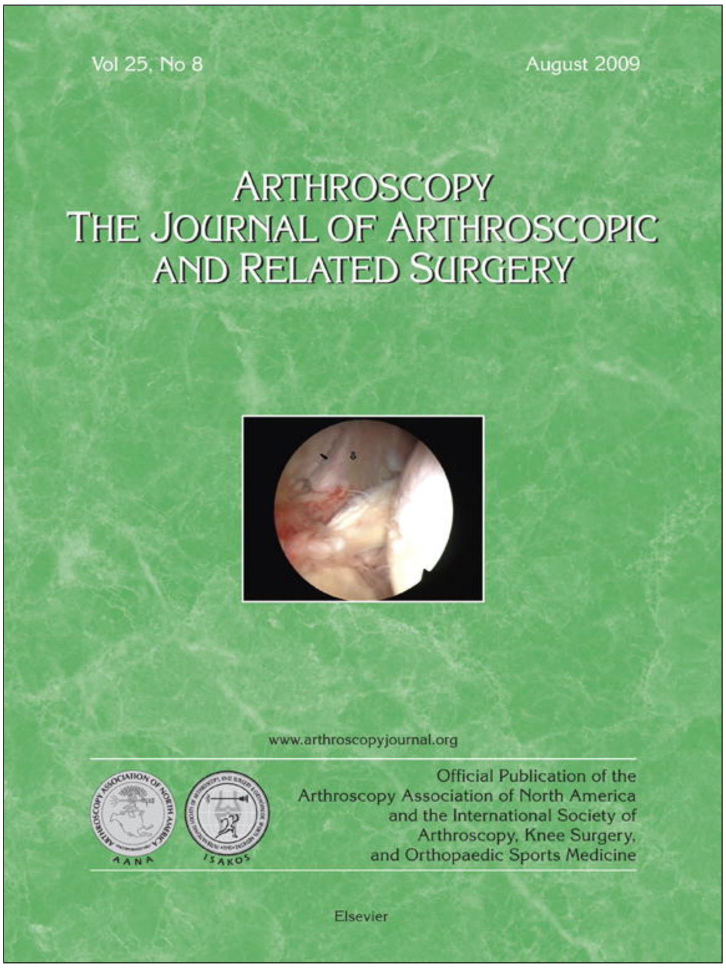
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Outcomes of Full-Thickness Articular Cartilage Injuries of the Shoulder Treated With Microfracture

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Purpose: The purpose of this study was to determine whether microfracture provides pain relief and improves shoulder function in patients with chondral defects of the glenohumeral joint. **Methods:** Microfracture was performed in glenohumeral joints with full-thickness chondral lesions. Concomitant procedures were performed as indicated. Patients aged 60 years or older and those with complete rotator cuff tears were excluded. We included 31 shoulders in 30 patients in this study. Included were 25 men and 5 women with a mean age of 43 years (range, 19 to 59 years). Of the 31 surgeries, 6 (19%) progressed to another surgery. Subjective data obtained at a minimum of 2 years' follow-up were available in 24 patients (25 shoulders). Patient pain and functional outcomes were measured by use of the American Shoulder and Elbow Surgeons (ASES) score and patient satisfaction. Data were analyzed by use of paired *t* tests and regression analysis. **Results:** The mean follow-up was 47 months (range, 25 to 128 months). The mean pain scores decreased from 3.8 to 1.6 postoperatively (0, no pain; 10, worst pain). The patients' ability to work, activities of daily living, and sports activity significantly improved postoperatively ($P < .05$). Painless use of the involved arm improved postoperatively ($P < .05$). The mean ASES score improved by 20 points over the preoperative score ($P < .05$). Mean satisfaction with surgical outcome was 7.6 of 10. There was no association between age or gender and surgical outcomes. The greatest improvements were seen in patients who had microfracture of isolated lesions of the humerus. **Conclusions:** Failure occurred in 6 of the 31 shoulders (19%). In the remaining patients there was a significant improvement of 20 points (range, −11 to 45 points) in the ASES score compared with preoperatively. In those patients in whom just the humerus was treated, the greatest improvement was seen, with an increase of 32 points (range, 3 to 87 points). There was a negative correlation between the size of the lesion and ASES improvement ($r = -0.351$, $P = .12$). Our data showed the greatest improvement for smaller lesions of the humerus with the worst results in patients with bipolar lesions. **Level of Evidence:** Level IV, therapeutic case series. **Key Words:** Microfracture—Glenoid—Humeral head—Cartilage defect—Shoulder arthroscopy—Shoulder—Articular cartilage.

