Functional Outcomes of Arthroscopic Acetabular Labral Repair with and without Bone Marrow Aspirate Concentrate

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Background: Osteoarthritis (OA) of the hip is a debilitating condition associated with inferior outcomes in patients undergoing hip arthroscopy. To provide symptom relief and improve outcomes in these patients, bone marrow aspirate concentrate (BMAC) has been applied as an adjuvant therapy with the hope of halting progression of cartilage damage. The current study examined the clinical efficacy of BMAC application in patients undergoing arthroscopic acetabular labral repair by comparing patient-reported outcome measures (PROMs) between groups with and without BMAC application.

Methods: Patients who received BMAC during arthroscopic acetabular labral repair from December 2016 to June 2019 were compared with a control cohort that underwent the same procedure but did not receive BMAC from November 2013 to November 2016. Patients in both cohorts were asked to prospectively complete PROMs prior to surgery and at 3, 6, 12, and 24-month follow-up intervals; those who completed the PROMs at enrollment and the 12-month follow-up were included in the study. An a priori subgroup analysis was performed among patients with moderate cartilage damage (Outerbridge grade 2 or 3). The analyses were adjusted for any differences in baseline factors between groups.

Results: Sixty-two patients with BMAC application were compared with 62 control patients without BMAC application. When compared with the no-BMAC cohort, the BMAC cohort did not report significantly different mean International Hip Outcome Tool-33 (iHOT-33) scores at any postoperative time point. However, when patients with moderate cartilage damage were compared across groups, the BMAC cohort reported significantly greater mean (95% confidence interval) scores than the no-BMAC cohort at the 12-month (78.6 [72.4 to 84.8] versus 69.2 [63.3 to 75.2]; p = 0.035) and 24-month (82.5 [73.4 to 91.6] versus 69.5 [62.1 to 76.8]; p = 0.030) follow-up. Similarly, these patients reported greater score improvements at 12 months (37.3 [30.3 to 44.3] versus 25.4 [18.7 to 32.0]; p = 0.017) and 24 months (39.6 [30.4 to 48.7] versus 26.4 [19.1 to 33.8]; p = 0.029).

Conclusions: Patients with moderate cartilage injury undergoing arthroscopic acetabular labral repair with BMAC application reported significantly greater functional improvements when compared with similar patients without BMAC application.

Level of Evidence: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

Despite advances in techniques to repair acetabular labral tears, mitigating damage to acetabular cartilage and the chondrolabral junction is an ongoing challenge for orthopaedic surgeons[1,2]. Since moderate-to-severe osteoarthritis (OA) has been associated with inferior outcomes for patients undergoing hip arthroscopy[3-6], there is a great need

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJS/G751).

A **data-sharing statement** is provided with the online version of the article (http://links.lww.com/JBJS/G753).

for an innovation that could potentially provide symptom relief and improve functional outcomes in these patients. Application of bone marrow aspirate concentrate (BMAC) in conjunction with various orthopaedic surgical procedures has recently emerged as a promising option to treat OA and possibly slow the progression of chondral deterioration[7,8].

BMAC is a composed of elements isolated from bone marrow, including mesenchymal stromal cells (MSCs), bone-marrow-derived platelets, red and white blood cells, and hematopoietic precursors[9]. MSCs are the fundamental component of BMAC and have been shown in some studies to have the ability to differentiate into important cells for mitigating chondral damage[7,10,11]. Additionally, bone-marrow-derived platelets are believed to produce growth factors, cytokines, and chemokines that promote wound-healing, collagen synthesis, and suppression of pro-inflammatory cytokines[8,12]. The utilization of BMAC alongside orthopaedic surgical procedures has become a particular area of interest due to its safety and practicality when compared with ex vivo methods of culturing MSCs[8]. While obtaining a sufficient quantity of bone marrow-MSCs (BM-MSCs) remains a concern for orthopaedic surgeons performing this adjuvant procedure, hip arthroscopists should be encouraged as the body of the ilium is a safe, technically feasible harvest site with a cell concentration that is similar to or exceeds that of other harvest sites described in published studies[13].

The current literature features numerous animal studies demonstrating the positive effects of BMAC on a histologic and macroscopic level[14-16]. Nevertheless, evidence of the clinical benefit of BMAC and other orthobiologics in humans is preliminary and has been limited to lower-level studies of the knee, shoulder, and ankle[17-19]. Thus, the potential of BMAC application alongside hip arthroscopy to treat OA remains largely unknown and worthy of investigation. The current study aimed to address the absence of literature on this topic by measuring functional outcomes of patients who had undergone arthroscopic acetabular labral repair with and without BMAC application.

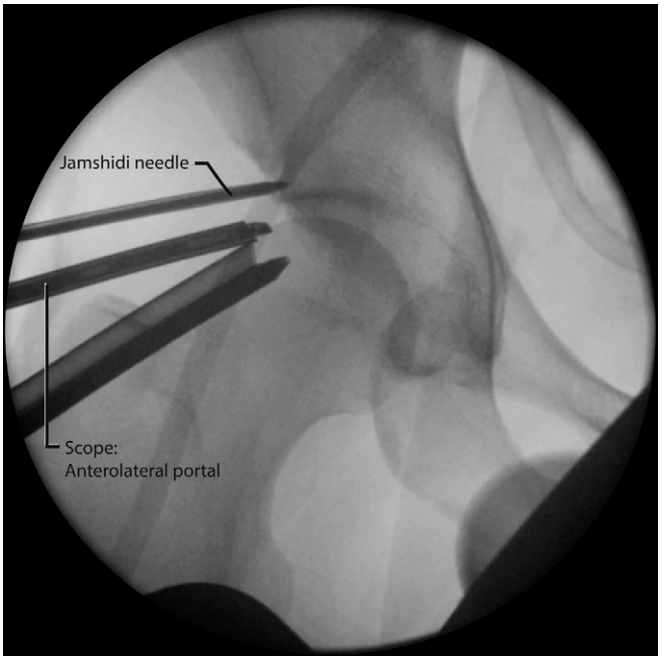

Fig. 1

The Jamshidi bone marrow aspiration needle is driven through the cortex of the ilium while the location is confirmed with fluoroscopy, as seen during this arthroscopy in the right hip. It is imperative to maintain fluoroscopic guidance throughout the harvesting process to ensure that the joint remains protected from violation.

