Article

AMERICAN ORTHOPAEDIC FOOT & ANKLE SOCIETY

Foot & Ankle International®
2021, Vol. 42(7) 841–850

DOI: 10.1177/1071100720983266
journals.sagepub.com/home/fai

Comparison of Functional and Radiographic Outcomes of Talar Osteochondral Lesions Repaired With Micronized Allogenic Cartilage Extracellular Matrix and Bone Marrow Aspirate Concentrate vs Microfracture

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Abstract

Background: Microfracture (MF) has been used historically to treat osteochondral lesions of the talus (OLTs), with favorable outcomes reported in approximately 80% to 85% of cases. However, MF repairs have been shown to degrade over time at long-term follow-up, suggesting that further study into optimal OLT treatment is warranted. The use of adjuvant extracellular matrix with bone marrow aspirate concentrate (ECM-BMAC) has not been extensively evaluated in the literature. We present a comparison of patient-reported and radiographic outcomes following ECM-BMAC repair vs traditional MF.

Methods: Patients who underwent MF (n = 67) or ECM-BMAC (n = 62) treatment for an OLT were identified and their charts were retrospectively reviewed. Postoperative magnetic resonance imaging (MRI) was evaluated and patient-reported outcome scores, either Foot and Ankle Outcome Scores (FAOS) or Patient-Reported Measurement Information System (PROMIS) scores, were collected. MRIs were scored by a radiologist, fellowship trained in musculoskeletal radiology, using the Magnetic Resonance Observation of Cartilage Repair Tissue (MOCART) system. Radiographic and clinical outcomes were compared between groups.

Results: On average, patients treated with ECM-BMAC demonstrated a higher total MOCART score compared to the MF group (73 ± SD 11.5 vs 54.0 ± 24.1; P = .0015). ECM-BMAC patients also had significantly better scores for the Infill, Integration, and Signal MOCART subcategories. Last, patients treated with ECM-BMAC had a lower rate of revision compared to those treated with MF (4.8% vs 20.9%; P = .007). FAOS scores were compared between groups, with no significant differences observed.

Conclusion: When comparing outcomes between patients treated for an OLT with ECM-BMAC vs traditional MF, we observed superior MRI results for ECM-BMAC patients. The rate of revision surgery was higher for MF patients, although patient-reported outcomes were similar between groups. The use of ECM-BMAC as an adjuvant therapy in the treatment of OLTs may result in improved reparative tissue when compared to MF.

Level of Evidence: Level III, comparative series.

Keywords: osteochondral lesions of the talus, microfracture, arthroscopic treatment, cartilage repair, extracellular cartilage matrix, bone marrow aspirate concentrate

Osteochondral lesions of the talus (OLTs) are cartilage injuries that occur in a variety of settings, including acute ankle fractures, sprains, and chronic chondral injuries. OLTs remain difficult to treat because hyaline cartilage does not regenerate once the native cartilage becomes damaged. Nonsurgical treatment is an option, but it is often ineffective.[6,40] Historically, microfracture (MF) has been the standard treatment to address OLTs surgically, as it is a simple, 1-stage arthroscopic procedure. The current literature suggests good to excellent results in approximately

80% to 85% of patients undergoing MF of the ankle.[41,42] However, the tissue that results following MF is fibrocartilage, which has been found to have inferior biomechanical properties when compared to native hyaline cartilage.[20] Moreover, some have argued that MF has an unacceptably high failure rate when looking at long-term clinical outcomes.[16,29] Several authors have also reported inferior outcomes for MF used to address larger lesions (>150 mm^2),[8-10,13] with failed MF procedures often requiring secondary procedures such as osteochondral allograft or autograft transplantation. These secondary procedures are associated with a number of limitations, including the potential for donor site morbidity and need for additional osteotomy.*

As a result of these limitations of traditional MF, new approaches to improve cartilage repair are being investigated.[4] One approach has been to use micronized allogenic cartilage extracellular matrix (ECM), as it can be introduced into a defect arthroscopically. BioCartilage Extracellular Matrix (Arthrex) is derived from allograft cartilage and consists of the extracellular components native to articular cartilage such as type II collagen, proteoglycans, and other cartilaginous growth factors. When mixed with bone marrow aspirate concentrate (BMAC), which consists of pluripotent mesenchymal stem cells, the ECM product is intended to serve as a scaffold, delivering its important growth factors and cellular components to the lesion site and promoting autologous cell interactions and repair. Thus, the goal of using ECM is to improve the degree of infill and the quality of the tissue in the repaired lesion. The ECM and BMAC mixture (ECM-BMAC) is applied during a dry arthroscopy following an abrasion chondroplasty and is secured with a minimal amount of fibrin glue.

