Long-term Clinical Outcomes After Microfracture of the Glenohumeral Joint

Average 10-Year Follow-up

Kevin C. Wang,* BS, Rachel M. Frank,[†] MD, Eric J. Cotter,[‡] BS, Annabelle Davey,[†] BS,
Maximilian A. Meyer,[†] MD, Charles P. Hannon,[†] MD, Timothy Leroux,[†] MD,
Anthony A. Romeo,[†] MD, and Brian J. Cole,[†§] MD, MBA
Investigation performed at Rush University Medical Center, Chicago, Illinois, USA

Background: Microfracture is an effective surgical treatment for full-thickness cartilage defects of the knee; however, little is known regarding long-term outcomes after microfracture in the shoulder.

Purpose: To present long-term clinical outcomes of patients undergoing microfracture of full-thickness articular cartilage defects of the glenohumeral joint.

Study Design: Case series; Level of evidence, 4.

Methods: Sixteen consecutive patients (17 shoulders) were retrospectively reviewed who underwent arthroscopic microfracture of the humeral head and/or glenoid surface, with or without additional procedures between 2001 and 2008 and with a minimum follow-up of 8.5 years. All patients completed pre- and postoperative surveys containing the visual analog scale, American Shoulder and Elbow Surgeons form, and Simple Shoulder Test. Complications and reoperations were analyzed. Failure was defined by biological resurfacing or conversion to arthroplasty.

Results: Of the original 16 patients (17 shoulders), 13 patients (14 shoulders) were available for mean follow-up at 10.2 ± 1.8 years after microfracture (range, 8.5-15.8 years), for an overall clinical follow-up rate of 82%. The patients (6 men, 7 women) were 36.1 ± 12.9 years old at time of microfracture. The average size of humeral head defects was 5.20 cm² (range, 4.0-7.84 cm²), and the average size of glenoid defects was 1.53 cm² (range, 1.0-3.75 cm²). Four patients (4 shoulders) underwent at least 1 reoperation, and 3 were considered structural failures. The average time to failure was 3.7 years after microfracture (range, 0.2-9.6 years). The overall survival rate was 76.6% at 9.6 years. For these patients, there were statistically significant improvements in visual analog scale, Simple Shoulder Test, and American Shoulder and Elbow Surgeons scores as compared with preoperative values at long-term follow-up ($P < .05$ for all), without any significant change from short-term (mean, 2.3 years) to long-term (mean, 10.2 years) follow-up. There was no significant difference in Single Assessment Numeric Evaluation or Short Form–12 Physical or Mental scores between short- and long-term follow-up. When compared with short-term follow-up, in which 2 patients had already failed, 1 additional patient progressed to failure at 9.6 years after the original microfracture. Two patients (2 shoulders) were considered clinical failures. Owing to the overall number of failures (3 structural failure and 2 clinical failure), the total long-term success rate of glenohumeral microfracture is 66.7% in the current study.

Conclusion: Treating full-thickness symptomatic chondral defects of the glenohumeral joint with microfracture can result in long-term improved function and reduced pain for some patients. However, in this case series, 21.4% of patients required conversion to arthroplasty <10 years after the index microfracture procedure, and 33% to 42% of patients were considered potential clinical failures. Additional studies with larger patient cohorts are needed.

Keywords: microfracture; glenohumeral; cartilage; long term

Cartilage defects of the glenohumeral joint can be a common source of shoulder pain and dysfunction. While the incidence of symptomatic chondral defects of the glenohumeral joint has not been established, the prevalence of

chondral defects encountered incidentally on diagnostic arthroscopy has been reported as ranging between 5% and 17%.[1,10,21] Similarly, while the origin of these defects is not fully understood, a variety of potential causative factors have been identified, including previous surgery, trauma, instability, osteonecrosis, infection, chondrolysis, osteochondritis dissecans, inflammatory arthritis, avascular necrosis, rotator cuff arthropathy, and osteoarthritis.[6,25] Regardless of origin, glenohumeral cartilage defects that

result in debilitating shoulder pain and disability often require operative management, with surgical options ranging from minimally invasive arthroscopic techniques to shoulder arthroplasty.[27]

Marrow stimulation surgery, including microfracture, has been identified as a promising potential alternative to arthroplasty in a younger patient population.[9,27] Microfracture surgery has been used with success in the knee and ankle, and long-term outcomes of this procedure have been reported in both these joints.[22,23,31] This technique has been established as an effective first-line option for isolated full-thickness cartilage defects, given its technical ease and low overall complication rate.[9,27,31] Multiple investigations have reported on the use of microfracture in the management of glenohumeral cartilage lesions.[9,18-20,27,30] Specifically, Frank et al[6] reported significant improvements in pain relief and shoulder function, with an overall 80% success rate at early clinical follow-up (average, 27.8 months). Unfortunately, there are relatively few data on long-term clinical outcomes after glenohumeral microfracture.[13,24] Recent reviews have raised concerns about the long-term durability of microfracture in other joints, and it is important to characterize these outcomes for the glenohumeral joint.[7,13-15]

Long-term outcomes after microfracture of the glenohumeral joint are unclear. The purpose of this study is to provide updated long-term clinical follow-up on a previously reported cohort of patients who underwent microfracture for symptomatic articular cartilage defects of the glenohumeral joint.[9] The hypothesis was that treatment of articular cartilage defects in the glenohumeral joint through microfracture would result in durable improvement at long-term follow-up, with a small percentage of patients progressing to biological resurfacing or arthroplasty.

METHODS

Following approval from our university's institutional review board (No. 16031504), information on the patient cohort from our previous publication,[9] on short-term clinical outcomes (mean, 27.8 months; range, 12.1-89.2 months) after glenohumeral joint microfracture, was obtained and reviewed. This patient cohort was established through retrospective review of the medical records of 4 senior shoulder surgeons at our institution between March 2001 and August 2007. No Current Procedural Terminology code for glenohumeral microfracture existed at that time; therefore, medical records were searched via arthroscopic glenohumeral joint debridement codes (29822 and 29823), as these had been used by the senior surgeons in cases where microfracture was performed, with individual operative reports reviewed to determine if microfracture of the glenoid and/or humeral head was performed. Inclusion and exclusion criteria, preoperative diagnosis, intraoperative findings, concomitant procedures, and demographic information were obtained from the data collection of the previous publication.