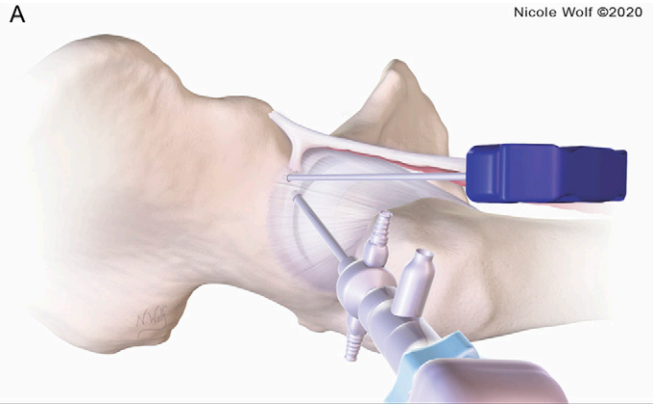

Fig. 2-A

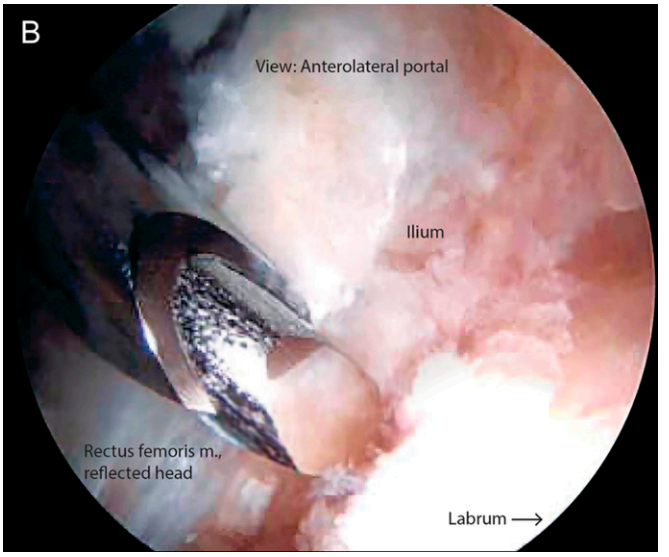

Fig. 2-B

Fig. 2-A The bone marrow needle insertion site can be identified on the ilium, approximately 1 to 2 cm proximal to the sourcil and laterally adjacent to the reflected head of the rectus femoris. (Illustration by Nicole Wolf, MS, ©2020. Published with permission. [nicolewolf@nicolewolfart.com]) **Fig. 2-B** While the surgeon is working through the Dienst portal and viewing through the anterolateral portal in the right hip, the site should be visualized intraoperatively before advancing the needle into the ilium, at which point fluoroscopic guidance can be used to ensure that the joint remains protected.

Materials and Methods

Data for this study were prospectively collected. All included patients underwent arthroscopic acetabular labral repair by

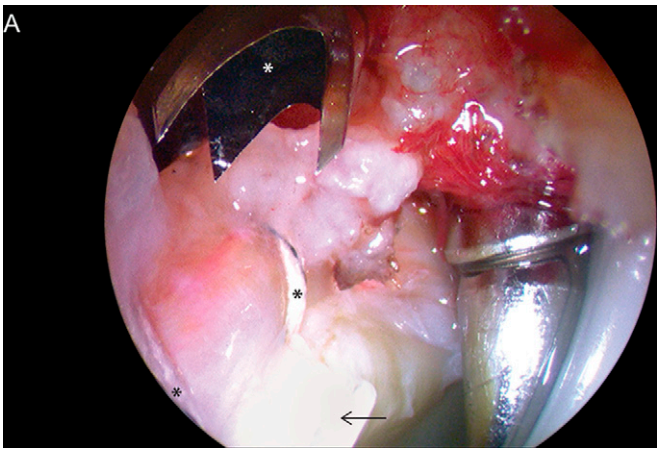

Fig. 3-A

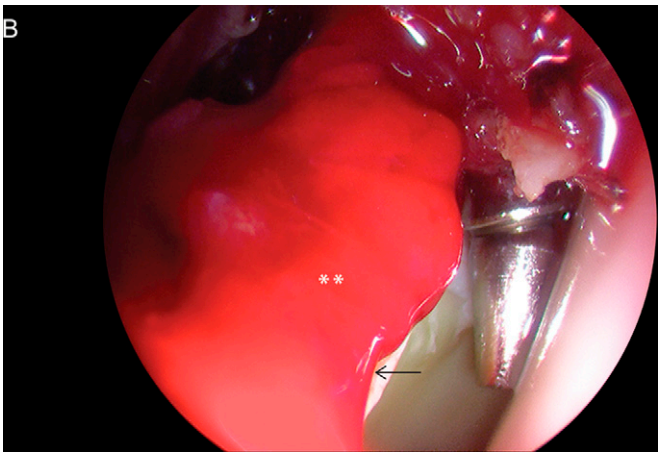

Fig. 3-B

Fig. 3-A Anterolateral view of the right hip. The Jamshidi needle (white asterisk) is positioned at the site of labral repair (black asterisks) through the Dienst portal. A chondral flap can be seen below the labral repair (black arrow). **Fig. 3-B** The megaclot (double white asterisks) is applied to the chondrolabral junction at the labral repair site (black arrow) through the Dienst portal. Slight traction is maintained to coat the chondrolabral junction.

the senior surgeon from November 2013 to June 2019 and completed patient-reported outcome measure (PROM) surveys at enrollment and the 12-month follow-up. The senior surgeon began utilizing BMAC in conjunction with hip arthroscopy in December 2016 as a potential method to improve patient outcomes, and from that point forward all patients scheduled to undergo hip arthroscopy at our practice were asked to provide informed consent preoperatively to receive BMAC. The cost associated with BMAC harvesting and application was paid for by the Conine Family Fund for Joint Preservation (a philanthropic organization without affiliations to industry); thus, patients' ability to pay played no role in whether they received BMAC. This study assessed the outcomes of the first 62 patients meeting the inclusion criteria who received BMAC (from December 2016 to June 2019) and compared them with the outcomes of the final 62 patients meeting the inclusion criteria who did not receive BMAC (from November 2013 to November 2016). There were no differences in surgical technique (other than the application of BMAC), indications, means of data collection, or rehabilitation between groups. Moreover, at the time of the surgery in the first control patient, the senior surgeon had already completed >1,000 hip arthroscopy procedures, thus mitigating any risk of expert bias[20].

