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Arthroscopic Treatment of Osteochondral Lesions of the Talus Using Juvenile Articular Cartilage Allograft and Autologous Bone Marrow Aspirate Concentration

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ABSTRACT

Juvenile allogenic chondrocyte implantation (JACI; DeNovo NT Natural Tissue Graft®; Zimmer, Warsaw, IN) with autologous bone marrow aspirate concentrate (BMAC) is a relatively new all-arthroscopic procedure for treating critical-size osteochondral lesions (OCLs) of the talus. Few studies have investigated the clinical and radiographic outcomes of this procedure. We collected the clinical and radiographic outcomes of patients who had undergone JACI-BMAC for talar OCLs to assess treatment efficacy and cartilage repair tissue quality using magnetic resonance imaging (MRI). Forty-six patients with critical-size OCLs (≥6 mm widest diameter) received JACI-BMAC from 2012 to 2014. We performed a retrospective medical record review and assessed the functional outcomes pre- and postoperatively using the Foot and Ankle Outcome Score (FAOS) and Short-Form 12-item general health questionnaire. MRI was performed preoperatively and at 12 and 24 months postoperatively. Cartilage morphology was evaluated on postoperative MRI scans using the magnetic resonance observation of cartilage tissue (MOCART) score. The pre- to postoperative changes and relationships between outcomes and lesion size, bone grafting, lesion location, instability, hypertrophy, and MOCART scores were analyzed. Overall, the mean questionnaire scores improved significantly, with almost every FAOS subscale showing significant improvement postoperatively. Concurrent instability resulted in more changes that were statistically significant. The use of bone grafting and the presence of hypertrophy did not result in statistically significant changes in the outcomes. Factors associated with outcomes were lesion size and hypertrophy. Increasing lesion size was associated with decreased FAOS quality of life subscale and hypertrophy correlating with changes in the pain subscale. Of the 46 patients, 22 had undergone postoperative MRI scans that were scored. The average MOCART score was 46.8. Most patients demonstrated a persistent bone marrow edema pattern and hypertrophy of the reparative cartilage. Juvenile articular cartilage implantation of the DeNovo NT allograft and BMAC resulted in improved functional outcome scores; however, the reparative tissue still exhibited fibrocartilage composition radiographically. Further studies are needed to investigate the long-term outcomes and determine the superiority of the arthroscopic DeNovo procedure compared with microfracture and other cartilage resurfacing procedures.

Osteochondral lesions (OCLs) of the talus often occur after traumatic ankle injuries such as sprains, fractures, and recurrent instability. The incidence of talar OCLs is difficult to define owing to ambiguity with the diagnosis and the presence of asymptomatic lesions; however, OCLs have been reported to occur in 17% to 79% of ankle fractures (1–7) and ≤38% of sprains (8). Microfracture has been considered the

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standard of care for small- to medium-size lesions (<15 mm in diameter), because it is a simple, single-stage procedure that can be performed arthroscopically. The success rates have varied, with good to excellent results occurring in 39% to 96% of cases in the short term (9). However, instead of producing normal articular cartilage, microfracture produces fibrocartilage composed of both type I and type II collagen, which is weaker than native hyaline cartilage (primarily type II collagen). The long-term efficacy and inferior biomechanical properties of the reparative tissue, which can degrade more quickly over time, have been questioned (10). Moreover, this reparative cartilage technique has been less successful in treating larger lesions (>15 mm in diameter) (11–13), many of which often require secondary procedures, such as osteochondral allografting, autografting, or autologous chondrocyte implantation (14–17). However, many of these procedures require an osteotomy for access, result in donor site morbidity at a cartilage harvest site, or require a staged procedure. This associated morbidity has led surgeons to search for other methods to improve the quality of the reparative tissue through minimally invasive techniques with biologic adjuncts, including growth factors, mesenchymal stem cells, and minced allograft tissue.

Juvenile allogenic chondrocyte implantation (JACI) with autologous bone marrow aspirate (BMAC) is a relatively new all-arthroscopic procedure that uses a prepackaged particulated articular cartilage allograft from donors aged 2 to 12 years (DeNovo NT Natural Tissue Graft®; Zimmer, Warsaw, IN). The graft is implanted into the base of the lesion and secured with a fibrin sealant diluted with BMAC. The use of BMAC is indicated, because it has been shown to improve the biomechanical and structural components of the reparative tissue (15,18–20). Immature juvenile chondrocytes have greater metabolic activity and a propensity to regenerate hyaline-like cartilage compared with adult chondrocytes (15,21), giving this repair method the potential to reliably reproduce hyaline cartilage without the morbidity and technical difficulties associated with other restorative techniques. However, few studies have investigated the clinical and radiographic outcomes of this procedure.

Our hypothesis was that the JACI with BMAC (JACI-BMAC) technique would effectively treat critical-size OCLs of the talus, with patients showing statistically and clinically significant improvement after 24 months. The purpose of the present study was to collect the clinical and radiographic outcomes data from patients who had undergone JACI-BMAC for talar OCLs to assess the efficacy of the treatment and evaluate the quality of cartilage repair tissue using magnetic resonance imaging (MRI).

Patients and Methods

Study Population and Design

After approval from our institutional review board, patients were consecutively recruited by all of us from our clinical practices after the diagnosis of a critical-size OCL (≥6 mm widest diameter) or a lesion that had failed conservative treatment or previous bone marrow-stimulation procedures. Patients were excluded if they were smokers, had rheumatoid or inflammatory joint disease, were immunosuppressed, or had uncontrolled diabetes, an autoimmune disorder, or systemic inflammatory disease. We discussed the procedure in detail with each patient and provided a letter detailing the study and information regarding the procedure. After the patients had provided informed consent, we performed a retrospective medical record review. The patient demographic information and whether the patient had a history of trauma to the ankle joint affected by the OCL were recorded. A total of 46 patients met the inclusion criteria and agreed to participate in the present study. Of the 46 patients, 21 were male and 25 were female, with an average age of 37.6 (range 14 to 67) years.