Current evidence suggests that the use of BMAC in cartilage repair may improve the quality of the reparative tissue,[12,22,25,35] and prior biological study in an animal model indicated that allogenic ECM is safe and could produce higher-quality, more completely integrated repair tissue when compared to MF.[18] However, few studies have examined both clinical and radiographic outcomes for ECM-BMAC repairs. Several authors have reported improvements in subjective patient-reported outcomes following ECM-BMAC procedures, but these studies did not report on objective radiographic outcomes and were limited to cohort sizes of fewer than 10 patients.[11,14] Another recent study evaluated clinical and radiographic outcomes with ECM, reporting a 96.7% success rate, although the study lacked a control group.[1]

The goal of the current study was to report both clinical and radiographic outcomes following the use of micronized allogenic ECM mixed with BMAC compared to traditional MF, with or without BMAC. We evaluated patient-reported outcome scores and used the semiquantitative Magnetic Resonance Observation of Cartilage Repair Tissue (MOCART) scoring system, which allows for evaluation of postoperative magnetic resonance imaging (MRI).[31] To our knowledge, this is the first study to evaluate ECM-BMAC as an adjuvant treatment with comparison to a historical control.

Methods

Study Population and Design

Approval was obtained from the institutional review board. Patients were identified who underwent ECM-BMAC or MF repair for an OLT. Patients were excluded if they underwent repair for a tibial lesion or if they underwent OLT treatment with a technique other than ECM-BMAC or MF, such as osteochondral autograft transplantation. Retrospective chart review was performed. Any time ECM was used at our institution, it was delivered in combination with BMAC. For MF patients, chart review was used to determine whether or not BMAC was injected into the lesion. Between 2004 and 2017, 166 eligible patients treated by 1 of 3 orthopedic foot and ankle surgeons were identified; 129 patients had radiographic follow-up (n = 54), clinical follow-up (n = 103, Foot and Ankle Outcome Scores [FAOS]; n = 55, Patient-Reported Measurement Information System [PROMIS]), or both (n = 43). Of these patients, 67 underwent arthroscopic MF treatment and 62 underwent arthroscopic ECM-BMAC treatment. Within the MF group, 36 patients had BMAC injected into the lesion, while 31 had MF only based on surgeon preference. For the purposes of this study, the MF-BMAC and MF-only groups were considered as a combined MF group, although statistical subgroup analysis was performed to compare the MF-BMAC and MF-only cohorts.

Lesion size (mm^2) and location on the talus (medial, lateral, or central) were recorded based on operative notes or

*References 4, 5, 8, 10, 21, 24, 27, 31, 32, 34.

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assessment of preoperative MRIs. A subset of patients presented with ankle instability, defined by a talar tilt greater than 10 degrees of varus or anterior drawer greater than or equal to 10 mm on stress x-ray. Ten patients in the ECM-BMAC group and 16 patients in the MF group underwent concurrent lateral ankle stabilization with Broström-Gould or lateral ligament reconstruction, depending on surgeon preference. In addition, 13 ECM-BMAC patients and 4 MF patients presented with significant bone defect and underwent bone grafting at the time of cartilage repair. The postoperative rehabilitation protocol was the same for patients with and without these concurrent procedures. Statistical subgroup analysis was performed to evaluate the effect of concurrent procedures.

Preoperative functional outcome scores, including the FAOS or PROMIS Physical Function, Pain Interference, Pain Intensity, Global Physical Health, Global Mental Health, and Depression domains, were collected prospectively through our institution's registry database. Our institution administered FAOS surveys until March 2016, at which time our department shifted to the administration of PROMIS surveys. As a result, only ECM-BMAC patients received PROMIS preoperatively, as ECM-BMAC was the senior surgeon's preference for treating OLTs at the time of this change. FAOS or PROMIS was typically administered at 1 year but at a minimum of 6 months postoperatively. In total, 51 of 62 ECM-BMAC patients (82%) and 63 of 67 MF patients (94%; 33 MF-BMAC and 30 MF only) had survey follow-up. Forty ECM-BMAC patients (17 with preoperative FAOS) and 63 MF patients (52 with preoperative FAOS) had postoperative FAOS. Average FAOS follow-up for the ECM-BMAC group was 23.5 (range, 12-40) months and 35.1 months (range, 6 months–9.5 years) for the MF group. Forty-three ECM-BMAC patients (30 with preoperative PROMIS) and 12 MF patients (0 with preoperative PROMIS) had postoperative PROMIS. Average time to PROMIS follow-up was 20.9 (range, 11-52) months in the ECM-BMAC group and 49 (range, 23-70) months in the MF group.