All patients initially presenting to the senior author's clinic with hip pain were assessed with hip and pelvic radiographs and a thorough physical examination, including provocative testing of the labrum and evaluation for femoroacetabular impingement syndrome (FAIS)[21]. Patients with positive findings on the physical examination (i.e., pain and/or a limited range of motion in flexion, adduction, and internal rotation [FADIR] or flexion, abduction, and external rotation [FABER]) underwent magnetic resonance arthrography (MRA), diagnostic/therapeutic intra-articular anesthetic/corticosteroid injection, and a trial of at least 3 months of nonoperative therapy including core-strengthening physical therapy. Patients with persistent hip pain despite nonoperative therapy were offered hip arthroscopy.

Patients were offered enrollment into the study if they met the inclusion criteria: an age of ≥18 years and a lateral center-edge angle (LCEA) of >25° on preoperative anteroposterior radiographs of the pelvis. Patients with previous ipsilateral hip arthroscopy, labral debridement, and <1 year of follow-up were excluded from data analysis. This study was approved by the institutional review board.

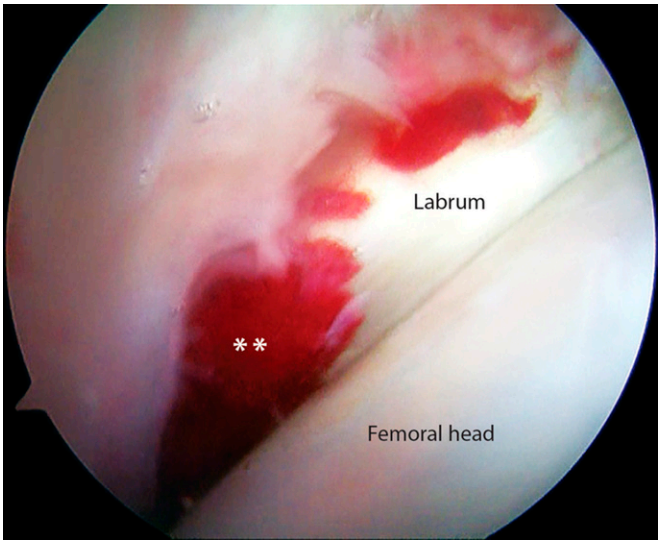

Fig. 4

Traction is released, and the labral repair site is viewed from the peripheral compartment. The hip is flexed from 0° to 45° to ensure that the megaclot (double white asterisks) remains attached to the labral repair site within the central compartment.

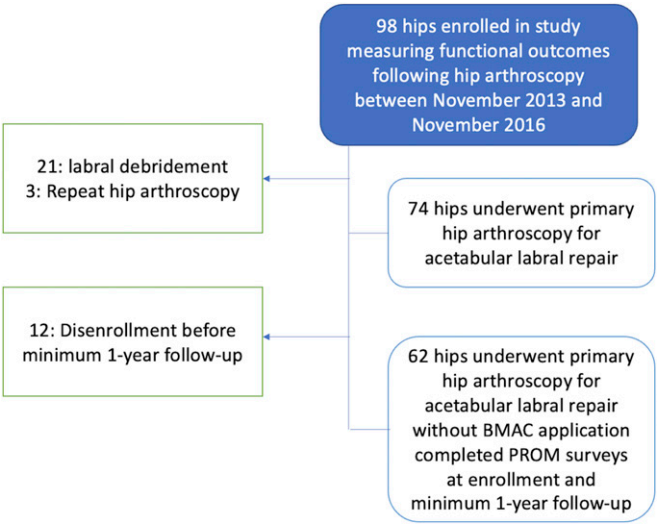

Fig. 5

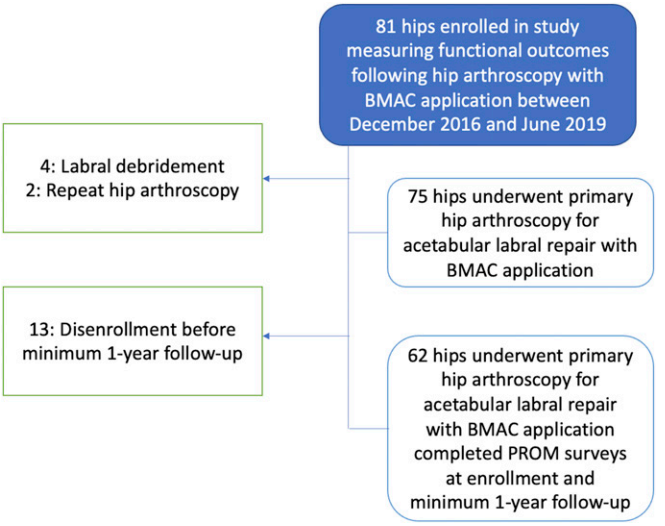

Fig. 6

Fig. 5 Flowchart detailing the inclusion of patients who underwent primary hip arthroscopy for acetabular labral repair without BMAC application (historical control cohort). **Fig. 6** Flowchart detailing the inclusion of patients who underwent primary hip arthroscopy for acetabular labral repair with BMAC application.