Patients were considered for surgery after failing attempts at nonoperative management. The indication for microfracture was the presence of a high-grade chondral lesion of the glenoid or humeral head surface in a younger active patient presenting with a complaint of activity-related pain deep inside the shoulder unlikely to be primarily attributable to another injury (labral tear or rotator cuff tear). Additional suspected pain generators (long head of the biceps tendon, subacromial impingement, loose body, or capsular adhesion) were addressed concomitantly per the clinical presentation and intraoperative findings. The presence of joint effusion and mechanical symptoms, such as locking or catching, supported the decision to proceed with microfracture. Given the paucity of literature on the subject, an upper size limit for the defects was not defined in our indications.

Sixteen consecutive patients (17 shoulders) who underwent arthroscopic microfracture of the humeral head and/or glenoid surface were deemed eligible for inclusion with a minimum follow-up of 8 years. One patient received microfracture surgery to the right and left shoulders. All patients from the original short-term follow-up study were included in this investigation, including the 2 patients (2 shoulders) who were lost to follow-up in the original study.[9] One patient (1 shoulder) declined to participate in the original short-term outcomes study and was not contacted for long-term follow-up.

All patients were contacted by telephone, standard mail, and/or email. Each patient received no less than 5 contact attempts spanning multiple modalities over a 3-month period. If there was no response after a minimum of 5 attempts at contact, that patient was considered lost to follow-up. Of the 15 patients (16 shoulders) who were contacted for follow-up, 1 patient declined to participate in the study, and 1 patient could not be reached. Thirteen patients (14 shoulders) were included in the study for an overall clinical follow-up rate of 82% (Figure 1).

Patients who consented to participate were administered patient-reported outcome (PRO) surveys. Visual analog score (VAS), Single Assessment Numeric Evaluation (SANE), subsequent surgery, and willingness to undergo

§Address correspondence to Brian J. Cole, MD, MBA, Department of Orthopaedics, Rush University Medical Center, Midwest Orthopaedics, 1611 West Harrison St, Suite 300, Chicago, IL 60612, USA (email: bcole@rushortho.com).
*Feinberg School of Medicine, Northwestern University, Chicago, Illinois, USA
†Department of Orthopaedics, Rush University Medical Center, Chicago, Illinois, USA
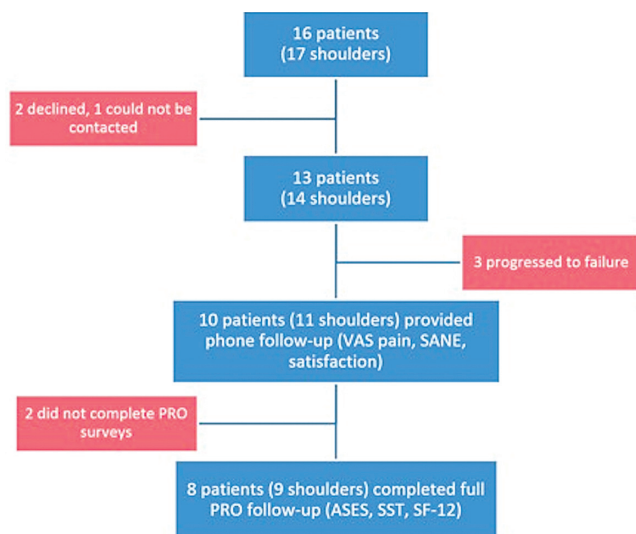‡School of Medicine, Georgetown University, Washington, DC, USA.[AQ: 1]

Figure 1. Flowchart depicting patient follow-up rates and reasons for dropout. ASES, American Shoulder and Elbow Score; PRO, patient-reported outcome; SANE, Single Assessment Numeric Evaluation; SF-12, Short Form–12; SST, Simple Shoulder Test; VAS, visual analog score.[AQ: 2]

the surgery again were assessed via phone interview. OBERD software was used to email patients PRO assessments, including the Simple Shoulder Test (SST), American Shoulder and Elbow Surgeons (ASES) form, and the Short Form–12 (SF-12). With the exception of the SANE score, these were the same PROs that patients were asked to fill out preoperatively and at short-term follow-up. In addition, patients were asked to state if they would undergo the procedure again (yes/no) and how satisfied they were with their outcome (1-10 scale).

Surgical Technique

The surgical technique used for microfracture in the glenohumeral joint and the postoperative rehabilitation protocol for these patients were previously described in detail.[9] For each patient, the chondral defect was located and debrided with an arthroscopic shaver, ring curette, or basket forceps to allow confirmation that the lesion was contained. After this, vertical walls were created with a curette or arthroscopic elevator before the layer of calcified cartilage was debrided with a curette, with care taken not to penetrate the subchondral bone. A microfracture awl (Linvatec) was then used to penetrate the clean area of exposed subchondral bone to create holes perpendicular to the surface of the bone. These were spaced approximately 3 to 4 mm apart and created to a penetration depth of approximately 2 to 4 mm (the depth of the awl tip) into the subchondral surface. After penetration, any bony remnants on the rims of the holes were removed by curettage or shaving. The irrigation pump pressure was decreased to allow visualization of marrow elements exiting the microfracture holes.

Rehabilitation Protocol

Postoperatively, patients are provided a sling for comfort for the first 2 to 4 weeks. Passive range of motion with progression to active assist and active range of motion is encouraged immediately after surgery. The standard protocol dictates immediate pendulum exercises for at least 800 rotations daily. Light strengthening is started at 6 weeks postoperatively if range of motion has been restored, and progression to unrestricted strengthening is allowed at 12 weeks postoperatively. All other activities are allowed at 16 weeks except for overhead competitive athletics, which are restricted for 6 months postoperatively.