Routine functional outcome scores, including the Foot and Ankle Outcome Score (FAOS) and Short-Form 12-item, version 2 (SF-12v2) score, were collected preoperatively at the last patient visit before surgery and at the 6-, 12-, and 24-month postoperative evaluations. MRI was performed preoperatively and at 12 and 24 months postoperatively.

Table 1
Magnetic resonance observation of cartilage tissue scoring system for evaluation of juvenile allogenic chondrocyte implantation bone marrow aspirate concentrate using DeNovo NT Natural Tissue Graft®

Scoring Category and Variables (Score)	MRI Characteristics
1. Degree of defect infill	
Complete (20)	On level with adjacent cartilage
Hypertrophy (15)	Over level of adjacent cartilage
Incomplete	Under level of adjacent cartilage; underfilling
>50% of Adjacent Cartilage (10)	
<50% of Adjacent Cartilage (5)	
Subchondral Bone Exposed (0)	
2. Integration to border zone	
Complete (15)	Complete integration with adjacent cartilage
Hypertrophy (15)	
Incomplete	Incomplete integration with adjacent cartilage
>50% of Adjacent Cartilage (10)	Presence of fissure or defect
<50% of Adjacent Cartilage (5)	
Subchondral Bone Exposed (0)	
3. Surface of repair tissue	
Surface intact (10)	Lamina splendens intact
Surface damaged	Fibrillations, fissures, and ulcerations
<50% of Repair Tissue Depth (5)	
>50% of Repair Tissue Depth (0)	
Degeneration (0)	
4. Structure of repair tissue	
Homogenous (5)	
Inhomogeneous (0)	
5. Signal intensity of repair tissue	
Isointense (30)	
Moderately hyperintense (10)	
Markedly Hyperintense (0)	
6. Subchondral lamina	
Intact (5)	
Not Intact (0)	
7. Subchondral bone	
Intact (5)	
Not Intact (0)	Edema, granulation tissue, cysts, sclerosis
8. Adhesions	
Yes (0)	
No (5)	
9. Effusion	
Yes (0)	
No (5)	

Scores from 0 to 100 represent the percentage of the total possible achievable score.

MRI Assessment

A radiologist trained in musculoskeletal radiology reviewed all MRI scans and evaluated the articular cartilage morphology using a modified magnetic resonance observation of cartilage tissue (MOCART) score. The MOCART scoring system has been accepted as a reliable method for assessing cartilage repair with low interobserver variability (22). The system uses 9 parameters to evaluate the morphology and signal intensity of the repair tissue compared with the native cartilage (Table 1).

Of the 46 patients who participated in the present study, 22 underwent postoperative MRI studies that could be scored using the MOCART system. MRI scans were performed across multiple institutions largely owing to patient convenience in terms of location and insurance requirements. The MRI scans were performed at our institution (n = 14), in the private radiology facility of 1 of the participating surgeons (n = 4), and at outside facilities (n = 4).

Surgical Technique

The surgical technique was performed as described by Drakos and Murphy (23). The patient is placed supine on the operating table, a tourniquet was applied to the proximal thigh, and general anesthesia and a nerve block were administered. The patient and operative leg were prepared and draped in the standard sterile fashion, with the leg elevated and placed in a positioner to keep the hip and knee flexed at 60° and 70°, respectively. Approximately 60 mL of bone marrow was aspirated from the anterior superior iliac crest and then concentrated in the Magellan Autologous Platelet Separator (Anteriocyte Medical Systems, Cleveland, OH), yielding about 3 mL of BMAC. If bone grafting was necessary owing to the presence of any bony defects below the articular cartilage in the talus, the graft was harvested at this point from either the iliac crest

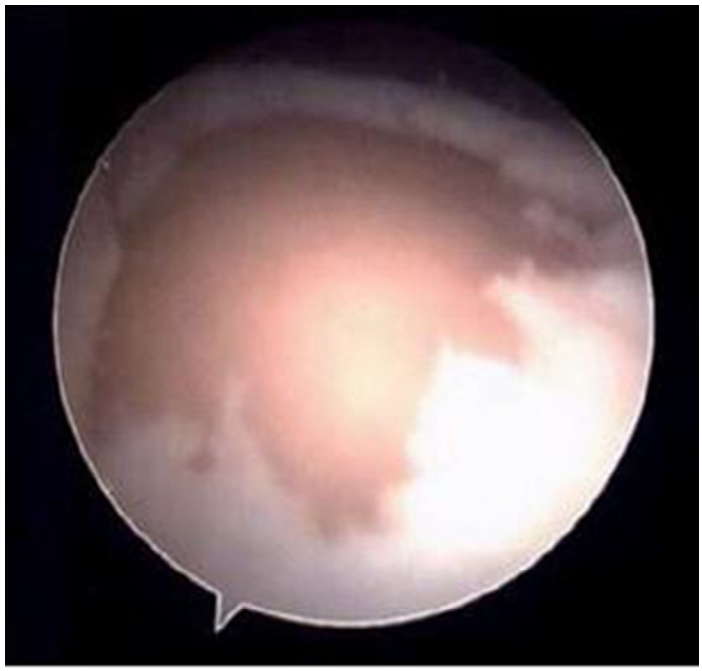

Fig. 1. Arthroscopic view of an osteochondral defect of the talus.

or the calcaneus, depending on the size of the defect and extent of cystic changes in the talus. Small defects (<10 mm) received bone grafting from the iliac crest using the Jamshidi Bone Marrow Needle (Carefusion, San Diego, CA). However, large defects (>15 mm^2) required cancellous bone grafts from the calcaneus harvested with a curette by way of a small lateral incision.