MRI Assessment

All MRIs were performed at our institution using a standardized protocol with no arthrogram at 1.5 T. Twenty ECM-BMAC patients and 34 MF patients (19 MF-BMAC and 15 MF-only patients) had postoperative MRIs at a minimum of 6 months postoperatively. All MRIs were reviewed by a single board-certified radiologist, fellowship trained in musculoskeletal radiology. The radiologist was blinded to treatment type. The MOCART scoring system, which includes 9 parameters to evaluate structure, fill, and signal of cartilage repairs on MRI, was used. This system has been used in the literature as a reliable and reproducible means of evaluating cartilage repair on MRI.[31]

Microfracture Surgical Technique

A standard MF technique was used.[16] For MF-BMAC cases, approximately 60 mL of bone marrow was aspirated from the anterior superior iliac crest and spun down using the Magellan Autologous Platelet Separator (Anteriocyte Medical Systems), yielding about 3 mL BMAC. A thigh tourniquet was raised and standard anteromedial and anterolateral portals for arthroscopy were established. The talar lesion was identified and inspected using a probe. It was then debrided back to normal cartilage borders. All loose and necrotic bone and cystic tissue was debrided. A small joint MF awl (Smith & Nephew) was used to puncture the subchondral plate. Small holes were placed at least 3 mm apart to avoid fracture propagation. In MF-BMAC cases, the BMAC was injected into the dry joint. The tourniquet was let down to confirm that blood from the underlying bone percolated through the holes.

ECM-BMAC Surgical Technique

The surgical technique for ECM-BMAC was also performed arthroscopically. BMAC was obtained using the same procedure described above. Bone grafting was used for patients presenting with significant bone defect or voids left by subchondral cyst or necrotic bone, defined as defects of approximately 1 cm or greater in depth. No bone grafting was performed on lesions smaller than this cutoff based on surgeon preference. In cases requiring bone grafting, the size of the defect and extent of cystic changes in the talus were assessed, and the graft was taken accordingly from either the iliac crest or the calcaneus.

Standard arthroscopy was used to identify the lesion. The area was debrided, and any scar tissue, osteophytes, and loose fragments were removed. All fluid was removed using an epidural spinal needle and vacuum suction, and the remainder of the arthroscopy was performed dry. During this time, the ECM (Arthrex) was mixed with BMAC. Once the ankle was completely dry and hemostasis was obtained, if necessary, the bone graft was placed into the defect using an arthroscopic cannula and was packed down using a Freer elevator to form an osseous foundation. The ECM-BMAC mixture was then placed into the defect directly on top of the bone graft using an arthroscopic cannula. A Freer elevator was used to place the mixture into position, ensuring that the whole defect was covered adequately. The cartilage graft was then covered with several drops of Evicel fibrin glue (Ethicon) for additional fixation. If no bone graft was necessary, an abrasion chondroplasty was performed, and the ECM-BMAC mixture was placed directly on the subchondral bone, followed by Evicel. The fibrin glue was then left to dry, which typically takes 10 minutes. Patients were placed in a splint and remained nonweightbearing for 2 weeks. At 2 weeks postoperatively, they were transitioned

Table 1. Demographic Comparison Between Combined MF/MF-BMAC Group and ECM-BMAC Group.

Characteristic	MF/MF-BMAC	ECM-BMAC	*P* value
Age, mean (range), y	37.27 (9.6-75.3)	36.0 (13.4-62.9)	.630
BMI, mean (range), kg/m^2	29.18 (22.6-40.5)	27.33 (19.6-39.30)	.247
Mean lesion size, mm^2	76.51	52.58	<.001[a]
Lesion location, %			
Medial	61.2	55.0	
Lateral	34.3	43.3	
Central	4.5	1.7	

Abbreviations: BMAC, bone marrow aspirate concentrate; BMI, body mass index; ECM, extracellular matrix; MF, microfracture.
[a]*P* values represent the significance of observed differences for each characteristic. Significance level .05.

to a boot and began active and passive range-of-motion exercises for the ankle in addition to hip and knee strengthening exercises. They remained nonweightbearing in the boot until 6 weeks postoperatively, at which point they began partial weightbearing with the boot and crutches. Approximately 8 weeks after surgery, patients advanced to full weightbearing in a sneaker.