Data Collection

Demographic and descriptive data were collected, including age, sex, laterality, body mass index (BMI), LCEA, and alpha angle. Intraoperatively, surgical time, traction time, number of anchors, and the extent of chondral damage according to the Outerbridge classification[22] were recorded by the senior surgeon. Patients in both cohorts were asked to prospectively complete the following PROMs at enrollment prior to surgery and at 3, 6, 12, and 24 months postoperatively: the International Hip Outcome Tool-33 (iHOT-33), Hip Outcome Score-Activities of Daily Living (HOS-ADL) subscale, and Hip Outcome Score-Sports subscale (HOS-Sports). Patients were only included for data analysis if they completed PROM surveys at enrollment and at the 12-month follow-up. Adverse events secondary to the acetabular labral repair, treatment of femoroacetabular impingement, and procedures for BMAC harvesting and application were prospectively collected. Based on an a priori hypothesis that BMAC would be most beneficial for patients with moderate OA (Outerbridge grade 2 or 3), we performed a subgroup analysis to investigate the potential effects of BMAC in such patients. This subgroup analysis was specified prior to data analysis based on previous studies demonstrating the utility (or lack thereof) of orthobiologics across different levels of OA[23-26].

Surgical Technique and BMAC Process

All operations were performed with the patient in the supine position on a hip distraction table (Smith & Nephew) and under general anesthesia. Once adequate intra-articular visualization of the lesion is established, BMAC is applied as described in a previous technical note[27] in conjunction with acetabular labral repair using a chondrolabral junction-preservation technique with intermittent traction[1,28,29].

A Jamshidi bone marrow biopsy needle (Becton, Dickinson and Company) is placed through the Dienst portal, just lateral to the reflected head of the rectus. With fluoroscopic guidance (Fig. 1), aspiration should be performed just above the sourcil (Figs. 2-A and 2-B). This location provides access to the ilium above the sourcil. If the

TABLE I Baseline Patient Demographic Information*

	BMAC	No BMAC	P Value
No.	62	62	
Age† *(yr)*	35.2 (32.9, 37.6)	38.6 (35.3, 41.9)	0.106
BMI† *(kg/m²)*	25.5 (24.5, 26.5)	25.3 (24.3, 26.4)	0.764
Sex *(no. [%])*			0.007‡
Female	23 (37%)	37 (60%)	
Male	39 (63%)	25 (40%)	
Laterality *(no. [%])*			0.281
Left	27 (44%)	34 (55%)	
Right	35 (56%)	28 (45%)	
Labral tear on MRI *(no. [%])*			1.000
Yes	62 (100%)	62 (100%)	
No	0 (0%)	0 (0%)	
LCEA† *(°)*	37.1 (35.7, 38.5)	36.8 (35.6, 38.0)	0.756
Alpha angle† *(°)*	59.0 (55.5, 62.4)	53.4 (50.4, 56.5)	0.020‡

*BMAC = bone marrow aspirate concentrate, BMI = body mass index, MRI = magnetic resonance imaging, and LCEA = lateral center-edge angle. †The values are reported as the mean (95% CI). ‡A significant difference between groups.

TABLE II Intraoperative Findings and Procedures Recorded*

	BMAC	No BMAC	P Value
No.	62	62	
Surgical details†			
Surgical time *(min)*	128.7 (122.3, 135.1)	103.8 (93.3, 114.3)	0.000‡
Time under traction *(min)*	75.5 (73.6, 77.4)	72.7 (70.4, 75.1)	0.080
No. of anchors used during labral repair	2.7 (2.6, 2.9)	2.5 (2.3, 2.7)	0.095
Outerbridge grade *(no. [%])*			0.217
0	2 (3%)	0 (0%)	
I	3 (5%)	3 (5%)	
2	15 (24%)	23 (37%)	
3	31 (50%)	29 (47%)	
4	11 (18%)	7 (11%)	
Procedures *(no. [%])*			
Labral repair	62 (100%)	62 (100%)	1.000
Acetabuloplasty	52 (84%)	44 (71%)	0.086
Femoroplasty	35 (56%)	24 (39%)	0.048‡
Subspinous impingement decompression	2 (3%)	0 (0%)	0.154
Removal of loose body	0 (0%)	2 (3%)	0.154
Debridement of chondrocalcinosis	0 (0%)	1 (2%)	0.315
Postoperative LCEA† *(°)*	34.3 (32.4, 36.2)	33.7 (32.3, 35.0)	0.600
Postoperative alpha angle† *(°)*	49.4 (47.0, 51.8)	48.8 (46.2, 51.4)	0.736

*BMAC = bone marrow aspirate concentrate and LCEA = lateral center-edge angle. †The values are reported as the mean (95% CI). ‡A significant difference between groups.

sourcil is exceedingly convex, a central anterior portal may be established to ensure that the hip joint is not violated during aspiration. This harvest site is ideal since it is technically feasible during hip arthroscopy, allows an adequate amount of aspirate to be obtained, and has a density of MSCs that is equal to or higher than that in other possible aspiration sites[13].

While the bone marrow is extracted, 51 mL of whole venous blood is drawn into a 60-mL syringe and combined

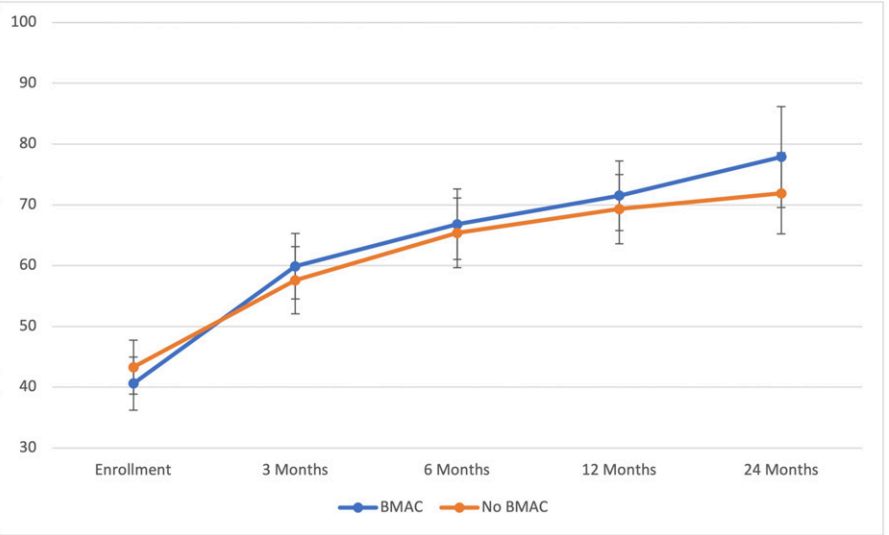

Fig. 7

Mean iHOT-33 scores (and 95% confidence intervals) over time for patients who did and did not undergo BMAC application.