Up to 20% of the elderly population are affected by degenerative joint disease (DJD) of the shoulder.[1] Persons with DJD of the glenohumeral joint can obtain pain relief and improved function from hemiarthroplasty or a total shoulder replacement. Although shoulder arthroplasty provides excellent pain relief, it comes with significant activity restrictions and a limited implant lifespan, particularly in younger individ-

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uals.[2] Young active patients with relevant articular cartilage lesions of the glenohumeral joint present a treatment challenge.[3-5] The prevalence of Outerbridge grade IV lesions at shoulder arthroscopy has been estimated at 5%.[6] Current treatment protocols for chondral injuries of the shoulder rely primarily on nonoperative treatment, which includes anti-inflammatory medication, injections, and/or physical therapy to relieve symptoms.[7]

Extensive research efforts have shown that articular cartilage defects rarely heal spontaneously, regardless of whether they are acute, chronic, or degenerative.[8] Most of the research studies have been devoted to treatment of knee articular cartilage defects. The spectrum of surgical techniques for damaged chondral surfaces in the shoulder includes debridement,[8] microfracture,[9] autologous chondrocyte implantation,[10-12] osteochondral drilling,[7] interpositional allografts, capsular release, osteoarticular autograft or allograft plugs, and prosthetic replacement. Microfracture has become the preferred treatment for knee chondral defects, and several studies have shown good long-term results.[13-15]

Microfracture is a marrow-stimulating procedure that brings undifferentiated stem cells from a subchondral perforation into the chondral defect. A marrow clot forms in the microfractured area, providing an environment for both pluripotent marrow cells and mesenchymal stem cells to differentiate into stable tissue.[16] Histologic analysis of microfractured lesions has shown that fibrocartilaginous hyaline-like tissue fills the defect.[17,18]

Although it seems logical to conclude that the same basic principles can be applied in the shoulder, there are no studies reporting patient outcomes of microfracture in the shoulder. The purpose of this study was to determine the outcomes of microfracture for full-thickness articular cartilage lesions of the glenohumeral joint. We hypothesized that microfracture of the shoulder can result in satisfactory pain and functional outcomes.

METHODS

Patients were retrospectively selected from a database to be included in the study, based on their prospectively collected findings at surgery and a minimum of 2 years' follow-up. Sixty-six patients underwent the microfracture technique for full-thickness contained chondral lesions of the glenohumeral joint from 1992 to 2003. Nine patients with full-thickness tears of the rotator cuff were excluded from this study because an insufficient rotator cuff may lead to asymmetric erosion of the cartilage. Nine patients who were aged 60 years or older were eliminated to limit confounding factors such as age-related joint degeneration. Forty-eight subjects who underwent concomitant procedures such as synovectomy, loose body removal, partial cuff tear debridement ($<$50% of tendon thickness), acromioplasty, capsular release, and instability reconstruction were included. Three patients died of unrelated causes and were unavailable for follow-up. Of the remaining 46 patients, an extensive effort was made to obtain subjective follow-up by mailed questionnaire. Of the 46 patients, 30 (67%) were included in this study (31 shoulders). There were 25 men and 5 women with a mean age of 45.5 years (range, 19 to 59 years). Of the 31 surgeries, 6 (19%) progressed to subsequent surgery, and these patients' pain and function scores were excluded from the reported outcome measures. Of the remaining patients, data from a minimum of 2 years' follow-up were available in 25 shoulders. The mean follow-up was 45 months (range, 25 to 131 months). The patients' pain and functional outcomes were measured by use of the American Shoulder and Elbow Surgeons (ASES) score (range, 0 to 100) and patient satisfaction level (1, unsatisfied; 10, very satisfied). Various other pain- and function-specific questions were measured on Likert scales.