Statistical Analysis

All results were analyzed with SPSS (v 24.0; IBM Corp) to compare preoperative measures and corresponding postoperative measures at final follow-up. A Shapiro-Wilk test was run on all PRO scores at preoperative and short- and long-term follow-up time points to assess for normality of data. A Friedman test was run to determine if there were differences in ASES, SST, or VAS scores at preoperative and short- and long-term follow-up time points. Pairwise comparisons were performed [AQ: 3]) with a Bonferroni correction for multiple comparisons. A Mann-Whitney U test was performed to compare PRO scores among independent groups, and a Fisher exact test was used to compare rates of failure among independent groups [AQ: 4]. A Spearman rank-order correlation was run to assess the relationships among patient demographics, including sex, defect, and pre- to postoperative PRO scores. Complications and reoperations were analyzed. Failure was defined by subsequent biological resurfacing or conversion to arthroplasty. Survivorship analysis with progression to failure as an endpoint was performed with Kaplan-Meier survival curves generated with MedCalc (v 17.1; MedCalc Software). Results with a P value $\leq$.05 were considered statistically significant.

RESULTS

Clinical Outcomes

Of the 2 patients who declined to participate, one cited dissatisfaction with outcome as a reason, and the other cited ongoing health problems as a reason. Average length of long-term follow-up was 10.2 years (range, 8.5-15.8 years). Of the 13 patients (14 shoulders) who were available for follow-up, microfracture surgery was performed on the humerus in 8 cases, the glenoid in 5 cases, and both surfaces in 1 case (Table 1). The average size of humeral head defects was 5.20 cm^2 (range, 4.0-7.84 cm^2), and the average size of glenoid defects was 1.53 cm^2 (range, 1.0-3.75 cm^2). One patient (2 shoulders) was treated with microfracture for avascular necrosis, and 12 patients were treated for focal cartilage defects. Three patients progressed to failure at the time of final follow-up and were excluded from the PRO score analysis. The remaining 10 patients (11 shoulders) all completed

TABLE 1
Preoperative Patient Characteristics and Patient-Reported Outcomes[a]

Shoulder	Age, y	Sex	Laterality[b]	Preoperative Diagnosis	Defect Location	Defect Size, mm	Concomitant Procedures	Previous Surgery	Preoperative Subjective Scores		
									VAS	SST	ASES
1	51	M	R / R	Injury (sports)	Humerus	25 × 30			6	5	48.3
2	48	M	L / R	Injury (work)	Glenoid	10 × 15	Capsular release, SAD, BT		4	8	60
3	55	F	R / L	Pain (insidious)	Glenoid	5 × 8	SAD		8	5	25
4	37	M	R / R	Pain (prior surgery)	Glenoid and humerus	Unknown and 20 × 20	SAD, BT	Labrum repair, SAD, RCR	5	10	N/A
5	42	M	L / R	Injury (sports)	Humerus	25 × 25	SAD		3	10	61.7
6	37	F	R / R	Injury (sports)	Glenoid	10 × 10	SAD				
7	55	F	R / R	Pain (prior surgery)	Glenoid	15 × 25	SAD, DCR, BT	SAD, DCR	N/A	4	N/A
8	18	F	R / L	AVN	Humerus	28 × 28			8	2	35
9	18	F	R / R	AVN	Humerus	20 × 20			8	2	33.3
10[c]	21	F	R / R	Pain (prior surgery)	Glenoid	Unknown		Stabilization, debridement			
11[c]	35	F	R / L	Injury (work)	Humerus	10 × 10	SAD				
12[c]	25	M	R / L	Pain (prior surgery)	Humerus	20 × 20	Capsular release	Labrum repair, SAD	4	5	41.7
13	48	M	R / L	Pain (insidious)	Humerus	20 × 20	SAD		9	1	8.3
14	18	F	R / R	Pain (prior surgery)	Humerus	20 × 20	BT	Capsulorrhaphy	6	5	45
15[d]	36	M	R / L	Pain (insidious)	Glenoid	10 × 10			1	11	85
16[d]	24	F	R / R	AVN	Humerus	20 × 20	Loose body removal		9	1	36.7
17[d]	38	M	R / R	Injury (sports)	Humerus	Unknown					

[a]ASES, American Shoulder and Elbow Surgeons; AVN, avascular necrosis; BT, biceps tenodesis; DCR, distal clavicle resection; F, female; L, left; M, male; N/A, not applicable; R, right; RCR, rotator cuff repair; SAD, subacromial decompression; SST, Simple Shoulder Test; VAS, visual analog scale.
[b]Dominant / operative.
[c]Denotes failure; patient was included in descriptive analysis but not in statistical analysis of patient-reported outcome scores.
[d]Denotes that patient was lost to follow-up; patient was not included in descriptive or statistical analysis.

the phone questionnaire, and all reported that, given their current knowledge of their surgical outcomes, they would choose to repeat the surgical procedure.

PRO scores at short- and long-term follow-up are reported in Table 2. VAS scores were statistically significantly different at the preoperative and short- and long-term follow-up time points ($\chi^2 = 11.029$, $df = 2$, $P = .004$). Pairwise comparisons revealed that VAS score was significantly improved at both short-term ($P = .003$, adjusted $P = .010$) and long-term ($P = .007$, adjusted $P = .020$) follow-up as compared with preoperative scores (Figure 2A). There was no significant difference in VAS scores between short- and long-term follow-up ($P = .814$, adjusted $P > .999$[AQ: 5]). ASES (Figure 2B) and SST (Figure 2C) scores were also significantly different between the time points (ASES: $\chi^2 = 9.478$, $df = 2$, $P = .009$; SST: $\chi^2 = 9.484$, $df = 2$, $P = .009$). Pairwise comparisons found that ASES and SST scores were significantly improved at short-term (ASES: $P = .006$, adjusted $P = .018$; SST: $P = .009$, adjusted $P = .026$) and long-term (ASES: $P = .014$, adjusted $P = .042$; SST: $P = .009$, adjusted $P = .026$) follow-up as compared with preoperative values. Neither ASES nor SST scores at long-term follow-up were significantly different from short-term follow-up (ASES: $P = .773$, adjusted $P > .999$; SST: $P = .999$, adjusted $P > .999$). There was no significant difference in SANE, SF-12 Physical, or SF-12 Mental scores between short- and long-term follow-up ($P = .400$ and $P = .207$, respectively). Preoperative PRO scores, patient sex, defect location (glenoid or humeral head),

and initial defect size did not have any significant correlation with postoperative PRO scores. Overall postoperative satisfaction scores (range, 0-10; 10 = very satisfied) for the 11 shoulders averaged 9.5 ± 1.0 (range, 7-10).