TABLE III Mean PROM Scores*

	BMAC			No BMAC			P Value	
	No.	Mean†	Improvement†	No.	Mean†	Improvement†	Mean	Improvement
Enrollment								
No.	62			62				
iHOT-33		40.6 (36.3, 45.0)			43.3 (38.8, 47.7)		0.404	
HOS-ADL		68.3 (63.6, 73.0)			75.6 (70.9, 80.4)		0.034‡	
HOS-Sports		40.4 (34.5, 46.4)			50.1 (44.0, 56.2)		0.030‡	
3 months								
No.	50			48				
iHOT-33		59.9 (54.5, 65.3)	19.8 (13.8, 25.8)		57.6 (52.1, 63.1)	15.4 (9.4, 21.5)	0.566	0.316
HOS-ADL		79.4 (74.8, 84.0)	11.5 (5.9, 17.1)		78.3 (73.8, 82.8)	3.4 (−2.1, 8.9)	0.745	0.047‡
HOS-Sports		39.9 (31.5, 48.3)	0.5 (−7.7, 8.7)		40.0 (31.7, 48.3)	−7.1 (−15.2, 1.0)	0.990	0.203
6 months								
No.	51			49				
iHOT-33		66.8 (61.0, 72.5)	25.6 (18.8, 32.5)		65.4 (59.7, 71.0)	22.8 (16.0, 29.6)	0.731	0.565
HOS-ADL		85.9 (82.0, 89.8)	15.5 (10.0, 21.0)		83.0 (79.2, 86.9)	7.8 (2.3, 13.4)	0.305	0.057
HOS-Sports		58.0 (49.6, 66.4)	14.5 (5.5, 23.6)		57.7 (49.3, 66.2)	9.6 (0.5, 18.7)	0.963	0.451
12 months								
No.	62			62				
iHOT-33		71.5 (65.8, 77.2)	30.9 (24.7, 37.1)		69.3 (63.6, 75.1)	26.1 (19.8, 32.3)	0.600	0.287
HOS-ADL		88.8 (85.1, 92.5)	20.9 (16.0, 25.7)		86.0 (82.3, 89.8)	10.4 (5.4, 15.3)	0.302	0.004‡
HOS-Sports		68.7 (61.4, 76.0)	29.1 (21.2, 37.1)		68.0 (60.7, 75.2)	17.8 (9.9, 25.7)	0.890	0.051
24 months								
No.	28			44				
iHOT-33		77.9 (69.6, 86.2)	33.9 (25.2, 42.5)		71.9 (65.2, 78.5)	30.2 (23.3, 37.1)	0.261	0.509
HOS-ADL		91.3 (86.6, 96.1)	22.6 (16.0, 29.2)		88.0 (84.2, 91.8)	14.1 (8.8, 19.4)	0.285	0.048‡
HOS-Sports		77.1 (67.6, 86.6)	33.7 (23.5, 43.9)		72.4 (64.7, 80.1)	26.3 (18.1, 34.6)	0.444	0.264

*Adjusted for baseline differences in sex, alpha angle, and whether a femoroplasty had been performed. PROM = patient-reported outcome measure, BMAC = bone marrow aspirate concentrate, iHOT-33 = International Hip Outcome Tool-33, HOS-ADL = Hip Outcome Score-Activities of Daily Living subscale, and HOS-Sports = Hip Outcome Score-Sports Subscale. †The values are reported as the mean (95% CI). ‡A significant difference between groups.

with 8 mL of normal saline solution and 1 mL of anticoagulant citrate dextrose solution A (ACD-A), which is centrifuged (Arthrex), yielding 16 mL of platelet-poor plasma (PPP) and 4 mL of platelet-rich plasma (PRP). The PPP and PRP are then combined to form a 20-mL PPP/PRP mixture. To prevent dilution of the whole venous blood, the blood should be drawn through an intravenous access site separate from the line used for fluids and medication throughout the procedure. Approximately 120 mL of bone marrow aspirate is obtained and then centrifuged to yield approximately 4 mL of BMAC. To prevent extended traction and surgical time, bone marrow harvesting is performed without traction and centrifugation of the bone marrow is performed simultaneously with the final stages of the surgery[27]. The 20-mL PPP/PRP mixture and 4 mL of BMAC are combined with thrombin to generate a megaclot, which is then applied to the central compartment of the hip (Figs. 3-A and 3-B) and the labral repair site through an anterolateral portal with slight traction. Once traction is released, the megaclot and repair site are visualized while the hip is flexed from 0° to 45° to ensure that the megaclot remains within the central compartment (Fig. 4).

Postoperative Rehabilitation

Patients in both cohorts followed the same postoperative protocol. They were allowed immediate weight-bearing as tolerated using a flat-footed gait with crutches for 6 weeks postoperatively, after which they could start using a stationary bicycle. At 10 weeks, they were allowed to swim or use an elliptical trainer. At 4 months, strengthening exercises including hamstring curls and short-arc leg presses with low weight and "high reps" (a high number of repetitions) were encouraged. At 6 months, the patients were permitted to resume impact-loading exercises as tolerated.

TABLE IV Baseline Patient Demographic Information for Patients with Moderate (Outerbridge Grade-2 or 3) Osteoarthritis*

	BMAC	No BMAC	P Value
No.	46	52	
Age† *(yr)*	34.2 (31.5, 37.0)	37.3 (33.9, 40.8)	0.172
BMI† *(kg/m²)*	25.6 (24.4, 26.8)	25.4 (24.3, 26.5)	0.813
Sex *(no. [%])*			0.014‡
Female	16 (35%)	31 (60%)	
Male	30 (65%)	21 (40%)	
Laterality *(no. [%])*			0.404
Left	20 (43%)	27 (52%)	
Right	26 (57%)	25 (48%)	
Labral tear on MRI *(no. [%])*			1
Yes	46 (100%)	52 (100%)	
No	0 (0%)	0 (0%)	
LCEA† *(°)*	37.4 (35.7, 39.1)	37.3 (36.0, 38.6)	0.927
Alpha angle† *(°)*	58.7 (54.5, 62.8)	54.6 (51.4, 57.8)	0.138

*BMAC = bone marrow aspirate concentrate, BMI = body mass index, MRI = magnetic resonance imaging, and LCEA = lateral center-edge angle. †The values are reported as the mean (95% CI). ‡A significant difference between groups.