All data were prospectively collected and stored in a database. Other surgical treatments performed in combination with microfracture included 6 instability procedures, 10 subacromial decompressions, 7 capsular releases or manipulations under anesthesia, 7 SLAP lesion debridements or repairs, and 3 biceps releases. The size of the chondral defects was estimated by the operating surgeons, who routinely quantify the size of chondral defects, using arthroscopic instruments of known sizes as references. We have shown previously in experimental settings the ability to accurately quantify the size of defects with this technique.[16]

Changes in responses to preoperative and postoperative pain and function questions were compared by use of paired t tests. Comparison of ASES improvement for binary categorical variables was performed by use of the independent-samples t test, and for multiple ($>$2) categorical variables, it was performed by use of 1-way analysis of variance. Comparison of ASES improvement for continuous variables was performed by use of the Pearson correlation coefficient. The ASES score and patient satisfaction with outcomes were the primary outcome measures, and a

Bonferroni test was used to control for multiple comparisons. Statistical analysis was performed with the SPSS software package (version 11.0; SPSS, Chicago, IL). All reported P values are 2-tailed with an α level of .05 indicating statistical significance.

Microfracture Technique

The indications for microfracture of humeral and glenoid chondral defects were based on the accepted principles for knee microfracture[9] and included focal and contained articular cartilage lesions, full-thickness (Outerbridge grade IV) defects, unstable lesions with intact subchondral bone, and focal DJD lesions. Patients were informed preoperatively about the treatment plan and risks of the microfracture procedure and provided consent. Contraindications to microfracture included partial-thickness lesions and chondral lesions associated with relevant bony defects, such as large Hill-Sachs lesions. General contraindications included active infection, systemic immune-mediated disease, or conditions inducing arthritis or cartilage disease.[9]

Although the technique for arthroscopic microfracture of the shoulder has not been described, the technique used in the subjects in this study was modified from the technique described by Steadman et al.[9] for the treatment of chondral injuries of the knee. The chondral defect was identified and probed to assess for any unstable cartilage (Fig 1). Unstable articular cartilage was debrided with a motorized shaver (Fig 2). A curette was used to create a vertical wall of articular cartilage to create perpendicular articular margins to entrap the marrow clot to allow for a better healing environment. The calcified cartilage layer was removed with the shaver or a curette while the surgeon maintained the integrity of the subchondral bone.[9] The calcified cartilage layer is thinner in the shoulder than in the knee, so care must be taken at this stage to maintain the subchondral plate.[19,20] Removal of the calcified cartilage layer is confirmed by punctate bleeding in the bone base (Fig 3). Arthroscopic awls were oriented perpendicular to the surface and were used to penetrate the exposed subchondral bone to a depth of 3 to 4 mm (Fig 4). Multiple holes, "microfractures," were created, spaced at 3- to 4-mm intervals to prevent fracturing between the perforations. After microfracture, the arthroscopic pump pressure was decreased and the release of marrow elements was observed (Fig 5). Treatment of associated pathologies was performed first as needed. To preserve the marrow elements, the actual perforation of the sub-

FIGURE 2. Debridement of chondral defect back to stable rims.

FIGURE 1. Chondral defect on humeral head.

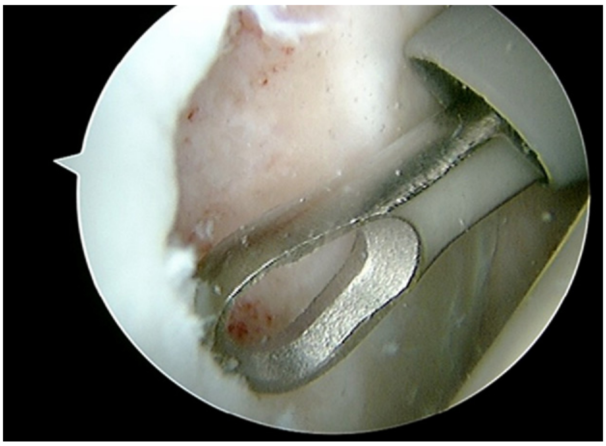

FIGURE 3. A curette is used to scrape the calcified cartilage layer.