The leg was exsanguinated, the tourniquet raised to 250 mm Hg, and the patient was placed in noninvasive traction to distract the ankle joint. The standard anteromedial and anterolateral portals were then established to begin the arthroscopic evaluation of the OCL. Once the lesion was identified, the area was debrided using a mechanical shaver to remove any scar tissue, osteophytes, and loose fragments. A microfracture kit and curette were then used to debride any bony cysts and loose cartilage. Subchondral bone was also exposed such that the borders of viable articular hyaline cartilage surrounding the defect were clearly visible and viable (Fig. 1). All fluid was then removed from the ankle using an epidural spinal needle and vacuum suction such that the remainder of the arthroscopy could be performed dry. During this time, the DeNovo NT graft was prepared. To prepare the graft, the package was drained with a 25-gauge needle and syringe to remove the packing fluid, and the juvenile articular cartilage particulates were loaded into the distal end of an arthroscopy cannula, packed with a trochar, and then set aside (Fig. 2). Once the ankle was completely dry, and all minor bleeding vessels had ceased, the bone graft was placed into the defect using an arthroscopic cannula. The bone graft was then packed down to form a stable bed using a Freer elevator. A fibrin glue sealant (Evicel; Ethicon, Rockville, MD) was layered over the bone graft. Next, the DeNovo articular cartilage allograft was placed into the defect using an arthroscopic cannula. It was then dispersed over the defect and placed into position to adequately cover the whole defect using a Freer elevator. The cartilage graft was covered with more fibrin glue for additional fixation. With the top layer of fibrin glue still wet, the BMAC was applied over the graft. The fibrin glue was then left to dry, which typically required 5 to 10 minutes. Final arthroscopic photographs were then taken to confirm the graft was properly placed and had had sufficient time to harden (Fig. 3).

Statistical Analysis

The results are presented as frequencies and percentages for categorical variables and the mean and 95% confidence intervals for continuous variables. The pre- to postoperative changes in outcome scores were assessed using the Wilcoxon signed rank tests. The pre- to postoperative changes were assessed for the overall method and for those patients who had received bone grafting (yes versus no), those with instability (yes versus no), and those with hypertrophy (yes versus no). Relationships between outcomes (preoperative FAOS and SF-12v2 scores, postoperative FAOS and SF-12v2 scores, and the pre- to postoperative changes in the scores) and lesion size were assessed using simple linear regression analysis. Associations between grafting (yes versus no) and outcomes were assessed using the Mann-Whitney *U* test. Parallel analyses were also conducted for associations with medial or lateral location, instability (yes versus no), and hypertrophy (yes versus no). Relationships between the MOCART score and postoperative outcomes (postoperative scores and pre- to postoperative changes in scores) were assessed with simple linear regression analysis. Analyses were conducted using Statistical Analysis Systems, version 9.3 (SAS Institute, Cary, NC), with a level of significance of $\alpha = 0.05$.

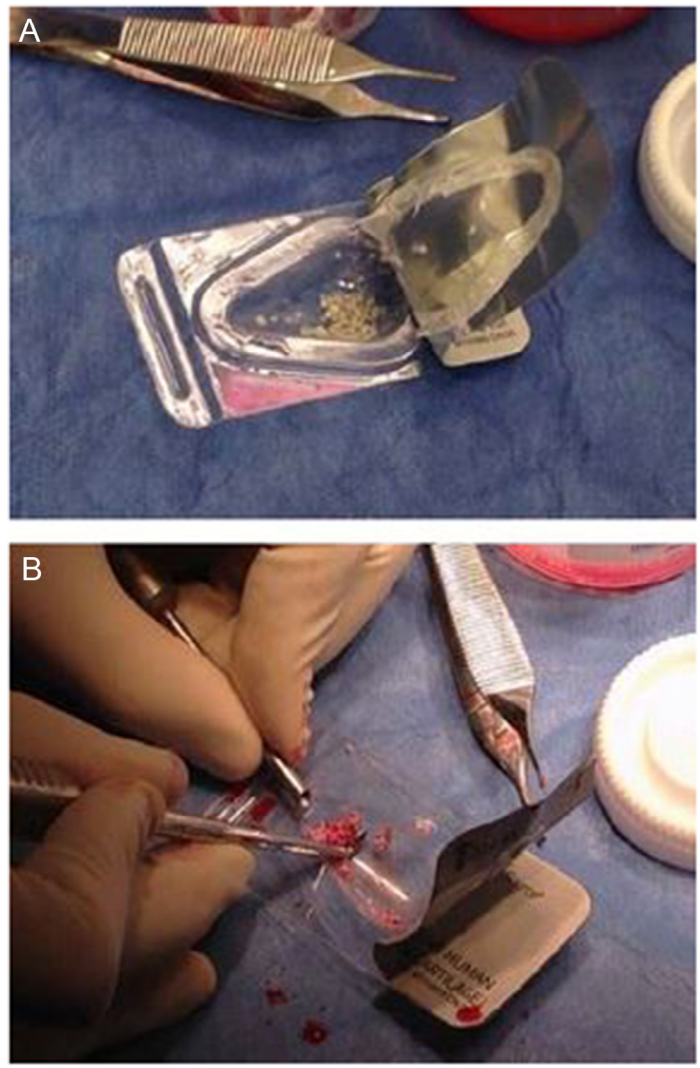

Fig. 2. JACI allograft drained from preservation fluid *(A)* and loaded into the trochar to prepare for application *(B)*.

Results

Functional Outcomes

The average follow-up period was 16.7 (range 4.6 to 39.6) months. Of the 46 patients included in the study, 29 completed the FAOS and SF-12 surveys preoperatively and 36 completed the surveys postoperatively. Twenty-four patients had complete pre- and postoperative surveys available for comparison. Overall, the SF-12 scores and mean FAOSs improved significantly from pre- to postoperatively, from 63.0 to 75.6 ($p = .023$) and 48.0 to 66.0 ($p = .004$), respectively. Every subscale of the FAOS showed significant improvement postoperatively, except for the symptoms subscale. The quality of life subscale showed the most significant improvement, increasing from 23.1 to 49.5 ($p < .001$). On average, the overall SF-12 score improved 10.6 points and the mean FAOS improved by 12.6 points ($p = .023$ and $p = .004$, respectively).