Five patients (6 shoulders) underwent isolated microfracture without any concomitant procedures, and 11 patients received microfracture with a concomitant procedure. Of those patients who underwent concomitant procedures, 1 underwent capsular release; 1, biceps tenodesis; 1, loose body removal; 5, subacromial decompression; and 3, multiple concomitant procedures (Table 1). No significant difference was found in long-term PROs between patients who did and did not undergo concomitant procedures at the time of microfracture (VAS, $P = .630$; ASES, $P = .714$; SST, $P = .714$; SANE, $P = .630$). Similarly, no significant difference was found in progression to failure between patients who did and did not undergo concomitant procedures ($P = .999$).

Survivorship Analysis

In the survivorship analysis, subjects were removed from the analysis, or censored, at the time of last known follow-up (Figure 3). This is denoted on the Kaplan-Meier curve by tick marks at the time of last known follow-up for each censored subject. Survivorship was 93.8% at 1 year, 87.5% at 3 years, and 76.6% at 9.6 years (average time of follow-up). Three patients were considered failures as defined by subsequent biological resurfacing or

TABLE 2
Postoperative Follow-up and PROs[a]

Shoulder	Short-term Follow-up, y	Short-term PROs						Long-term Follow-up, y	Long-term PROs					
		VAS	SST	ASES	SANE	SF-12 M	SF-12 P		VAS	SST	ASES	SANE	SF-12 M	SF-12 P
1	2.8	0	11	98.3	100	57.8	55.2	11.1	1	12	83.3	70	40.7	34.5
2	1.1	0	12	100	95	58.8	57.2	9.4	1	11	90	85	63.9	46.4
3	1.9	1	10	95	100	57.8	55.5	10.1	4	11	80	100	59.9	53.1
4	7.5	1	12	93.3	90	57.8	55.5	15.8	2	9	73.3	65	59.5	36.5
5	1.1	0	12	100	85	57.8	55.5	9.4	0	12	100	100	56.6	53.7
6	Lost							9.0	0	12	100	100	48.6	51.5
7	3.0	2	6	80	70	56.2	46	11.2	1	5	80	80	49.5	46.2
8	1.7	4	10	76.7	70	60	45.8	9.6	1	11	93.3	100	34.4	61.2
9	1.9	3	9	76.7	70	60	45.8	9.7	1	11	93.3	100	34.4	61.2
10[b]	N/A							10.8	N/A					
11[b]	N/A							8.5	N/A					
12[b]	2.8	5	6	45	65	29.9	36.1	10.4	N/A					
13	1.0	0	12	100	90	44.6	61.2	8.7	2			70		
14	1.5	7	10	61.7		53.2	46	9.6	4			75		
15[c]	2.5	1	12	95	92	55.9	57.2	Lost						
16[c]	1.4	0	12	100	100			Refused						
17[c]	Refused							Refused						

[a]ASES, American Shoulder and Elbow Surgeons; N/A, not applicable; PRO, patient-reported outcome; SANE, Single Assessment Numeric Evaluation; SF-12 (M, P), Short Form–12 (Mental, Physical); SST, Simple Shoulder Test; VAS, visual analog scale.
[b]Denotes failure; patient was included in descriptive analysis but not in statistical analysis of PRO scores.
[c]Denotes that patient was lost to follow-up; patient was not included in descriptive or statistical analysis.
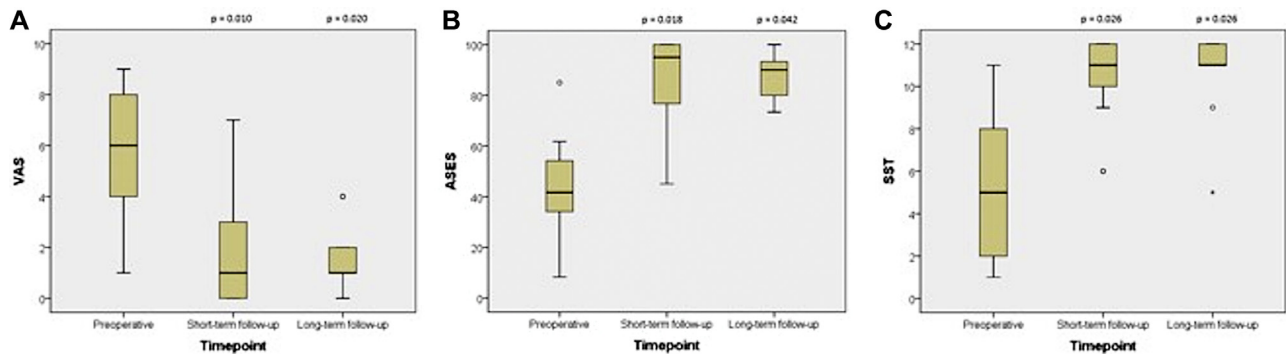

Figure 2. Boxplots depicting median and upper and lower quartile values for patient-reported outcomes scores at preoperative and short- and long-term follow-up time points: (A) visual analog scale (VAS), (B) American Shoulder and Elbow Surgeons (ASES), and (C) Simple Shoulder Test (SST). All *P* values depicted are for Bonferroni-corrected pairwise Friedman test as compared with the preoperative time point, with significance set at $P \leq .05$. [AQ: 6]

conversion to arthroplasty (overall failure rate of 21.4% at long-term follow-up). These patients progressed to failure at 2.5 months (hemiarthroplasty), 1.4 years (distal tibia allograft), and 9.6 years (total shoulder arthroplasty [TSA]) (Table 3). A fourth patient underwent a subsequent operation consisting of debridement, synovectomy, subacromial decompression, and distal clavicle excision 2.7 years after the microfracture procedure, but he did not undergo arthroplasty or biological resurfacing and thus was not considered a failure. This patient reported pain and functional limitation at 8.7-year follow-up (VAS, 2; SANE, 70) but was satisfied with the outcome of his surgery. This patient unfortunately did not complete full PRO surveys at long-term follow-up despite multiple requests.