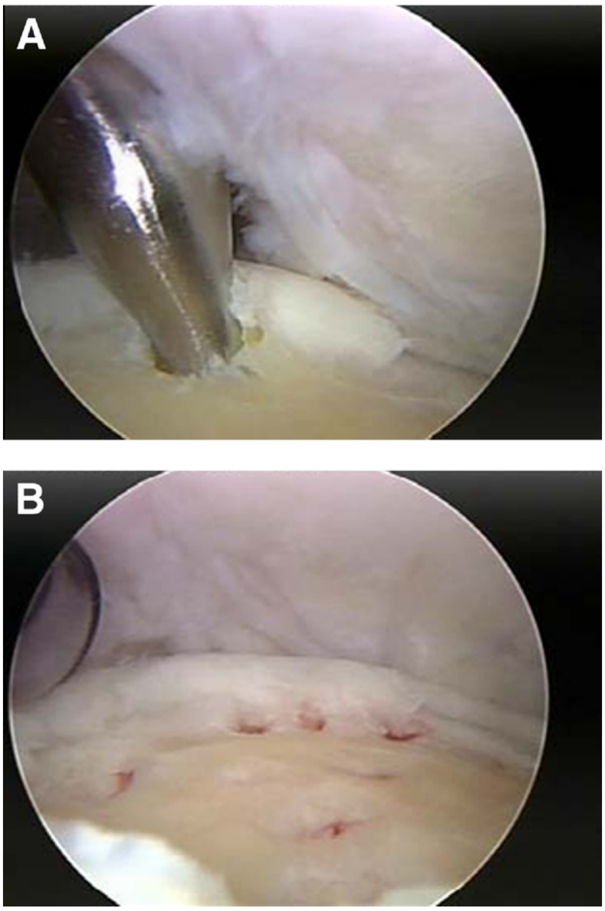

FIGURE 4. (A) Arthroscopic awl oriented perpendicular to surface to a depth of 3 to 4 mm. (B) The awl penetrates the exposed subchondral bone spaced at 3- to 4-mm intervals.

chondral plate was performed at the conclusion of the procedure so that the stem cells and growth factors would not be diluted by the arthroscopy fluid. Although most defects can be accessed from standard anterior and posterior portals, accessory portals can be helpful to obtain the appropriate perpendicular orientation. The use of a mechanical arm holder can also be helpful to rotate the defect into an accessible position.

Postoperative management was modified from the principles that have been developed for knee microfracture.[21,22] Because the shoulder experiences lower loading conditions than the knee, weight bearing was not restricted, although patients were encouraged to avoid heavy lifting. In some instances the treatment of associated pathologies influenced the rehabilitation, but typically, full active and passive range of motion was allowed immediately. The use of constant passive motion machines, which are used after knee microfracture, was not routinely prescribed postoperatively in this patient population because of the risk posed to the results of the other surgical procedures performed.[9] Regular passive motion was encouraged, although excessive loading was discouraged. Strengthening was started at 8 weeks postoperatively, with return to sport typically allowed at 4 to 6 months postoperatively.

RESULTS

Of the patients, 6 had microfracture treatment of both the humeral cartilage (mean 442 mm^2; range, 120 to 1,200 mm^2) and glenoid cartilage (mean 273 mm^2; range, 80 to 1,200 mm^2), 13 had microfracture treatment just on the glenoid (mean 137 mm^2; range, 25 to 400 mm^2), and 12 had microfracture of the humeral head only (mean 422 mm^2; range, 100 to 1,600 mm^2). Six patients underwent arthroscopic capsular releases in combination with microfracture treatment. In this series of 30 patients (31 shoulders) treated for full-thickness articular defects, 6 patients went on to have subsequent surgery.

Of the 6 subsequent surgeries, 3 were total shoulder replacements and were considered failures of the microfracture treatment. The mean time to total shoulder replacement was 41 months (range, 8 to 66 months) (Table 1). One patient had surgical treatment for instability after a new injury while windsurfing 3 years after the microfracture procedure. Another patient had instability surgery and treatment for a painful biceps. No subsequent surgical information was available on the last patient, but he did undergo an intra-articular injection that provided 100% pain relief. However, it