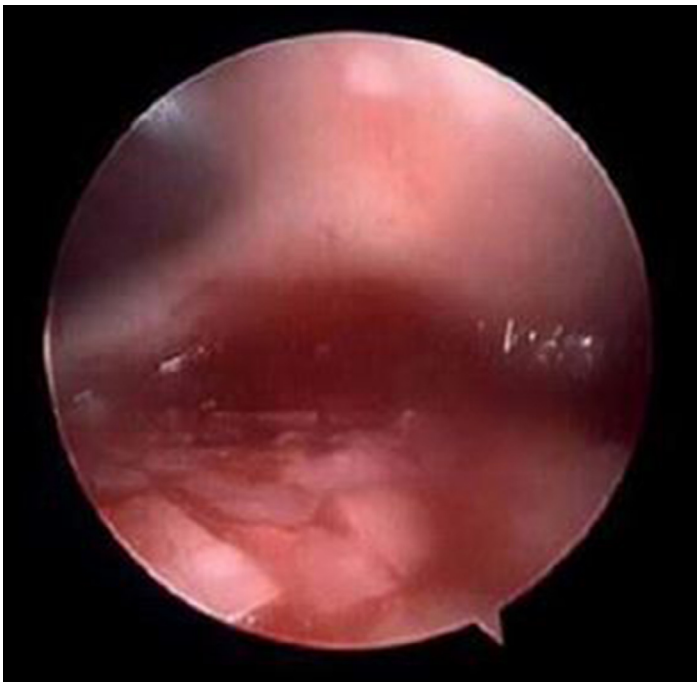

Fig. 3. Final arthroscopic view of hardened DeNovo NT allograft.

The quality of life subscale increased an average of 23.7 points postoperatively ($p < .001$), the sports activities subscale increased by 15.7 points ($p = .004$), the pain subscale by 12.8 points ($p = .006$), the daily activities subscale by 10.7 points ($p = .010$), and the symptoms subscale by 5.5 points ($p = .189$; Table 2).

Comparing the overall mean scores for the patients with and without concurrent instability showed that the presence of instability resulted in more significant pre- to postoperative changes in the outcomes. Patients with instability had statistically significant improvements in the overall SF-12 scores and FAOSs and all 5 subscales of the FAOS, with the largest improvement seen in the quality of life subscale, with an average pre- to postoperative change of 43.7 points ($p = .002$; Table 3).

Patients without instability only showed significant changes in the quality of life subscale, improving 20.1 points ($p = .007$). These results support the notion that patients with ankle instability and an OCL will experience significant clinical improvement postoperatively compared with those with pain due to an isolated OCL. Bone grafting did not result in more significant pre- to postoperative changes in outcomes. Rather, more significant changes were seen in patients who had not received additional bone grafting, with a statistically significant difference in the pre- and postoperative values for the overall SF-12 score ($p = .027$) and FAOS ($p = .006$), as well as in the pain ($p = .027$), sports activities ($p = .003$), and quality of life ($p = .001$) FAOS subscales (Table 4). The presence of hypertrophy did not affect the outcomes. No significant changes were found from pre- to postoperatively in patients with and without hypertrophy (Table 5).

The relationships between outcomes and lesion location, lesion size, bone grafting, instability, and hypertrophy were assessed for the 24 patients with both pre- and postoperative scores. Lesion location (medial versus lateral) was not associated with any outcomes pre- or postoperatively. Lesion size was not associated with any functional outcomes, except for the pre to postoperative change in the FAOS quality of life subscale. A decrease of 3.7 points in the quality of life

Table 2
Overall functional outcome scores (N = 46 patients)

Variable	Preoperative Score (n)	Postoperative Score (n)	Change in Score (n)	*p* Value
Overall SF-12	63.0 ± 16.0 (27)	75.6 ± 17.8 (34)	10.6 (22)	.023*
FAOS				
Pain	55.8 ± 19.8 (28)	71.6 ± 24.3 (36)	12.8 (23)	.006*
Symptoms	59.6 ± 20.8 (29)	66.5 ± 23.6 (36)	5.5 (24)	.180
Daily activities	68.1 ± 20.6 (27)	81.0 ± 24.2 (35)	10.7 (22)	.010*
Sports activities	38.9 ± 20.4 (28)	58.6 ± 31.0 (33)	15.7 (23)	.004*
Quality of life	23.1 ± 17.4 (29)	49.5 ± 29.0 (35)	23.7 (24)	<.001*
Overall	48.0 ± 13.8 (26)	66.0 ± 21.8 (32)	12.6 (21)	.004*

Data presented as mean ± standard deviation (n).
Abbreviations: FAOS, Foot and Ankle Outcome Score; SF-12, Short-Form 12-item scale.
* Statistically significant ($p < .05$).

Table 3
Overall functional outcome scores for instability patients (N = 11 patients)

Variable	Instability	Preoperative Score (n)	Postoperative Score (n)	Change in Score	*p* Value
Overall SF-12	Yes	60.2 ± 13.4 (6)	79.8 ± 16.4 (10)	19.6	.027*
	No	63.8 ± 16.9 (21)	73.8 ± 18.4 (24)	10.0	.066
FAOS					
Pain	Yes	43.9 ± 17.1 (5)	75.3 ± 21.7 (10)	31.4	.015*
	No	58.4 ± 19.7 (23)	70.2 ± 25.5 (26)	11.8	.079
Symptoms	Yes	48.2 ± 18.2 (6)	72.1 ± 19.3 (10)	23.9	.028*
	No	62.6 ± 20.7 (23)	64.3 ± 25.0 (26)	1.7	.791
Daily activities	Yes	52.4 ± 17.2 (5)	85.3 ± 19.4 (10)	32.9	.007*
	No	71.7 ± 19.9 (22)	79.2 ± 26.1 (25)	7.5	.279
Sports activities	Yes	22.5 ± 14.7 (6)	60.0 ± 31.7 (10)	37.5	.017*
	No	43.4 ± 19.6 (22)	58.0 ± 31.4 (23)	14.6	.067
Quality of life	Yes	18.8 ± 14.3 (6)	62.5 ± 24.7 (10)	43.7	.002*
	No	24.2 ± 18.2 (23)	44.3 ± 29.4 (25)	20.1	.007*
Overall	Yes	35.6 ± 13.8 (5)	71.0 ± 21.8 (10)	35.4	.006*
	No	51.0 ± 15.0 (21)	63.7 ± 26.1 (22)	12.7	.059