Clinical Failure

In addition to the 3 patients defined as structural failures (who underwent shoulder arthroplasty or biological resurfacing), 2 patients were defined to be clinical failures. One patient who was lost to follow-up declined to participate in the study because he was unsatisfied with his surgical outcome and is considered to be a clinical failure. The other patient who declined to participate did so because of ongoing health issues, and no conclusions can be made about the outcomes of her surgery. One additional patient stated during data collection that while he had not yet undergone subsequent surgery, his symptoms had progressed to the point where he was considering evaluation for additional surgical treatment. At 15.8 years out from the index

TABLE 3
Subjects Who Underwent Subsequent Surgery[a]

Shoulder	Age, y	Sex	Subsequent Operations[b]	Time to Failure, y
10	21	F	Hemiarthroplasty[c] (0.2), revision shoulder arthroplasty (8.8), capsular release (10.7)	0.2
11	35	F	Distal tibia allograft[c] (1.4), debridement with subacromial decompression and distal clavicle excision (5.7), pectoralis major transfer (6.6), reverse shoulder arthroplasty (7.3)	1.4
12	25	M	SLAP repair, posterior labral repair, anterior stabilization, HH chondroplasty (2.8), HH debridement with glenoid microfracture and capsular release (9.5), TSA[c] (9.6)	9.6
13	48	M	Debridement with synovectomy, subacromial decompression, and distal clavicle excision (2.7)	Did not meet failure criteria

[a]F, female; HH, humeral head; M, male; SLAP, superior labrum anterior posterior; TSA, total shoulder arthroplasty.
[b]Numbers in parentheses indicate years since initial surgery.[AQ: 7]
[c]Denotes failure; patient was included in descriptive analysis but not in statistical analysis of patient-reported outcome scores.
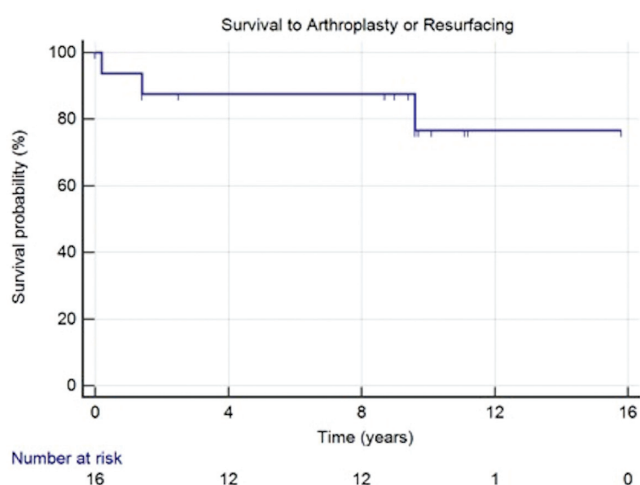

Figure 3. Kaplan-Meier survival analysis curve at a minimum 8.5-year follow-up after the index microfracture procedure. Tick marks indicate censored patients.

procedure, he cited limitations in recreational activities and activities of daily living (VAS, 2; ASES, 73.3; SST, 9; SANE, 65). However, he also reported that he was satisfied with the outcome of the procedure. At the time of final follow-up, he had not undergone shoulder arthroplasty or biological resurfacing and thus was not considered a structural failure. There were no other complications or reoperations. Given these numbers (3 structural failures and 2 clinical failures), the total long-term success rate of glenohumeral microfracture is 66.7% in the current study.

DISCUSSION

This study provides valuable information on the long-term outcomes of microfracture of the glenohumeral joint. Most data on cartilage fill after microfracture have been obtained for the knee and ankle joint, which, unlike the glenohumeral joint, are weightbearing joints and may demonstrate different long-term outcomes after microfracture. The principal finding of this study suggests that the long-term clinical outcomes of microfracture as a treatment for full-thickness cartilage defects of the glenohumeral joint are durable and similar to previously reported short-term outcomes, with overall improvements in pain and function. Patients undergoing microfracture experience significant and lasting improvements in self-reported shoulder-specific pain and function scores with high patient satisfaction at long-term follow-up. In this study, we defined failure as progression to biological resurfacing or arthroplasty, and survivorship was 93.8% at 1 year, 87.5% at 3 years, and 76.6% at 9.6 years. Failure correlated with poor patient satisfaction; thus, those who generally continued to do well remained satisfied with their microfracture outcome. Three patients had experienced structural failure at final follow-up, and 2 additional patients experienced clinical failure for an overall failure rate of 33.3%. While statistical analysis for subgroups was limited by small sample sizes, no significant differences were found in long-term PRO scores or progression to failure between patients who underwent microfracture alone and patients who underwent concomitant procedures. High patient satisfaction and stable PRO at long-term follow-up support the use of microfracture to treat focal articular cartilage defects of the glenohumeral joint with the goal of relieving symptoms and delaying the need for TSA in appropriately selected patients [AQ: 8]. No minimal clinically important difference changes in PRO scores have been defined for glenohumeral cartilage procedures. However, the mean change in ASES score from the preoperative time (43.63) to the long-term follow-up (88.15) was 44.52, significantly greater than that defined as being necessary for a minimal clinically important difference (9 points) or a substantial clinical benefit (23 points) for patients undergoing TSA for glenohumeral arthritis or rotator cuff arthropathy.[35]

Recently, there has been an increased interest in the arthroscopic management of glenohumeral articular cartilage defects, particularly for younger patients.[18,20,25,27] These investigations were spurred by concerns regarding long-term implant survival after arthroplasty.[4,28] While TSA is an effective treatment option for advanced glenohumeral arthritis, the concerns regarding implant survival, particularly among younger patients, support the

use of alternative treatments for less widespread disease.[4,6,12,27,28] Specifically, in studies investigating long-term (>10 years) outcomes among patients <55 years old after TSA, implant survival ranged between 62.5% and 83.2%.[4,28] Given the high morbidity of revision TSA procedures, alternatives to TSA that alleviate symptoms and delay the need for TSA can improve quality of life and preserve joint function, particularly for younger patients with less severe disease.[2,9,20,30] Glenohumeral microfracture offers an arthroscopic treatment option that has the potential to delay the need for arthroplasty in a number of patients.