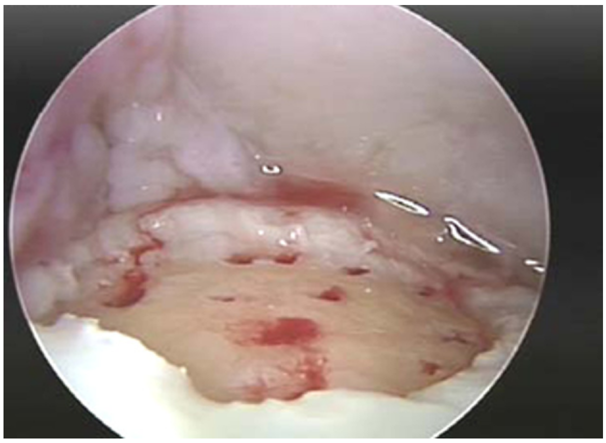

FIGURE 5. The pump pressure is decreased to observe release of marrow elements.

TABLE 1. *Copathology and Surgical Treatments of Patients in Whom Failure Occurred or Who Had Subsequent Surgery*

Age (yr), Gender	Prior Surgery	Copathology	Surgical Treatment	Second Surgery
59, male	None	Grade 4 chondral defect of humeral head (25%), type II SLAP tear, impingement, partial bursal tear of infraspinatus	Microfracture, sutured superior labrum, SAD	Arthroscopic biceps release
19, male	Arthroscopic labral (posterior/superior) debridement and acromioplasty	Grade 4 chondral defect of humeral head (5%), type II SLAP tear	Microfracture, sutured posterior/superior labrum	Type of surgery unknown, intra-articular injection yielded 100% pain relief
50, male	None	Grade 4 chondral changes of humeral head (75%) and glenoid (75%) with AVN, type II SLAP tear, impingement	Microfracture, SAD, open tenodesis	Total shoulder arthroplasty
45, female	Arthroscopic Bankart repair	Grade 4 chondral changes of humeral head (45%) and glenoid (50%), type II SLAP tear, impingement, frayed biceps	Microfracture, sutured superior labrum, biceps release, SAD	Total shoulder arthroplasty
52, male	Open rotator cuff repair followed by biceps tenodesis	Grade 4 chondral changes of humeral head of 20 mm^2, adhesive capsulitis, ruptured biceps	Microfracture, arthroscopic capsular release	Total shoulder arthroplasty
45, male	None	Grade 4 chondral changes of glenoid (25%), type III SLAP tear, 50% biceps tear, impingement, AC joint DJD	Microfracture, arthroscopic SAD, biceps release	Rotator cuff repair with thermal capsulorrhaphy for continued instability

Abbreviations: SAD, subacromial decompression; AVN, avascular necrosis; AC, acromioclavicular.

could not be determined whether his continued shoulder pain was from a SLAP lesion or the chondral defect. This patient elected to have surgery elsewhere because the pain was interfering with his tennis performance at the collegiate level. Two patients who underwent second-look arthroscopy for new injuries were remarkable in that the area of the previous microfracture was well filled with fibrocartilage. It was noted that the prior microfracture did not seem to compromise the reconstructive options. The mean time from the microfracture procedure to reoperation on the index shoulder averaged 35 months (range, 6 to 66 months). Outcomes and functional data comparisons of these 6 patients are excluded from reported outcomes because they would reflect the subsequent surgeries' results.

The results in the patients included in this series showed a decrease in pain and an improvement in function with microfracture (Table 2). The ability to work ($P = .014$), perform activities of daily living

TABLE 2. *Patient 2-Year Outcomes*

	Preoperative Data	Postoperative Data	*P* Value
Pain today†	3.8 (range, 0-7)	1.6 (range, 0-5)	<.001*
Pain at its worst‡	7.9 (range, 5-10)	5.0 (range, 0-10)	<.001*
ASES score	60 (range, 20-80)	80 (range, 45-100)	.000*
Painless use of arm above neck§	22% (4/18)	55% (11/20)	.002*
Participation in sports slightly below or equal to preinjury level	2/15	9/18	.002*
Inability to compete in sports at any intensity compared with before injury	5/12 (41%)	2/19 (10%)	.004*
Median score for satisfaction with outcomes (1, very unsatisfied; 10, very satisfied)		9.5 (range, 1-10)	

*Statistically significant at $P < .05$.
†Patients answered the question "What is your pain today?" on a scale ranging from 1 to 10, with 1 indicating no pain and 10 indicating worst pain.
‡Patients answered the question "What is your pain level at its worst?" on a scale ranging from 1 to 10, with 1 indicating no pain and 10 indicating worst pain.
§Patients answered the question "At what level can you use your arm for painless reasonably strong activities: (1) waist, (2) nipple, (3) neck, (4) head, (5) overhead?"