Data presented as mean ± standard deviation.
Abbreviations: FAOS, Foot and Ankle Outcome Score; SF-12, Short-Form 12-item scale.
* Statistically significant ($p < .05$).

Table 4
Overall functional outcome scores for bone graft patients (N = 14 patients)

Variable	Bone Graft	Preoperative Score (n)	Postoperative Score (n)	Change in Score	*p* Value
Overall SF-12	Yes	62.7 ± 16.6 (10)	75.2 ± 17.4 (8)	12.5	.140
	No	63.2 ± 16.2 (17)	75.7 ± 18.3 (26)	12.5	.027*
FAOS					
Pain	Yes	55.2 ± 13.0 (11)	68.8 ± 31.2 (8)	13.6	.208
	No	56.3 ± 23.5 (17)	72.4 ± 22.6 (28)	16.1	.027*
Symptoms	Yes	66.6 ± 15.7 (11)	62.9 ± 32.8 (8)	-3.7	.747
	No	55.4 ± 22.7 (18)	67.5 ± 20.9 (28)	12.1	.071
Daily activities	Yes	67.2 ± 11.5 (10)	80.0 ± 21.4 (8)	12.8	.123
	No	68.6 ± 24.7 (17)	81.3 ± 25.4 (27)	12.7	.110
Sports activities	Yes	51.7 ± 19.1 (11)	63.8 ± 31.8 (8)	12.1	.314
	No	30.6 ± 16.9 (17)	57.0 ± 31.2 (25)	26.4	.003*
Quality of life	Yes	22.2 ± 15.4 (11)	41.9 ± 29.3 (8)	19.7	.073
	No	23.6 ± 18.9 (18)	51.8 ± 29.1 (27)	28.2	.001*
Overall	Yes	51.5 ± 10.3 (10)	63.5 ± 27.7 (8)	12	.221
	No	45.9 ± 18.4 (16)	66.8 ± 24.2 (24)	20.9	.006*

Data presented as mean ± standard deviation.
Abbreviations: FAOS, Foot and Ankle Outcome Score; SF-12, Short-Form 12-item scale.
* Statistically significant ($p < .05$).

Table 5
Overall functional outcome scores for patients with hypertrophy (N = 15 patients)

Variable	Hypertrophy	Preoperative Score (n)	Postoperative Score (n)	Change in Score	*p* Value*
Overall SF-12	Yes	69.4 ± 14.9 (12)	75.9 ± 15.1 (12)	6.5	.300
	No	57.6 ± 17.6 (6)	68.2 ± 19.3 (8)	10.6	.312
FAOS					
Pain	Yes	60.6 ± 18.8 (12)	69.8 ± 23.6 (12)	9.2	.302
	No	43.3 ± 23.5 (7)	64.2 ± 24.3 (8)	20.9	.083
Symptoms	Yes	67.3 ± 17.2 (12)	67.9 ± 18.7 (12)	0.6	.935
	No	42.3 ± 23.7 (7)	59.4 ± 24.5 (8)	17.1	.194
Daily activities	Yes	70.8 ± 16.7 (12)	78.4 ± 24.2 (12)	7.6	.380
	No	60.8 ± 32.4 (7)	74.6 ± 33.4 (8)	13.8	.433
Sports activities	Yes	40.0 ± 18.3 (11)	50.4 ± 31.7 (11)	10.4	.357
	No	29.5 ± 21.8 (7)	47.1 ± 30.8 (7)	17.6	.241
Quality of life	Yes	28.1 ± 17.8 (12)	42.4 ± 26.5 (11)	14.3	.141
	No	11.6 ± 14.2 (7)	35.2 ± 26.1 (8)	23.6	.053
Overall	Yes	52.6 ± 13.2 (11)	61.9 ± 24.3 (10)	9.3	.283
	No	37.5 ± 20.3 (7)	57.7 ± 25.5 (7)	20.2	.127

Data presented as mean ± standard deviation.
Abbreviations: FAOS, Foot and Ankle Outcome Score; SF-12, Short-Form 12-item scale.
* Statistically significant if $p < .05$.

subscale was found for every 1-mm increase in lesion size ($p = .002$; Fig. 4). However, examining our data, we did not find any obvious thresholds or breaks beyond which a certain lesion size will result in a drastic decrease in successful postoperative outcomes. Bone grafting was not associated with the postoperative outcomes or change in outcomes. Preoperatively, patients with instability scored lower on activities, sports, and overall FAOS ($p = .042$, $p = .022$, and $p = .044$, respectively) relative to patients without instability. However, postoperatively, no significant differences were found in outcomes or the pre- to postoperative changes between these groups. Patients demonstrating hypertrophy on MRI had higher MOCART scores postoperatively, with an average score of 85 compared with those without hypertrophy, with an average score of 55 ($p = .010$). The MOCART scores also correlated negatively with the pre- to postoperative change in pain ($p = .045$). For every 10-point increase in the MOCART score, the change in pain decreased by 5 points (Fig. 5), and the variations in the scores explained 20% of the variations in the pre- to postoperative change in scores.

