented in this review that authors with large MAT cohorts should report outcomes by
stratifying them into exclusively short-, mid- and long-term follow-up times, as this may significantly contribute to the understanding of how MAT procedures perform over time.

Another key finding of this study is the lack of consistency in defining failure after MAT. In this review, we report varying definitions for failure across the included studies. This directly affects reported survivorship rates and makes comparisons between studies difficult and interpretation of data misleading. We propose a standardized definition of MAT failure, such as removal of meniscal allograft or conversion to TKA, be utilized to aid in the standardization of MAT outcomes reporting across literature. We argue that these two commonly used criteria (by as many as eight studies included in this review)\textsuperscript{5,6,12,19-24}, are more objective than others such as pain and functional outcomes, and MRI criteria (extrusion, signal) may not directly correlate with patient symptoms.

Though the heterogeneity of included studies precluded a pooled meta-analysis, the wide range of surgical and meniscus preparation techniques provides a more realistic overview of the differences in current MAT techniques. The most commonly performed MAT fixation techniques are bone fixation and a suture-only fixation techniques. A recent international consensus has shown that approximately 75\% of surgeons perform bone fixation technique compared to suture-only fixation technique\textsuperscript{37}. In this review, we observed a more even distribution between techniques with MAT bone fixation techniques performed in 54\% of the cases. Interestingly, a geographic influence could be observed: all studies from North America used MAT bone fixation technique while all European studies reported use of MAT suture-only fixation technique, in agreement with previous study\textsuperscript{37}. There is controversy in the literature regarding superiority of either technique, with positive results reported for both\textsuperscript{37,42}. A recent meta-analysis observed no difference between techniques regarding clinical outcomes, allograft extrusion and MAT longevity\textsuperscript{43}. Thus, the type of MAT fixation technique does not seem to influence the results of the procedure. The most commonly used graft preparation technique in this systematic review was cryopreservation. Cryopreservation utilizes a controlled freezing process that has been shown to preserve meniscal ultrastructure and biomechanical properties with a duration of maintenance up to 10 years\textsuperscript{44}. Therefore, it is an interesting alternative to fresh allografts due to safety and logistic issues (short period of time to perform serologic testing and to find proper recipient) with the latter. Still, given the higher cost and difficulty of the controlled freezing process of cryopreservation, fresh-frozen allografts have gained popularity. This simpler technique stores allograft at -80\textdegree C and has been shown to be less likely to provoke an immune response due to denaturation of histocompatibility antigens with duration of maintenance of up to 5 years\textsuperscript{19,45,46}. Although two studies (21 patients, 21 MATs) included in this review reported lyophilized allografts\textsuperscript{19,25}, this technique has been related to shrinkage of the allograft and detrimental effects to its structure\textsuperscript{1}; thus, this preservation technique has been abandoned. Interestingly, besides being one of the first storage techniques, the study with the longest follow-up reporting survivorship rates (24 years) did not use lyophilized grafts; instead, either fresh or fresh-frozen meniscal allografts were used. Therefore, the results of MAT seem to be influenced by graft type. Graft size is another important factor to be considered in MAT. A previous study has shown that oversized lateral meniscal allografts resulted in greater forces across the articular cartilage, whereas undersized allografts led to greater forces across the meniscus\textsuperscript{47}. Thus, less than 10\% of mismatch between allograft and native meniscus is recommended\textsuperscript{47}, although it is unknown if this mismatch may still
preclude MAT from optimal results. MAT was also performed concomitantly with other procedures to address chondral damage (20.8% of the cases), ligament injuries (12.4% of the cases), and malalignment (9.4% of the cases). The higher number of concomitant procedures highlights the multifaceted and challenging condition meniscus deficient patients present for treatment. However, a limited number of complications were reported in the included studies. The most common complications observed that were not directly related to concomitant procedures were meniscal allograft partial tears (11.1%), arthrofibrosis (3.6%) and infection (2.0%). We were unable to stratify survivorship rates or functional outcomes with the included studies between: isolated MATs and the ones with concomitant procedures, fixation techniques, graft preparation techniques or side of injury (medial/lateral). Regarding prevention of osteoarthritis (OA) after MAT, a recent systematic review concluded that there is some evidence to support the hypothesis of reduction of OA progression after MAT\(^{48}\). Although MAT may not completely prevent OA, the delay of its progression in the young population may be of great value, being a bridging procedure for a possible arthroplasty in the future, which may save these patients from a revision TKA in their lifetime\(^{13}\). A satisfactory activity level can be expected after MAT, with sports activities being possible, as a mid-term follow up (mean follow-up 4.2 years) study observed that 74% of patients resumed sports practice, while 49% returned to preinjury activity level.

This review has a number of strengths. The thorough search strategy with inclusion of studies regardless of patient sex, age and date of publication minimized the possibility of omission of relevant studies. Furthermore, at each stage, all articles were independently screened in duplicate to minimize reviewer bias. The strict restriction of studies of patients with a minimum 10-year follow-up for the functional outcomes analysis (5/11 studies included in this review), in order to homogenize the population and more accurately report results in this specific cohort, may have minimized potential bias of overestimating outcomes with more recent procedures included. Future studies should uniformly define failure of MAT when reporting outcomes for a more appropriate comparison of survivorship rates across the literature. Additionally, long-term follow-up studies after MAT should report outcomes exclusively in patients with a minimum of 10 years after surgery to avoid potential bias of overestimating results if more recent procedures are also included.

**LIMITATIONS**

One of the main limitations of this review is the quality of evidence of included studies: all 11 included articles were of Level III or IV evidence. The inclusion criteria of studies reporting survivorship rates at minimum 10-year follow-up may exclude studies with poorer results that did not reach 10 years after MAT, thereby overestimating survivorship rates. However, short- and mid-term follow-up studies have shown excellent survivorship rates\(^2,27\), thus the aforementioned potential bias may be less likely. Another limitation is the relatively small samples sizes in some of the included studies. The restriction of English-only studies may have excluded other potentially relevant studies. The significant heterogeneity in the procedures performed [fixation technique, graft preparation technique, concomitant procedures, and side of injury (medial/lateral)] and reported outcomes prevented a meta-analysis from being performed.
MAT can yield good long-term survivorship rates, with 73.5% and 60.3% of allografts remaining functional after 10 and 15 years, respectively. Functional outcomes 10 years after MAT were fair and improved compared to pre-operative scores.

REFERENCES