Statistical Analysis

Baseline patient factors were compared between the groups using t tests or chi-square/Fisher exact tests, as appropriate. Differences between groups in PROMs at enrollment and 3, 6, 12, and 24 months and PROM improvements at 3, 6, 12, and 24 months were assessed while adjusting for differences in baseline factors (i.e., sex, alpha angle, and whether a femoroplasty had been performed) using multivariate regressions. For our subgroup analysis of patients with moderate OA, we built a model including the aforementioned covariates along with OA severity, BMAC, and OA severity × BMAC interaction. Independent-sample t tests were used for unadjusted analyses (see Appendix). Statistical analyses were performed using SAS, version 9.4 (SAS Institute) or SPSS, version 26.0.0 (IBM SPSS Statistics). $P < 0.05$ was considered significant.

Source of Funding

The Conine Family Fund for Joint Preservation provided funding for this study.

Results

Sixty-two hips with BMAC application and 62 without BMAC application were included in this study (Figs. 5 and 6). The groups were compared with regard to preoperative demographics, including age (BMAC: mean = 35.2 years [95% confidence interval (CI) = 32.9 to 37.6] versus no BMAC: 38.6 [35.3 to

TABLE V Intraoperative Findings and Procedures Recorded for Patients with Moderate (Outerbridge Grade-2 or 3) Osteoarthritis*

	BMAC	No BMAC	P Value
No.	46	52	
Surgical details†			
Surgical time *(min)*	128.8 (120.7, 136.9)	103.9 (92.7, 115.1)	0.001‡
Time under traction *(min)*	76.0 (73.9, 78.1)	72.9 (70.5, 75.3)	0.065
No. of anchors used during labral repair	2.7 (2.5, 2.9)	2.6 (2.4, 2.8)	0.430
Outerbridge grade *(no. [%])*			0.239
2	15 (32.6%)	23 (44%)	
3	31 (67%)	29 (56%)	
Procedures *(no. [%])*			
Labral repair	46 (100%)	52 (100%)	1.000
Acetabuloplasty	39 (89%)	39 (75%)	0.230
Femoroplasty	23 (50%)	21 (40%)	0.340
Subspinous impingement decompression	2 (4%)	0 (0%)	0.129
Removal of loose body	0 (0%)	2 (4%)	0.179
Debridement of chondrocalcinosis	0 (0%)	1 (2%)	0.344
Postoperative LCEA† *(°)*	35.0 (32.7, 37.3)	34.2 (32.7, 35.7)	0.611
Postoperative alpha angle† *(°)*	48.9 (46.0, 51.8)	49.9 (47.6, 52.2)	0.608

*BMAC = bone marrow aspirate concentrate and LCEA = lateral center-edge angle. †The values are reported as the mean (95% CI). ‡A significant difference between groups.

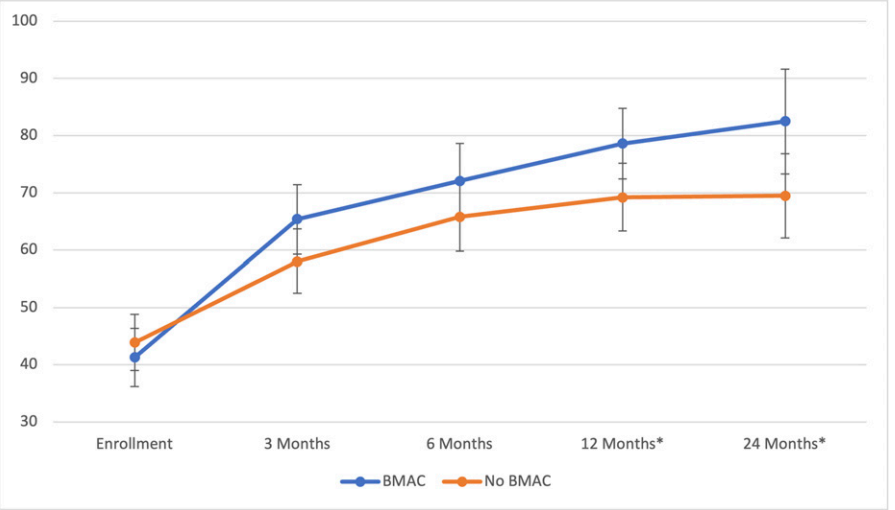

Fig. 8

Mean iHOT-33 scores (and standard deviations) over time for patients with Outerbridge grade 2 or 3 who did and did not undergo BMAC application. *P < 0.05.

41.9]; p = 0.106), BMI (mean = 25.5 kg/m^2 [95% CI = 24.5 to 26.5] versus 25.3 [24.3 to 26.4]; p = 0.764), sex (female: 23 [37%], male: 39 [63%] versus female: 37 [60%], male: 25 [40%]; p = 0.007), laterality (left: 27 [44%], right: 35 [56%] versus left: 34 [55%], right: 28 [45%]; p = 0.281), LCEA (mean = 37.1° [95% CI = 35.7° to 38.5°] versus 36.8° [35.6° to 38.0°]; p = 0.756), and alpha angle (mean = 59.0° [95% CI = 55.5° to 62.4°] versus 53.4° [50.4° to 56.5°]; p = 0.020) (Table I).