Radiographic Outcomes

Of the 46 patients in the study, 22 had postoperative MRI scans that could be scored, with an average radiographic follow-up period of 15.1 (range 2.2 to 39.9) months. Overall, these patients' lesions averaged 12.7 (range 7.0 to 25.0) mm in diameter. The average MOCART score was 46.8 (range 10.0 to 85.0). Regarding the degree of defect infill, 63.6% demonstrated hypertrophic coverage (n = 14). Regarding the integration to border zone, 40.9% had >50% integration with the adjacent cartilage (n = 9) and 36.4% had <50% integration (n = 8). Regarding the surface of the repair tissue, its structure, and its signal intensity, 59.1% (n = 13) had a repair tissue depth of <50%, 83.4% (n = 19) had an inhomogeneous repair tissue structure, and 54.5% (n = 16) had tissue that was moderately hyperintense. Of the subchondral lamina and subchondral bone, 77.7% (n = 16) and 95.5% (n = 21) were not intact, respectively. In terms of the presence of adhesions and effusion, 81.8% (n = 18) showed adhesions and 72.7% (n = 16) effusion (Table 6).

Nearly all patients demonstrated a persistent bone marrow edema pattern (95.5%) (Fig. 6). Most patients demonstrated hypertrophy, as demonstrated by thickening and a convex bulbous contour of the overlying reparative cartilage (63.6%; Fig. 7).

Complications

Four patients required a return to the operative room for revision procedures because their lesions had continued to be symptomatic after the DeNovo procedure. Of the 4 patients, 1 underwent microfracture with BMAC; 1, osteochondral allograft transplantation; 1, microfracture and bone grafting; and 1, debridement. The average interval before the return to the operating room was 24.1 (range 20.9 to 26.4) months. No infections or acute synovitis reactions developed.

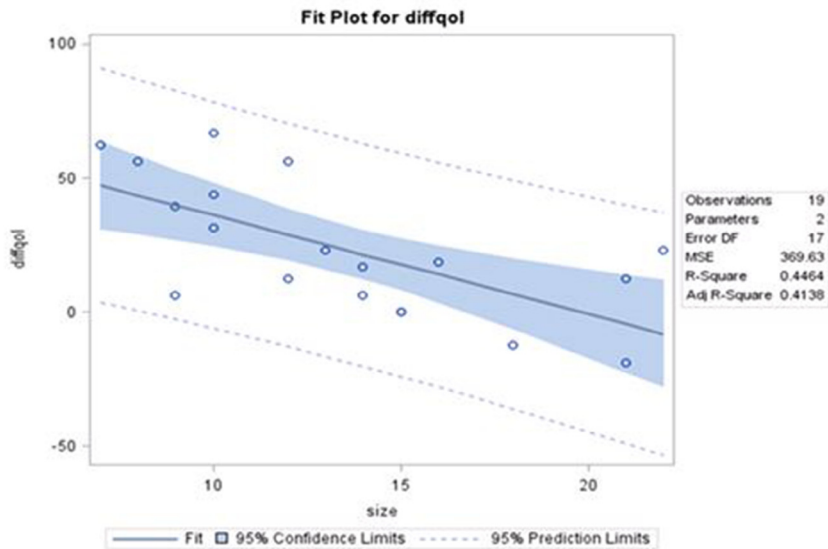

Fig. 4. Correlation between increasing lesion size and the pre- to postoperative difference in Foot and Ankle Outcome Score quality of life scores (N = 24 patients). Adj, adjusted; DF, degrees of freedom; diffqol, difference in quality of life; MSE, mean squared error.

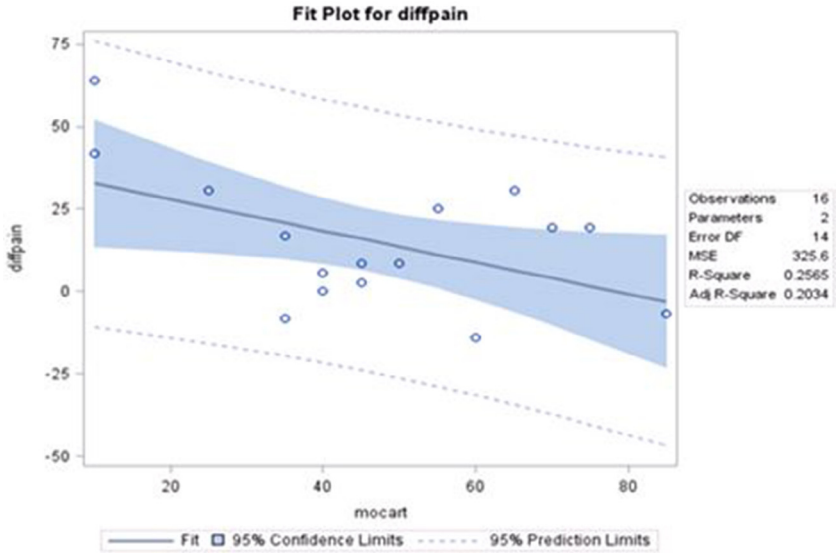

Fig. 5. Correlation between magnetic resonance observation of cartilage tissue scores and the pre- to postoperative differences in Foot and Ankle Outcome Score pain scores (N = 19 patients). Adj, adjusted; DF, degrees of freedom; diffpain, difference in pain; MSE, mean squared error.

Discussion

We report a significant improvement in clinical outcomes from pre- to postoperatively in patients undergoing JACI-BMAC to treat OCLs in the talus. The results of our study support our hypothesis that this cartilage repair technique effectively treats talar OCLs, with most patients showing significant improvement in the SF-12 scores (68.2%) and mean FAOSs (63.3%). However, our findings also showed that the postoperative functional outcomes and quality of repair tissue found on MRI were still less than ideal. The average outcome scores were only 75.6 for the SF-12 and 66.0 for the FAOS, and MRI analysis of the lesions showed persistent hypertrophy and edema at the 24-month postoperative follow-up examination. These results suggest that juvenile articular cartilage implantation might be equivalent to but without significant advantages compared with other current cartilage repair techniques such as microfracture, osteochondral autografting, allografting, and autologous chondrocyte implantation.