Indications for Revision

Patients were recommended for revision surgery if they reported continued pain and symptoms at a minimum of 5 months postoperatively without resolution following steroid injections or further conservative measures such as physical therapy. In several cases in the MF group, the symptoms actually worsened following these conservative measures. In combination with patient symptoms, MRIs were assessed and the fill of the lesions was evaluated prior to pursuing revision surgery. If the lesion fill was deemed to be suboptimal or insufficient due to apparent deterioration, this was further evidence to pursue a revision procedure.

Statistical Analysis

Descriptive statistics are reported as means and standard deviations while categorical variables are reported as frequencies and percentages. Student paired t tests were used to evaluate the differences in preoperative and postoperative clinical outcome scores within each group. To assess differences between the ECM-BMAC, MF-BMAC, and MF groups, Wilcoxon 2-sample tests or Student 2-sample t tests were used to compare postoperative scores and the change in pre- to postoperative scores, depending on the distribution of data. Multivariate analysis was performed to evaluate the effect of lesion size on MOCART scores and patient-reported outcomes scores. Due to an insufficient number of MRIs for concurrent ankle stabilization or bone grafting patients, multivariate analysis was used to evaluate the effect of these concurrent procedures only on patient-reported outcome scores. An analysis of variance (ANOVA) test was used to compare overall MOCART scores between groups. Finally, a χ^2 test was used to compare the rates of revision surgery. All analyses were run with a significance level of .05.

Results

Demographic information for both cohorts is provided in Table 1. In total, 81 patients were female, and 85 were male. There were no significant differences in average age or body mass index (BMI) between groups. Average lesion size in the ECM-BMAC group was 76.5 (range, 12-225) mm^2 compared to only 52.6 (range, 8-225) mm^2 in the combined MF group ($P < .0001$). Thus, all statistical comparisons between groups were run with an adjustment for lesion size.

Clinical Outcomes

Within each group, pre- to postoperative change in patient-reported outcome scores was evaluated, using PROMIS scores for ECM-BMAC patients and FAOS scores for MF patients. On average, functional outcome scores improved pre- to postoperatively in both groups. PROMIS Physical Function, Pain Interference, Pain Intensity, and Global Physical Health domains significantly improved pre- to postoperatively in the ECM-BMAC group (Table 2). For the MF group, FAOS Pain, Daily Activities, Sports Activities, Quality of Life, and Total scores improved significantly (Table 3). No influence of concurrent ankle stabilization or bone-grafting procedures was detected when evaluating patient-reported outcome scores.

Due to standard departmental practice at our institution when MF was the standard treatment for OLTs, no MF patients were administered preoperative PROMIS surveys. As a result, the pre- to postoperative change in PROMIS scores cannot be evaluated for our historical MF control group. All patients received postoperative FAOS and PROMIS, although postoperative FAOS was completed for 40 ECM-BMAC patients (17 with preoperative FAOS) and

Table 2. Pre- and Postoperative Patient-Reported Measurement Information System (PROMIS) Scores for Extracellular Matrix With Bone Marrow Aspirate Concentrate Patients.

Characteristic	Preoperative (n = 31), mean ± SD	Postoperative (n = 43), mean ± SD	Δ Pre- to postoperative (n = 30), mean ± SD	*P* value
Physical Function	42.03 ± 7.06	50.98 ± 8.14	7.72 ± 10.25	<.0001[a]
Pain Interference	58.57 ± 7.39	49.95 ± 9.45	−7.08 ± 9.95	<.0001[a]
Pain Intensity	47.19 ± 8.88	39.00 ± 8.49	−6.80 ± 9.27	.00015[a]
Global Physical Health	46.23 ± 7.64	53.27 ± 8.33	5.78 ± 8.05	.0004[a]
Global Mental Health	51.99 ± 10.10	52.77 ± 9.20	−0.24 ± 8.76	.732
Depression	48.76 ± 9.26	46.68 ± 8.04	−2.74 ± 9.46	.316

[a]*P* values represent the significance of pre- to postoperative change for each PROMIS domain. Significance level .05.