Arthroscopic debridement alone has demonstrated variable outcomes for glenohumeral articular cartilage lesions. While a report by Weinstein et al[34] cited good to excellent outcomes after arthroscopic debridement in 80% of patients with mild arthritis changes, 37.5% of patients with grade 4 changes were unsatisfied with their outcome. Additionally, a recent report by Skelley et al[29] demonstrated that 60.6% of patients expressed dissatisfaction with isolated debridement at a minimum 2 years postoperatively. Of the 33 patients in this study, 42.4% underwent conversion to TSA at an average of 8.8 months after arthroscopy, and PRO scores for the cohort as a whole were not significantly improved at final follow-up[AQ: 9]. The population investigated by Skelley et al represented a range of disease, with 4 patients demonstrating grade 2 cartilage defects, 17 grade 3 (4 bipolar), and 12 grade 4 (6 bipolar), with conversion to arthroplasty more likely to occur in patients with bipolar disease. This increased risk for failure among patients with bipolar disease is seen consistently throughout the literature.[16,18,32] These findings suggest that debridement alone is not an effective management plan for glenohumeral osteoarthritis, especially among patients with bipolar disease, and it is necessary to incorporate other techniques, such as microfracture, to effectively manage symptoms and delay the need for shoulder arthroplasty. Our data set includes only 1 patient with bipolar disease who is currently considering further surgical intervention after 15.8 years of satisfactory pain relief and shoulder function after microfracture surgery. The higher rates of conversion to shoulder arthroplasty after arthroscopic management of bipolar disease presented in the literature suggest that, for these patients, arthroscopic management may not be as successful.[16,18,32] This question is an important one to address with future research.

As a technique, microfracture has demonstrated successful long-term outcomes in managing articular cartilage defects of the knee and ankle joint in limited cohort studies.[23,31] However, the shoulder presents a unique challenge, as there are significant differences between the glenohumeral joint and other joints, such as thinner articular cartilage and convex shape, which may influence clinical outcomes.[36] Additionally, these procedures are often planned and performed concurrently with other surgical interventions because the exact cause for shoulder pain is more difficult to pinpoint and chondral lesions encountered during arthroscopic exploration of the glenohumeral joint may be incidental or secondary findings. Nonetheless, previous investigations of microfracture of the glenohumeral joint showed success in improving symptoms. An investigation by Millet et al[18] demonstrated significant improvement in ASES scores with reoperation rates of 19% at a mean 47-month follow-up. Our previous report on the short-term outcomes of the current cohort also demonstrated significant improvement in ASES, SST, and VAS scores and an 18% reoperation rate at a mean 28-month follow-up.[9] The results of the current study augment these findings by providing additional data representing, to our knowledge, the longest clinical follow-up to date.

While the results presented in the current study do not suggest improved outcomes with concomitant procedures as compared with microfracture alone, previous authors demonstrated success when using multiple techniques in the treatment of shoulder pain in the setting of underlying osteoarthritis. A recent investigation by Mitchell et al[19] with a mean 5.7-year follow-up provided the clinical outcomes of comprehensive arthroscopic management (CAM) for patients with advanced glenohumeral osteoarthritis. CAM is a treatment methodology that incorporates a number of techniques, including debridement, chondroplasty, synovectomy, loose body removal, capsular release, and subacromial decompression.[24] CAM may also use inferior humeral osteoplasty, axillary nerve neurolysis, biceps tenodesis, and microfracture, depending on pre- and intraoperative findings.[19,20] Of 47 patients undergoing CAM, 11 (23%) underwent concomitant microfracture. The results for these patients were not reported independently. The midterm outcomes of CAM among patients with moderate to severe osteoarthritis include a reported survivorship of 95.6% at 1 year, 86.7% at 3 years, and 76.9% at 5 years. Additionally, PRO scores remained stable between short-term (2-year) and long-term (6-year) follow-up, similar to the results of the current study. While the CAM cohort presented by Mitchell et al represented much more significant disease than those investigated in our study, these corroborating results suggest that arthroscopic management, when it includes microfracture and other advanced techniques, can provide lasting symptomatic relief for appropriately selected patients.

Another option available for the treatment of symptomatic humeral head articular cartilage defects is osteochondral allograft transplantation. While more technically demanding and resource-intensive than microfracture, osteochondral allografts have been used very successfully in other joints, including the knee.[8] This technique has been demonstrated to be especially useful in cases with subchondral bone involvement (as determined by preoperative magnetic resonance imaging) and for revision microfracture cases in the knee.[3,11] While reports of outcomes in the glenohumeral joint are limited, a recent case series reported 78% graft survival at a mean 67-month follow-up with significant improvements in VAS, ASES, SST, and SF-12 scores.[25] Of all patients available for follow-up, 61% reported satisfaction with the procedure. By replacing the entire subchondral unit, this technique will likely show positive results with similar indications as in the knee, but further research is necessary to confirm this. Other nonarthroplasty techniques that have been

employed to treat focal glenohumeral cartilage defects include autologous chondrocyte implantation, autologous matrix-induced chondrogenesis, and osteochondral autograft transfer; however, outcomes data on these techniques are limited.[2,5,17,26,33]

The indications and contraindication for glenohumeral microfracture have not been fully developed, but a recent theoretical decision model reported by Spiegl et al[30] proposed that arthroscopic management for glenohumeral osteoarthritis be considered for patients <47 years old and that TSA be the preferred treatment for patients >66 years old. However, their sensitivity analysis demonstrated that these age cutoffs were very sensitive to changes in assigned quality-adjusted life years and treatment utilities. Because individual treatment utility may vary greatly among patients, it is important to ensure adequate patient-centered decision making and preoperative expectation setting when discussing management strategies for glenohumeral osteoarthritis. However, this decision model provides a reasonable argument that younger patients be offered the option of pursuing arthroscopic management, including microfracture, before undergoing shoulder arthroplasty. In the senior author's current practice, glenohumeral microfracture continues to be an option offered to patients with similar indications as defined in this series: younger active patients suffering from deep pain in the shoulder with activity who demonstrate the presence of full-thickness glenohumeral cartilage defects. Because of the paucity of literature on the topic, size limitations, risk factors for failure, and ideal patient populations have not been well defined for glenohumeral microfracture. It is possible that future research will reveal a paradox: that some important predictors of functional improvement for microfracture of the knee (eg, age) will have parallel relationships to microfracture of the glenohumeral joint whereas other factors (eg, body mass index) may not demonstrate correlations with clinical outcomes.[AQ: 10]