Table 6
Overall descriptives of repair tissue for components of magnetic resonance observation of cartilage tissue (N = 22 patients)

Variable	n (%)
Infill	
>50% of Adjacent cartilage	4 (18.2)
Hypertrophy	14 (63.6)
Subchondral bone exposed	4 (18.2)
Integration	
<50% of Adjacent cartilage	2 (9.1)
>50% of Adjacent cartilage	9 (40.9)
Hypertrophy	3 (13.6)
Subchondral bone exposed	8 (36.4)
Surface	
<50% of Repair tissue depth	13 (59.1)
>50% of Repair tissue depth or total degeneration	7 (31.8)
Surface intact	2 (9.1)
Structure	
Homogenous	3 (13.6)
Inhomogeneous	19 (86.4)
Signal intensity	
Isointense	10 (45.5)
Moderately hyperintense	12 (54.5)
Subchondral lamina	
Intact	6 (27.3)
Not intact	16 (72.7)
Subchondral bone	
Intact	1 (4.5)
Not intact	21 (95.5)
Adhesions	
No	4 (18.2)
Yes	18 (81.8)
Effusion	
No	16 (72.7)
Yes	6 (27.3)

Although each of these restorative techniques has benefits, they also have disadvantages, with few studies showing the superiority of any specific procedure (9,24–26). Microfracture has been considered the standard of care for small to medium OCLs. It is a single-stage arthroscopic procedure that has demonstrated good to excellent results in 39 to 96% of cases; however, it produces fibrocartilage that is biomechanically inferior to hyaline cartilage and has been shown to progressively degenerate over time (9). Osteochondral autografting has a rate of success similar to that of microfracture and offers the advantage of replacing the defective cartilage with the patient's own hyaline cartilage. However, a potential exists for donor site morbidity, and the procedure is technically difficult, often requiring a malleolar osteotomy (27). Osteochondral allografting is similarly advantageous, and the use of a cadaver graft eliminates the concern of donor site morbidity; however, the procedure is still technically demanding, grafts must be transplanted quickly after harvest, and the possibility of disease transmission exists. Autologous chondrocyte implantation has been successful in treating larger lesions and has been shown to produce good outcomes and good quality of repair cartilage on MRI (15,28). However, it remains a 2-stage procedure that requires cell manipulation with the potential for pathogenicity and the tendency for the chondrocytes to lose their chondrogenic phenotype, or "dedifferentiate," during culture expansion (21). The latter results in the development of repair cartilage more similar to fibrocartilage than to hyaline cartilage after implantation (21).

Our reason for using juvenile articular particulated cartilage and BMAC was to treat OCLs arthroscopically with immature chondrocytes in the hope of reliably reproducing hyaline-like cartilage more effectively and without the morbidity and technical difficulties associated with other repair techniques. However, few studies have investigated the clinical outcomes of JACI-BMAC in the ankle (29,30), and,

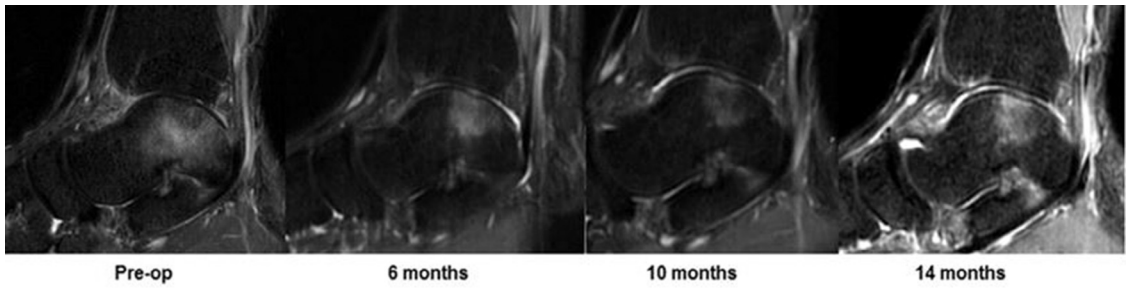

Fig. 6. Sagittal inversion recovery images on the same lesion showing significant bone marrow edema preoperatively that improved and then stabilized throughout the postoperative course.

to the best of our knowledge, no studies have examined the radiographic outcomes after JACI-BMAC.

Kruse et al (30) was the first to report a study detailing the use of DeNovo graft in the talus and its implantation arthroscopically. They presented the clinical results for a 30-year-old female, who became pain free with no activity limitations postoperatively. However, no outcome scores were used, and no radiographic assessment was performed. The only other study reporting the results of using a juvenile allograft in the talus was by Coetzee et al (29). They presented a retrospective case series of 23 patients treated with the DeNovo graft and followed up for an average of 16 months. Only 3 ankles were treated using an all-arthroscopic approach; however, good pain and functional outcomes were observed in most of the patients according to the American Orthopaedic Foot and Ankle Society ankle-hindfoot scale (score 85 ± 18 for 78%), SF-12 scale (physical component summary score 46 ± 10 and mental component summary score 55 ± 7.1), Foot and Ankle Ability Measure (daily living score 82 ± 14 and sports score: 63 ± 27), and visual analog scale (score 24 ± 25 of 100). However, the investigators did not report any preoperative scores for comparison and did not conduct any radiographic analysis.