Intraoperative and postoperative findings included surgical time (BMAC: mean = 128.7 minutes [95% CI = 122.3 to 135.1] versus no BMAC: 103.8 minutes [93.3 to 114.3]; p = 0.000), time under traction (mean = 75.5 minutes [95% CI = 73.6 to 77.4] versus 72.7 [70.4 to 75.1]; p = 0.080), number of anchors used during labral repair (mean = 2.7 [95% CI = 2.6 to 2.9] versus 2.5 [2.3 to 2.7]; p = 0.095), Outerbridge grade (grade 0: 2 patients [3%], grade 1: 3 [5%], grade 2: 15 [24%], grade 3: 31 [50%], grade 4: 11 [18%] versus grade 0: 0 [0%], grade 1: 3 [5%], grade 2: 23 [37%], grade 3: 29 [47%], grade 4: 7 [11%]; p = 0.217), postoperative LCEA (mean = 34.3° [95% CI = 32.4° to 36.2°] versus 33.7° [32.3° to 35.0°]; p = 0.600), and postoperative alpha angle (mean = 49.4° [95% CI = 47.0° to 51.8°] versus 48.8° [46.2° to 51.4°]; p = 0.736). In terms of procedures, the number of patients who underwent femoroplasty (BMAC: 35 [56%] versus no BMAC: 24 [39%]; p = 0.048) was the only significant difference between groups (Table II).

In the adjusted analysis, patients treated with and without BMAC had similar mean baseline iHOT-33 scores (40.6 [95% CI = 36.3 to 45.0] versus 43.3 [38.8 to 47.7]; p = 0.404). Similarly, the BMAC and no-BMAC cohorts had similar mean iHOT-33 scores at 3 months (59.9 [54.5 to 65.3] versus 57.6 [52.1 to 63.1]; p = 0.566), 6 months (66.8 [61.0 to 72.5] versus 65.4 [59.7 to 71.0]; p = 0.731), 12 months (71.5 [65.8 to 77.2] versus 69.3 [63.6 to 75.1]; p = 0.600), and 24 months (77.9 [69.6 to 86.2] versus 71.9 [65.2 to 78.5]; p = 0.261) (Fig. 7). Likewise, the mean HOS-ADL and HOS-Sports scores did not differ significantly between groups at any postoperative follow-up time point (Table III). In terms of improvement in the mean scores, the only outcome to significantly differ between groups was the HOS-ADL score, which was higher in the BMAC group at the 3-month (mean = 11.5 [95% CI = 5.9 to 17.1] versus 3.4 [−2.1 to 8.9]; p = 0.047), 12-month (20.9 [16.0 to 25.7] versus 10.4 [5.4 to 15.3]; p = 0.004), and 24-month (22.6 [16.0 to 29.2] versus 14.1 [8.8 to 19.4]; p = 0.048) follow-up intervals (Table III).

The interaction analysis revealed that the improvements associated with the use of BMAC differed significantly as a function of OA severity ($p_{interaction}$ = 0.025). In the adjusted subgroup analysis of patients with moderate hip OA (Outerbridge grade 2 or 3), 46 patients (15 with grade 2 and 31 with grade 3) in the BMAC cohort were compared with 52 control patients (23 with grade 2 and 29 with grade 3). The preoperative demographics and intraoperative findings/procedures in these subgroups are reported in Table IV and Table V, respectively. Among the patients included in the subgroup analysis, the mean iHOT-33 scores were comparable at enrollment (BMAC: mean = 41.3 [95% CI = 36.2 to 46.4] versus no BMAC: 43.9 [39.0 to 48.8]; p = 0.468). However, the BMAC cohort reported significantly higher mean iHOT-33 scores than the no-BMAC cohort at 12 months (78.6 [72.4 to 84.8] versus 69.2 [63.3 to 75.2]; p = 0.035) and 24 months (82.5 [73.4 to 91.6] versus 69.5 [62.1 to 76.8]; p = 0.030) (Fig. 8). The BMAC cohort experienced significantly greater improvements in all PROMs from baseline to the 12-month and 24-month follow-up intervals when compared with the no-BMAC group (Table VI).

Among the 62 patients in the prospective BMAC cohort, 2 (3%) had evidence of heterotopic ossification and 1 (2%) experienced pudendal neuralgia immediately following surgery, which resolved within 1 month. Among the 62 patients in the historical control cohort, 3 (5%) had evidence of heterotopic ossification.

TABLE VI Mean PROM Scores for Patients with Moderate (Outerbridge Grade-2 or 3) Osteoarthritis*

	BMAC			No BMAC			P Value	
	No.	Mean†	Improvement†	No.	Mean†	Improvement†	Mean	Improvement
Enrollment								
No.	46			52				
iHOT-33		41.3 (36.2, 46.4)			43.9 (39.0, 48.8)		0.468	
HOS-ADL		67.4 (61.9, 72.9)			76.2 (70.9, 81.4)		0.026‡	
HOS-Sports		39.1 (32.2, 46.1)			51.0 (44.4, 57.7)		0.017‡	
3 months								
No.	37			39				
iHOT-33		65.4 (59.3, 71.4)	23.6 (16.6, 30.5)		58.0 (52.2, 63.7)	14.7 (8.1, 21.4)	0.084	0.075
HOS-ADL		83.2 (78.2, 88.4)	15.2 (9.0, 21.5)		76.5 (71.9, 81.1)	0.4 (−5.2, 6.1)	0.057	0.001‡
HOS-Sports		44.1 (34.3, 53.8)	3.8 (−5.4, 13.2)		39.6 (30.7, 48.5)	−9.5 (−18.1, −0.7)	0.508	0.041‡
6 months								
No.	37			41				
iHOT-33		72.1 (65.5, 78.6)	30.6 (22.6, 38.6)		65.8 (59.8, 71.9)	22.2 (14.9, 29.6)	0.172	0.130
HOS-ADL		88.2 (83.7, 92.8)	18.8 (12.3, 25.3)		82.7 (78.6, 86.9)	6.6 (0.7, 12.5)	0.079	0.007‡
HOS-Sports		62.7 (52.6, 72.7)	20.1 (9.4, 30.7)		57.5 (48.3, 66.7)	7.5 (−2.2, 17.2)	0.454	0.086
12 months								
No.	46			52				
iHOT-33		78.6 (72.4, 84.8)	37.3 (30.3, 44.3)		69.2 (63.3, 75.2)	25.4 (18.7, 32.0)	0.035‡	0.017‡
HOS-ADL		92.6 (88.6, 96.7)	25.6 (20.2, 31.0)		84.5 (80.7, 88.4)	8.3 (3.2, 13.5)	0.005‡	<0.001‡
HOS-Sports		76.0 (68.1, 83.9)	37.3 (28.9, 45.7)		63.8 (56.4, 71.2)	12.7 (4.8, 20.5)	0.028‡	<0.001‡
24 months				33				
No.	22							
iHOT-33		82.5 (73.4, 91.6)	39.6 (30.4, 48.7)		69.5 (62.1, 76.8)	26.4 (19.1, 33.8)	0.030‡	0.029‡
HOS-ADL		92.2 (87.0, 97.4)	25.8 (18.6, 33.0)		85.8 (81.5, 90.2)	11.6 (5.6, 17.5)	0.066	0.004‡
HOS-Sports		79.0 (68.8, 89.2)	38.8 (27.8, 49.8)		67.2 (58.8, 75.6)	21.1 (12.0, 30.2)	0.078	0.016‡