This study has several limitations, including the retrospective nature, small sample size, lack of control group, and potential nonresponder bias. Limited conclusions can be drawn from this small heterogeneous retrospective cohort of patients. In our study, 3 patients failed on the basis of subsequent shoulder replacement, and 2 patients were considered clinical failures. Of the 2 patients who declined to participate, one did so because he was unsatisfied with his clinical outcomes and was considered a clinical failure. The other declined because of ongoing health issues, and no conclusions can be drawn regarding her outcomes. These 2 patients, while censored from the analysis, likely experienced poor outcomes after microfracture surgery. Thus, the current study may overestimate PRO improvements after microfracture while underestimating treatment failure. No further data were available for the patient who was unable to be contacted for follow-up. If we assume a worst-case scenario—that both patients who declined to participate and the single patient who was unable to be contacted were treatment failures at last known follow-up—our cohort would demonstrate clinical success in 10 of 17 shoulders (58.8%) at a minimum follow-up of 8.5 years.

The small sample size of this study and preoperative patient selection—restricted to younger active patients with full-thickness defects of the glenoid and/or humeral surfaces—limits the generalizability of our findings. However, previous investigations suggested that this group is the most likely to benefit from arthroscopic management, and our study provides valuable insight into the long-term outcomes after microfracture surgery in this population.[27,30] Similar to previous reports of arthroscopic management for glenohumeral arthritis, we omitted patients with significant comorbidities, such as rotator cuff tear or labral tear, in an effort to minimize confounding variables, but we included patients who underwent biceps tenodesis, capsular release, arthroscopic debridement, subacromial decompression, distal clavicular resection, and/or loose body removal. While the inclusion of patients who underwent concomitant procedures limits our ability to demonstrate that our findings are attributable to microfracture alone, our analysis did not demonstrate any difference between patients who underwent concomitant operations and those who underwent microfracture alone. Furthermore, the senior authors primarily indicated their patients for microfracture based on the belief that the focal chondral defect was likely to be a significant source of pain for their patients at the time of treatment. Other studies demonstrated that glenohumeral arthritis is a complicated condition that may be best managed by using various techniques concomitantly.[19,24,29]

Another limitation of our study is the lack of objective outcomes data, such as physical examination or imaging data. However, multiple other studies published in high-quality journals were also limited to patient-reported follow-up.[18,19,29,31] Because a primary goal of arthroscopic management of glenohumeral articular cartilage disease is to delay the need for arthroplasty—rather than to reverse the progression of the disease—subjective clinical outcomes data and survival analysis of these techniques, especially at long-term follow-up, provide valuable, clinically useful data even without objective physical examination and imaging findings. However, imaging results or the results of second-look arthroscopy and/or histologic findings (for patients who undergo subsequent arthroplasty) could be performed in future studies to clarify the nature of cartilage fill in the shoulder joint, a nonweightbearing joint known to have thinner cartilage than that of the better-studied knee joint.[36]

CONCLUSION

Although glenohumeral microfracture can provide lasting improvement in some patients, it is associated with a high reoperation rate (28.6%) and a clinical failure rate of 33% to 42% with patient dissatisfaction, conversion to arthroplasty, and biological resurfacing as endpoints. While limited by sample size and potential nonresponder bias, our findings provide valuable evidence for the long-term durability of microfracture in some patients while demonstrating significant rates of reoperation and clinical failure. Because of sample size limitations, our study was able to identify only those associations between patient

and lesion characteristics and clinical outcomes. Further studies of larger cohorts are necessary to ensure that the outcomes of this study are reproducible and to further characterize risk factors for failure. Additionally, future randomized controlled trials comparing CAM with and without microfracture would be helpful to clarify the effect of microfracture surgery on postoperative outcomes and delay of progression to arthroplasty.