To the best of our knowledge, our study is the first to evaluate subjective clinical outcomes and objective radiographic outcomes of JACI-BMAC in the ankle. The clinical outcomes for our 46 patients were similar to those previously reported (29,30), with most patients showing significant improvement in general health, pain, symptoms, daily function, sports, activities, and quality of life, according to the SF-12 scores and FAOSs. However, the average postoperative scores were only 75.6 for the SF-12 and 66.0 for the FAOS, showing that patients were still far from excellent in terms of the subjective outcomes. In addition, 4 patients required a return to the operating room for revision procedures. Our radiographic findings also showed that the quality of repair tissue was less than ideal. Of the 22 lesions analyzed using MRI, none were completely filled or integrated with the surrounding cartilage, and most showed persistent hypertrophy and subchondral bone marrow edema (63.6% and 95.5%, respectively). Most patients demonstrated hypertrophy of the overlying reparative cartilage. Cartilage hypertrophy after periosteal autologous chondrocyte implantation in the knee is a known negative outcome that can sometimes lead to the requirement for second-look arthroscopy and debridement (31). The immature cartilage in the DeNovo graft might have a similar biologic response with the production of neocartilage owing to the presence of growth factors and chondrocyte precursor cells. This could have led to overgrowth.

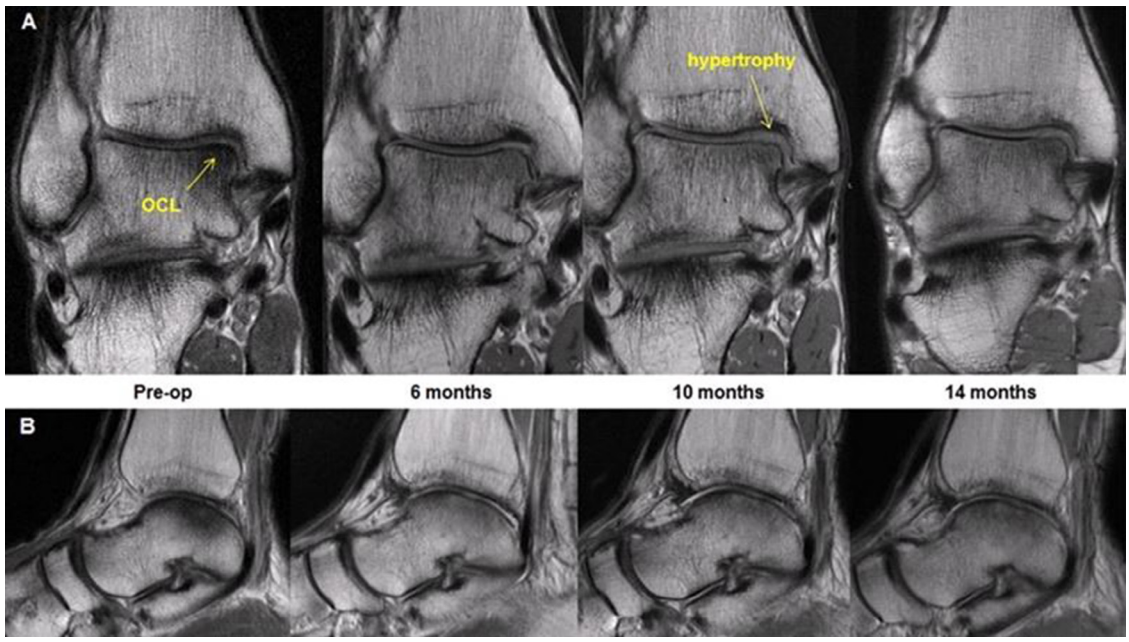

Fig. 7. *(A)* Coronal and *(B)* sagittal fast spin echo proton density images of an osteochondral lesion in a 42-year-old patient.

When considering the subgroups, no differences were found between the patients who did and did not undergo bone grafting. An increasing lesion size did lead to worse results, consistent with previously reported findings. The lesion size of the 4 patients with treatment failure was 8, 8, 9, and 15 mm in diameter. The largest lesion we treated was 25 mm. Interestingly, the concomitant presence of ankle instability was actually a positive predictive variable. This is in contrast to ankle stabilization studies, which showed worse outcomes with the presence of an OCL (10,31). We speculate that because ankle instability may be a more predictable pathology to treat, this subgroup of patients had better outcomes. In effect, if the patient were experiencing pain from both instability and the OCL or primarily from the instability, by treating the instability and the cartilage lesion, the higher scores might have resulted primarily from stabilizing the ankle. Thus, we would recommend that treating physicians evaluate patients with OCLs for instability because, if present, addressing the instability, in addition to the OCL, might produce better outcomes.

One significant limitation of the present study was the heterogeneity of the MRI scans performed across multiple institutions. The absence of high-resolution fast spin echo proton density images for all patients resulted in greater difficulty in providing a detailed analysis of the morphology of the overlying reparative cartilage. This could have affected the MOCART scoring. In addition, only 22 of the 46 patients had postoperative MRI scans available for inclusion in the present study. These limitations in the follow-up data resulted from the high travel and MRI costs and that several MRI scans were determined to be unsatisfactory for analysis by our board-certified radiologist. The clinical limitations included completion of functional outcomes scores both preoperatively and postoperatively. Furthermore, the heterogeneity of the group, including those patients who received bone grafting or ankle stabilization, did not allow for a pure group of OCLs for analysis. We chose to use BMAC because some of us had had experience with BMAC and microfracture and the potential improvement of reparative tissue with mesenchymal stem cells, which have the potential to differentiate into healthy chondrocytes.

In conclusion, the present study has objectively quantified the radiographic outcomes of treating OCLs of the talus with a juvenile particulated articular cartilage allograft. JACI of the DeNovo NT allograft and BMAC resulted in improved functional outcome scores. However, the reparative tissue still exhibited a fibrocartilage composition radiographically, as evidenced by the low percentage of surface continuity (9.1%) and homogenous structure (13.6%) on the postoperative MRI studies and the less than ideal cartilage integration (40.9%). Based on our early results, this technique has not demonstrated a significant advantage compared with other repair techniques, specifically microfracture. Further studies are needed to investigate the long-term outcomes and determine the superiority of the arthroscopic DeNovo procedure compared with microfracture and other cartilage resurfacing procedures.

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