Table 3. Pre- and Postoperative Foot and Ankle Outcome Scores for Microfracture Patients.

Characteristic	Preoperative (n = 52), mean ± SD	Postoperative (n = 63), mean ± SD	Δ Pre to postoperative (n = 52), mean ± SD	*P* value
Pain	55.29 ± 20.73	75.06 ± 23.14	26.29 ± 31.84	<.0001[a]
Symptoms	60.00 ± 21.11	67.01 ± 23.48	12.79 ± 32.27	.1022
Daily Activities	70.50 ± 22.01	84.47 ± 20.12	22.96 ± 37.97	.0008[a]
Sports Activities	37.97 ± 26.04	61.11 ± 30.19	27.02 ± 36.90	<.0001[a]
Quality of Life	24.54 ± 19.03	50.50 ± 32.32	28.75 ± 29.88	<.0001[a]
Total	49.40 ± 17.66	67.67 ± 23.10	21.73 ± 25.73	<.0001[a]

[a]*P* values represent the significance of pre- to postoperative change for each Patient-Reported Measurement Information System (PROMIS) domain. Significance level .05.

63 MF patients (52 with preoperative FAOS), while postoperative PROMIS was completed for 43 ECM-BMAC patients (30 with preoperative PROMIS) and 12 MF patients (0 with preoperative PROMIS). Given the available survey responses, postoperative FAOS and pre- to postoperative change in FAOS were analyzed to compare the ECM-BMAC and MF groups. After adjusting for lesion size, no statistically significant differences were detected between groups for postoperative FAOS scores or pre- to postoperative change in FAOS (Table 4).

Radiographic Outcomes

Twenty patients in the ECM-BMAC group and 34 patients in the MF group (19 MF-BMAC and 15 MF only) had MRIs performed at a minimum of 6 months postoperatively. In the ECM-BMAC group, average radiographic follow-up was 10.7 (range, 7-35) months while average radiographic follow-up was 27.7 (range, 9-50) months in the MF-BMAC group and 40.8 (range, 8-79) months in the MF-only group. When comparing total MOCART scores for the ECM-BMAC group and the combined MF group, the ECM-BMAC group had a significantly higher average MOCART score (mean ± SD, 73 ± 11.5) compared to the combined MF group (mean ± SD, 54.0 ± 24.1; P = .0015). After controlling for lesion size, on average, patients treated with ECM-BMAC had total MOCART scores 18.4 points higher than patients treated with MF (Figures 1 and 2). Of note, average total MOCART scores for the MF-BMAC (56.1 ± 23.0) and MF-only (51.3 ± 25.3) groups were similar (P = .57).

When evaluating individual MOCART categories and adjusting for lesion size, ECM-BMAC patients had significantly higher scores for the Infill, Integration, and Signal categories compared to MF patients. For the Infill category, 85% of ECM-BMAC MRIs demonstrated complete (15%) or hypertrophic (70%) infill, compared to 59% of MF MRIs (18% complete, 41% hypertrophic; P = .033). When evaluating all postoperative MRIs across both groups, only 16% of all treated patients exhibited complete infill on the level of adjacent native cartilage, with 53% of patients exhibiting hypertrophic infill. For the Integration category, 70% of ECM-BMAC MRIs showed complete integration, compared to 34% of MF MRIs (P = .011). For the Signal category, 75% of ECM-BMAC MRIs demonstrated isointense signal, compared to 38% of MF MRIs (P = .019; Table 5).

Revision Rate

Patients were recommended for revision surgery if they reported continued pain and symptoms postoperatively without resolution following conservative measures. Three patients in the ECM-BMAC group (4.8%) and 14 patients in the MF group (20.9%; P = .007) were deemed to have failed their initial procedure and underwent revision surgery. This included 9 of 36 patients (25%) in the MF-BMAC

Table 4. Comparison of Postoperative FAOS and Pre- to Postoperative Change in FAOS Between ECM-BMAC Patients and MF Patients.[a]