REFERENCES

1. Cameron ML, Kocher MS, Briggs KK, Horan MP, Hawkins RJ. The prevalence of glenohumeral osteoarthrosis in unstable shoulders. *Am J Sports Med*. 2003;31(1):53-55.
2. Cuéllar A, Ruiz-Iban MA, Cuellar R. The use of all-arthroscopic autologous of humeral and glenoid chondral defects in the shoulder. *Arthrosc Tech*. 2016;5(2):e223-e227.
3. De Caro F, Bisicchia S, Amendola A, Ding L. Large fresh osteochondral allografts of the knee: a systematic clinical and basic science review of the literature. *Arthroscopy*. 2015;31(4):757-765.
4. Denard PJ, Raiss P, Sowa B, Walch G. Mid- to long-term follow-up of total shoulder arthroplasty using a keeled glenoid in young adults with primary glenohumeral arthritis. *J Shoulder Elbow Surg*. 2013;22(7):894-900.
5. Depalma AA, Gruson KI. Management of cartilage defects in the shoulder. *Curr Rev Musculoskelet Med*. 2012;5(3):254-262.
6. Elser F, Braun S, Dewing C, Millett PJ. Articular cartilage lesions in young, active patients. *Arthroscopy*. 2010;26(5):685-696.
7. Frank RM, Cotter EJ, Nassar I, Cole B. Failure of bone marrow stimulation techniques. *Sports Med Arthrosc*. 2017;25(1):2-9.
8. Frank RM, Lee S, Levy D, et al. Osteochondral allograft transplantation of the knee analysis of failures at 5 years. *Am J Sports Med*. 2017;45(4):864-874.
9. Frank RM, Van Thiel GS, Slabaugh MA, Romeo AA, Cole BJ, Verma NN. Clinical outcomes after microfracture of the glenohumeral joint. *Am J Sports Med*. 2010;38(4):772-781.
10. Gartsman GM, Taverna E. The incidence of glenohumeral joint abnormalities associated with full-thickness, reparable rotator cuff tears. *Arthroscopy*. 1997;13(4):450-455.
11. Gracitelli GC, Meric G, Briggs DT, et al. Fresh osteochondral allografts in the knee: comparison of primary transplantation versus transplantation after failure of previous subchondral marrow stimulation. *Am J Sports Med*. 2015;43(4):885-891.
12. Gross CE, Chalmers PN, Chahal J, et al. Operative treatment of chondral defects in the glenohumeral joint. *Arthroscopy*. 2012;28(12):1889-1901.
13. Gudas R, Kalesinskas RJ, Kimtys V, et al. A prospective randomized clinical study of mosaic osteochondral autologous transplantation versus microfracture for the treatment of osteochondral defects in the knee joint in young athletes. *Arthroscopy*. 2005;21(9):1066-1075.
14. Hannon CP, Smyth NA, Murawski CD, et al. Osteochondral lesions of the talus: aspects of current management. *Bone Joint J*. 2014;96(2):164-171.
15. Hunt SA, Jazrawi LM, Sherman OH. Arthroscopic management of osteoarthritis of the knee. *J Am Acad Orthop Surg*. 2002;10(5):356-363.
16. Kerr BJ, McCarty EC. Outcome of arthroscopic debridement is worse for patients with glenohumeral arthritis of both sides of the joint. *Clin Orthop Relat Res*. 2008;466(3):634-638.
17. Kircher J, Patzer T, Magosch P, Lichtenberg S, Habermeyer P. Osteochondral autologous transplantation for the treatment of full-thickness cartilage defects of the shoulder results at nine years. *J Bone Joint Surg Br*. 2009;91(4):499-503.
18. Millet PJ, Huffard BH, Horan MP, Hawkins RJ, Steadman JR. Outcomes of full-thickness articular cartilage injuries of the shoulder treated with microfracture. *Arthroscopy*. 2009;25(8):856-863.
19. Mitchell JJ, Horan MP, Greenspoon JA, Menge TJ, Tahal DS, Millett PJ. Survivorship and patient-reported outcomes after comprehensive arthroscopic management of glenohumeral osteoarthritis: minimum 5-year follow-up. *Am J Sports Med*. 2016;44(12):3206-3213.
20. Mook WR, Petri M, Greenspoon JA, Millett PJ. The comprehensive arthroscopic management procedure for treatment of glenohumeral osteoarthritis. *Arthrosc Tech*. 2015;4(5):e435-e441.
21. Paley KJ, Jobe FW, Pink MM, Kvitne RS, ElAttrache NS. Arthroscopic findings in the overhand throwing athlete: evidence for posterior internal impingement of the rotator cuff. *Arthroscopy*. 2000;16(1):35-40.
22. Pareek A, Reardon PJ, Macalena JA, et al. Osteochondral autograft transfer versus microfracture in the knee: a meta-analysis of prospective comparative studies at midterm. *Arthroscopy*. 2016;32(10):2118-2130.
23. Polat G, Ersen A, Erdil ME, et al. Long-term results of microfracture in the treatment of talus osteochondral lesions. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(4):1299-1303.
24. Richards DP, Burkhart SS. Arthroscopic debridement and capsular release for glenohumeral osteoarthritis. *Arthroscopy*. 2007;23(9):1019-1022.
25. Riff AJ, Yanke AB, Shin JJ, Romeo AA, Cole BJ. Midterm results of osteochondral allograft transplantation to the humeral head. *J Shoulder Elbow Surg*. 2017;36(7):e207-e215.
26. Romeo AA, Cole BJ, Mazzocca AD, Fox JA, Freeman KB, Joy E. Autologous chondrocyte repair of an articular defect in the humeral head. *Arthroscopy*. 2002;18(8):925-929.
27. Sayegh ET, Mascarenhas R, Chalmers PN, Cole BJ, Romeo AA, Verma NN. Surgical treatment options for glenohumeral arthritis in young patients: a systematic review and meta-analysis. *Arthroscopy*. 2015;31(6):1156-1166.e8.
28. Schoch B, Schleck C, Cofield RH, Sperling JW. Shoulder arthroplasty in patients younger than 50 years: minimum 20-year follow-up. *J Shoulder Elbow Surg*. 2015;24(5):705-710.
29. Skelley NW, Namdari S, Chamberlain AM, Keener JD, Galatz LM, Yamaguchi K. Arthroscopic debridement and capsular release for the treatment of shoulder osteoarthritis. *Arthroscopy*. 2015;31(3):494-500.
30. Spiegl UJ, Faucett SC, Horan MP, Warth RJ, Millett PJ. The role of arthroscopy in the management of glenohumeral osteoarthritis: a Markov decision model. *Arthroscopy*. 2014;30(11):1392-1399.
31. Steadman JR, Briggs KK, Rodrigo JJ, Kocher MS, Gill TJ, Rodkey WG. Outcomes of microfracture for traumatic chondral defects of the knee: average 11-year follow-up. *Arthroscopy*. 2003;19(5):477-484.
32. Van Thiel GS, Sheehan S, Frank RM, et al. Retrospective analysis of arthroscopic management of glenohumeral degenerative disease. *Arthroscopy*. 2010;26(11):1451-1455.
33. Wang VM, Karas V, Lee AS, et al. Assessment of glenoid chondral healing: comparison of microfracture to autologous matrix-induced chondrogenesis in a novel rabbit shoulder model. *J Shoulder Elbow Surg*. 2015;24(11):1789-1800.
34. Weinstein DM, Bucchieri JS, Pollock RG, Flatow EL, Bigliani LU. Arthroscopic debridement of the shoulder for osteoarthritis. *Arthroscopy*. 2000;16(5):471-476.
35. Werner BC, Chang B, Nguyen JT, Dines DM, Gulotta LV. What change in American Shoulder and Elbow Surgeons score represents a clinically important change after shoulder arthroplasty? *Clin Orthop Relat Res*. 2016;474(12):2672-2681.
36. Zumstein V, Kraljević M, Müller-Gerbl M. Glenohumeral relationships: subchondral mineralization patterns, thickness of cartilage, and radii of curvature. *J Orthop Res*. 2013;31(11):1704-1707.