*Adjusted for baseline differences in sex, alpha angle, and whether a femoroplasty had been performed. PROM = patient-reported outcome measure, BMAC = bone marrow aspirate concentrate, iHOT-33 = International Hip Outcome Tool-33, HOS-ADL = Hip Outcome Score-Activities of Daily Living subscale, and HOS-Sports = Hip Outcome Score-Sports Subscale. †The values are reported as the mean (95% CI). ‡A significant difference between groups.

Discussion

In the current study, when compared with the control cohort, patients treated with BMAC did not experience significantly different postoperative mean PROM scores. Critically, however, patients with Outerbridge grade-2 or 3 OA reported significantly greater improvements in all PROMs at the 12-month and 24-month follow-up intervals. Moreover, patients with Outerbridge grade-2 or 3 cartilage damage in the BMAC cohort outperformed their no-BMAC counterparts by 13.2 points in terms of iHOT-33 score improvement at the 24-month follow-up, which accounts for nearly 1 full minimal clinically important difference (MCID) in the score (13.9) as defined by Nwachukwu et al.[30]. These results have important clinical implications, as adjuvant BMAC application alongside hip arthroscopy seems to provide a benefit for selected patients with moderate OA, who historically have had inferior outcomes following hip arthroscopy[31-34].

The current study adds to the growing body of literature addressing the utilization of BMAC and other novel orthobiologics in the setting of hip arthroscopy. Rivera et al.[35] conducted a similar study with comparable cohorts, but with a smaller sample size and no subgroup analysis to determine which patients experienced the greatest benefit from adjuvant BMAC application. Furthermore, Rivera et al.[35] did not report on the safety or details of the adjuvant procedure. The current study reinforces the safety of BMAC harvesting and application since rates of adverse events were similar between the 2 groups and consistent with reported rates of adverse events in the current literature[36,37].

The line of demarcation of the Outerbridge grade used in this study is clinically relevant since long-term studies have found that patients with a grade of ≥2 have worse outcomes when compared with patients with a grade of ≤1[31]. Moreover, BMAC application would likely be redundant in patients with minimal OA (Outerbridge grade 0 or 1) since these patients have historically excellent outcomes without any adjuvant orthobiologic therapy or secondary procedures[38]. Comparably, BMAC is unlikely to provide a

benefit for patients with exposed subchondral bone[32-34], as the current literature has reported conflicting evidence with respect to the ability of cells within BMAC to undergo chondrogenesis to fill extensive full-thickness defects[7,8,18,39]. It is more likely that the MSCs within BMAC are responsible for stimulating a more robust cartilage repair tissue response, which may halt the progression of moderate OA over time[8,10,18]. Thus, assuming that the patient's signed surgical consent includes use of BMAC and that the materials are available in the operating room, it is reasonable for surgeons to make the decision to utilize BMAC at the time of hip arthroscopy upon direct visualization of the articular cartilage, as preoperative imaging may be an imperfect tool for detecting which patients have moderate OA[40,41].

While this study has several strengths, including its large sample of patients undergoing BMAC treatment alongside hip arthroscopy, prospective collection of outcome measures, and utilization of a similar historical control cohort for comparison, it is not without limitations. First, while the surgeon was highly experienced at hip arthroscopy at the time that the first control patient was treated and there were no other differences in surgical technique, indication, or rehabilitation between cohorts, as with any nonrandomized study, unobserved confounders may have contributed to the results. However, the senior surgeon's practice reached a volume of at least 1,000 hip arthroscopies between 2002 and 2013, which mitigates expert bias between cohorts[20]. Second, as is the case with questionnaire studies, loss to follow-up and selection bias for patients who chose to enroll in the survey collection process are potential sources of bias. However, this bias should not have differed between the groups as the methods of enrollment and survey collection did not change since the inception of the historical cohort in 2013. Third, while the cohorts differed in baseline characteristics such as sex, alpha angle, and the number of patients who underwent femoroplasty, we performed multivariate regressions adjusting for these variables and used those results for our primary and subgroup analyses. Moreover, since BMAC was paid for by a philanthropy organization without affiliations with industry, differences in socioeconomic status between groups were not a confounding factor. Fourth, it is possible that the placebo effect contributed to some of the additional improvement seen in the BMAC group, as the patients and provider were not blinded to the fact that BMAC harvesting and application were performed during the hip arthroscopy. However, such an effect should have applied equally across the Outerbridge grades of OA severity. Also, since the differences between groups seen in this study were primarily limited to the patients for whom improvement from BMAC is most biologically plausible (i.e., those with moderate cartilage damage), this appears less likely. Finally, since BMAC application to the hip is a novel procedure, our patient outcomes are currently limited to mid-term follow-up. Long-term studies examining the efficacy and safety of BMAC application in the hip must be implemented before drawing definitive conclusions.

Conclusions

Patients with moderate cartilage injury undergoing arthroscopic acetabular labral repair with BMAC application reported significantly greater functional improvements at 3, 6, 12, and 24-month follow-up intervals when compared with similar patients without BMAC application and experienced no adverse events secondary to the additional procedure. These findings are preliminary and future randomized controlled trials examining the long-term functional benefits of BMAC application in the setting of hip arthroscopy are needed.

Appendix

eA Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJS/G752). ■

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