FAOS category	Preoperative, mean ± SD	*P* value	Postoperative, mean ± SD	*P* value	Δ Pre- to postoperative, mean ± SD	*P* value
Pain						
ECM-BMAC	56.11 ± 22.21	.93	77.08 ± 19.99	.45	21.73 ± 29.02	.94
MF	55.29 ± 20.73		75.06 ± 23.14		26.29 ± 31.84	
Symptoms						
ECM-BMAC	59.27 ± 16.07	.88	70.82 ± 23.35	.16	12.50 ± 18.45	.47
MF	60.00 ± 21.11		67.01 ± 23.48		12.79 ± 32.27	
Daily Activities						
ECM-BMAC	71.91 ± 20.58	.86	87.46 ± 15.73	.32	14.19 ± 23.34	.55
MF	70.50 ± 22.01		84.47 ± 20.12		22.96 ± 37.97	
Sports Activities						
ECM-BMAC	40.24 ± 22.99	.93	62.13 ± 30.86	.53	21.91 ± 31.52	.76
MF	37.97 ± 26.04		61.11 ± 30.19		27.02 ± 36.90	
Quality of Life						
ECM-BMAC	30.75 ± 20.38	.13	50.23 ± 29.30	.55	12.75 ± 24.81	.20
MF	24.54 ± 19.38		50.50 ± 32.32		28.75 ± 29.88	
Total						
ECM-BMAC	50.68 ± 18.19	.71	69.32 ± 21.63	.55	16.32 ± 22.05	.97
MF	49.40 ± 17.66		67.67 ± 23.10		21.73 ± 25.73	

Abbreviations: BMAC, bone marrow aspirate concentrate; ECM, extracellular matrix; FAOS, Foot and Ankle Outcome Scores; MF, microfracture.
[a]*P* values reflect multivariate analysis adjusting for lesion size, which was significantly larger in the ECM-BMAC group.

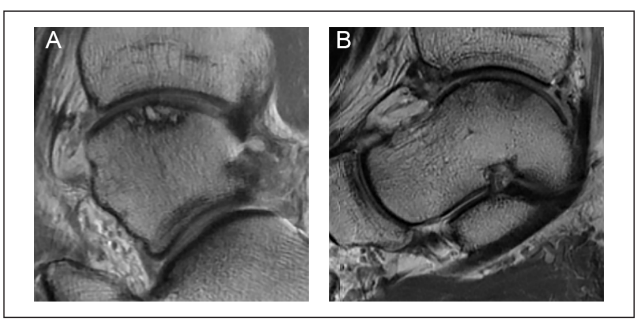

Figure 1. (A) Preoperative magnetic resonance imaging (MRI) of an osteochondral lesion of the talus in a patient who received treatment with extracellular matrix with bone marrow aspirate concentrate (ECM-BMAC). (B) T-1 weighted MRI showing healing of the defect 35 months after treatment with ECM-BMAC with good infill and integration and only mild persistence of low signal.

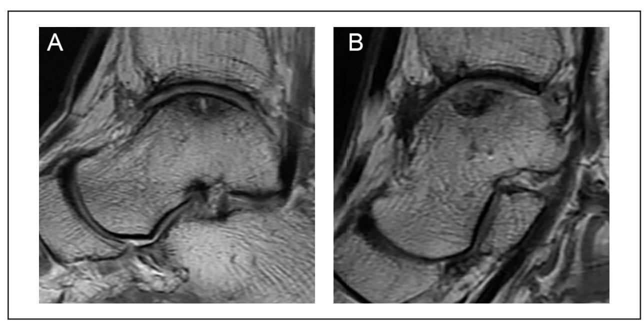

Figure 2. (A) Preoperative magnetic resonance imaging (MRI) of an osteochondral lesion of the talus in a patient who received treatment with microfracture. (B) T-1 weighted MRI showing inhomogeneous fill, low signal, and fragmentation of the subchondral plate 33 months after treatment with microfracture.

group and 5 of 31 patients (16.1%) in the MF-only group. For the ECM-BMAC patients undergoing revision, average time from index to revision procedure was 11.1 (range, 8.7-12.9) months. For all MF patients, average time to revision was 32.8 (range, 5-77.1) months, with the 9 MF-BMAC patients undergoing revision at an average of 24.2 (range, 5-53.8) months and the 5 MF-only patients undergoing revision at an average of 54.2 (range, 32.8-77.1) months.

Discussion

Our results suggest that both MF and ECM-BMAC can be used to treat an OLT with significant improvement in clinical outcomes. When comparing FAOS scores between ECM-BMAC and MF patients, no significant differences were detected, although longer follow-up is needed. Our radiographic results suggest that the ECM-BMAC group achieved better postoperative fill and structural integrity of

Table 5. Significant MOCART Comparisons Between ECM-BMAC and Combined MF/MF-BMAC Groups.[a]

MOCART category	Treatment group	Radiographic characteristic	Percentage	*P* value
Infill	ECM-BMAC	Complete or hypertrophic	85	.033[b]
		Incomplete	15	
	MF	Complete or hypertrophic	59	
		Incomplete	41	
Integration	ECM-BMAC	Complete	70	.011[b]
		Incomplete	30	
	MF	Complete	34	
		Incomplete	66	
Signal	ECM-BMAC	Isointense	75	.019[b]
		Hyperintense	25	
	MF	Isointense	38	
		Hyperintense	62	
Total MOCART, mean ± SD	ECM-BMAC	73 ± 11.53		.0015[b]
	Combined MF and MF-BMAC	53.97 ± 24.05		

Abbreviations: BMAC, bone marrow aspirate concentrate; ECM, extracellular matrix; MF, microfracture; MOCART, Magnetic Resonance Observation of Cartilage Repair Tissue.
[a]*P* values compare the ECM-BMAC group to combined MF-BMAC and MF-only group, and analysis adjusts for lesion size.
[b]Significance level .05.

the reparative tissue when compared to MF. In addition, the significant difference in rate of revision surgery between groups suggests that the use of adjuvant ECM-BMAC may have the potential to improve long-term outcomes, addressing the concern of degradation of reparative tissue and poor long-term outcomes following MF. These findings support our hypothesis that the ECM-BMAC procedure may be superior to MF in treating OLTs, with higher-quality repair on MRI and lower rates of revision.

MF has historically been the preferred surgical treatment for small- to medium-sized OLTs, with favorable outcomes reported in approximately 80% to 85% of patients.[41,42] Some authors, however, report favorable outcomes in fewer than 60% of patients based on American Orthopaedic Foot & Ankle Society ankle-hindfoot scores.[26] Poor longer-term outcomes may also arise as a result of the inferior biomechanical properties of the fibrocartilage that fills the defect following MF. Basic science models have shown that fibrocartilage degrades quickly over time,[20] and when evaluating clinical outcomes at an average of 66 months, Hunt and Sherman[29] report favorable outcomes in fewer than 50% of patients following MF-type procedures. Similarly, Ferkel et al[16] evaluated long-term outcomes following drilling and/or microfracture at an average of 71 months, with deterioration of reparative tissue demonstrated in 35% of patients. The MF procedure has also been found to be less effective for lesions larger than 150 mm^2.[8,10,13,23,25,36] Chuckpaiwong et al[10] show good to excellent results for 73 patients with lesions smaller than the critical size of 15 mm in diameter, with only 1 success for larger lesions at an average of 31.6 months of follow-up. Choi et al[8] report a similar correlation between lesion size and success of MF. In their cohort, 20 of 25 (80%) patients with a lesion larger than 150 mm^2 were deemed to have failed MF treatment. Failed MF may require subsequent procedures, although these procedures may present limitations such as the need for additional osteotomy, donor site morbidity, or multiple stages of the procedure.[4,22,24,27] This study evaluated ECM-BMAC and microfracture in lesions smaller than 150 mm^2 on average, and thus future studies are needed to elucidate the utility of these procedures in addressing larger lesions.

The addition of BMAC for augmentation of MF repairs has been explored by several authors. Fortier et al[19] used an equine model to compare MF alone and MF-BMAC, with results suggesting that BMAC may improve the quality of the repair tissue. However, clinical studies have shown no significant differences in patient-reported outcomes when comparing MF to MF-BMAC.[27,33] One study did report a significant difference in average total MOCART scores between groups, 73 for MF-BMAC patients and 53.97 for MF-only patients, although in the present study, we did not observe a substantial difference in total MOCART scores for MF-BMAC vs MF repairs (average 56.1 ± 23.0 for MF-BMAC patients, 51.3 ± 25.3 for MF only). Based on the existing evidence and our clinical and radiographic results, we believe that combining the MF-BMAC and MF-only patients into a single MF cohort provides a group that is sufficiently homogeneous for comparison with our ECM-BMAC group. However, this comparison does represent a limitation of the study design.

The mixture of ECM with BMAC creates a paste-like material that incorporates with the surrounding native articular cartilage. This study suggests that the quality of the reparative tissue, although not normal hyaline cartilage based on

MRI, may be improved by the ECM-BMAC combination. In studies that have evaluated MF repairs using MRI and MOCART scoring, average total MOCART scores were 59.5 ± 17.2 points in a study evaluating 10 MF MRIs[3] and 64 ± 14 points in a study of 15 MF MRIs.[5] With an average total MOCART of 54.0 ± 24.1, our MF patients' MOCART scores were comparable to those previously reported. In our cohort, ECM-BMAC patients had an average overall MOCART score that was significantly greater than the average for MF patients. Furthermore, when evaluating individual MOCART categories, the ECM-BMAC patients scored significantly better than MF patients with respect to infill, integration with surrounding cartilage, and signal intensity of the repair tissue. However, when evaluating all patients with postoperative MRIs in both groups, only 16% of all treated patients exhibited complete infill to the level of adjacent native cartilage, with 53% of patients exhibiting hypertrophic infill. This result suggests that no treatment appears to result consistently in normal reparative cartilage tissue with respect to the fill of the defect. Of note, several authors have explored the correlation between MOCART scores and clinical outcomes with varying results.[2,7,15,17,28,30,37,39] To determine the clinical impact of these results, more evidence is needed regarding the relationship between MOCART scores and clinical outcomes. Still, MOCART remains an accepted standard for semiquantitative evaluation of cartilage repair on postoperative MRI.

If using adjunctive ECM-BMAC helps improve the structural quality of reparative tissue, the degradation of fibrocartilage associated with MF procedures may be lessened, potentially resulting in reduced presence of clinical symptoms over time.[16] This result may also be consistent with the significant difference observed in the rate of revision surgery between ECM-BMAC and MF patients. The presentation of clinical symptoms and evaluation of postoperative MRI led MF patients to undergo revision surgery at a significantly higher rate than ECM-BMAC patients. Although we did not observe any major complications in our MF cohort, traditional MF requires penetrating the subchondral bone, introducing the potential for subchondral fracture, avascular necrosis, and persistent edema. One clinical study has shown a correlation between persistent bone marrow edema and poorer clinical outcomes at 4 years following OLT repair.[38]

A primary limitation of this study is that follow-up times were substantially different between groups, as a result of a paradigm shift in preferred treatment method by the senior author, and several patients were lost to follow-up and did not undergo radiographic evaluation. However, other authors who have used MOCART scoring to assess cartilage repair have evaluated MRIs performed 1 to 2 years postoperatively, and the average times to MRI follow-up in our cohort generally align with this standard. Furthermore, MOCART scores for our MF cohort are consistent with previously published literature, which evaluated OLT repairs using MOCART,[3,5] so we believe the comparison made between MOCART scores for our MF group and ECM-BMAC group is valid. Longer follow-up could prove especially beneficial in better detecting any differences in functional and clinical outcomes between groups, as well as any differences in revision rates. In addition, longer follow-up in the ECM-BMAC group is needed to confirm if the differences observed in MOCART scores with regard to the structural integrity of reparative tissue persist over time and correlate with better long-term clinical outcomes. The representation of 3 surgeons may also influence the results, although we believe this may make the results more generalizable without the influence of 1 specific surgeon's technique.

With regard to the comparison of patient-reported outcome scores, our current sample sizes likely limit our ability to detect statistically significant differences at this time. Another limitation in this study is that a subset of patients in our cohort underwent concurrent ankle stabilization or bone-grafting procedures, which may have affected postoperative outcomes. We did not have a sufficient number of MRIs for these patients to compare the quality of their cartilage repairs radiographically, but we did not detect an influence of concurrent procedure on patient-reported outcome scores. Future studies should be performed to examine the quality of cartilage repair in the setting of different ankle pathologies.

Conclusion

In this study, we compared radiographic and clinical outcomes for patients undergoing ECM-BMAC or traditional MF to determine whether ECM-BMAC could produce higher-quality reparative cartilage tissue. Patient-reported outcome scores improved significantly within both treatment groups, although no statistically significant differences were observed between groups. However, a significant difference in radiographic outcomes was observed between groups, with the ECM-BMAC group demonstrating a higher average total MOCART score and higher scores for the Infill, Integration, and Signal MOCART subcategories. These results suggest that using ECM-BMAC as an adjuvant therapy in OLT repair may result in improved integration and structural integrity of the reparative tissue when compared to MF, which may improve long-term clinical outcomes.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Jonathan T. Deland, MD, reports personal fees from Arthrex. ICMJE forms for all authors are available online.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Supplemental Material

A supplemental video for this article is available online.

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