(P = .001), and participate in sports (P = .001) had significant improvements postoperatively. When more than 2 other pathologies were addressed at the same surgery, outcome scores were lower. Prior surgery, coded binary, was also a predictor of lower ASES scores (P = .04). ASES was correlated with patient satisfaction (r = 0.653, P = .02); however, satisfaction with outcomes was not correlated with pain. Despite the lack of correlation between satisfaction and pain, the 4 patients with the highest levels of pain reported that they were all very unsatisfied with their surgical outcomes.

There was no association between age at the time of surgery and any outcome parameters. Various other subjective responses to questions measuring pain and function improved significantly postoperatively ($P <$ .05) (Table 2). Of the patients with subjective follow-up, 50% (12/24) were involved in sports and reported that their ability to compete significantly improved postoperatively ($P <$ .05). Improvement in ASES scores varied by location of the lesions treated. When both the glenoid and humerus were treated with microfracture, there was only a 19-point improvement (range, 8 to 36 points) in the ASES score. When the glenoid was treated alone, there was an improvement of 17 points (range, −11 to 42 points). In those patients in whom just the humerus was treated, the greatest improvement was seen, with an increase of 32 points (range, 3 to 87 points). There was a negative correlation between the size of the lesion and ASES improvement (r = −0.351, P = .124). With the numbers available for analysis, no correlation could be found between preoperative pain and lesion size. Lesion size and pain were correlated at follow-up (r = 0.65, P = .004).

DISCUSSION

Chondral lesions of the shoulder may be effectively treated with arthroscopic microfracture in patients with proper indications for surgery. In this small study group, microfracture was a viable treatment for both chronic and acute articular cartilage lesions. As patients continue to remain active as they age, restoring articular cartilage in the shoulder will become more common.

To date, outcomes of microfracture have been reported extensively in the knee. A recent study by Steadman et al.[14] described outcomes after arthroscopic microfracture of isolated knee chondral defects. They noted significantly improved patient function in 95% of the patient cohort at a mean follow-up of 11 years. Rodrigo et al.[21] reported second-look arthroscopic appearances of chondral lesions of the knee treated with microfracture. They used a scale of 1 to 5, with 1 indicating normal-appearing cartilage and 5 indicating a full-thickness lesion. In patients treated with postoperative continuous passive motion, the mean improvement in cartilage grade was 2.67. The results of these studies have shown that healing of chondral defects and improvement in functional outcomes are possible after microfracture.

The shoulder differs from the knee in several important ways in regard to the microfracture procedure. The shoulder is a much less constrained joint than the knee, has thinner cartilage on the humerus, and is a not a weight-bearing joint. The calcified cartilage layer is also thinner.[19,20] In addition, the shoulder's anatomy makes it technically challenging to perforate the bone perpendicularly.

McCarty and Cole[8] proposed a treatment algorithm for shoulder chondral lesions that included microfracture for smaller, contained defects to induce formation of fibrocartilage. In addition, the patient's age and desired activity level should be factored into the treatment algorithm for shoulder cartilage defects. They suggest that a low-demand patient with a focal, symptomatic lesion may respond well to arthroscopic lavage and debridement.

Weinstein et al.[23] reported on 25 patients with a mean age of 46 years who underwent arthroscopic debridement for early osteoarthritis of the shoulder. Patients had arthroscopic debridement of the chondral surface with subacromial space bursectomy without decompression or other concomitant procedures. At a mean follow-up of 30 months, 78% had good or excellent results. All patients with unsatisfactory results had some degree of pain relief for a minimum of 8 months. The authors also noted a trend between severity of chondral damage and inferior outcome results. Our results differed from their study, in that our patients were younger and were treated with a marrow-stimulating technique for focal cartilage defects, not osteoarthritis. We did find a negative correlation between lesion size and ASES improvement, so patients with larger lesions had less improvement postoperatively in their ASES scores.

In 2003 Siebold et al.[11] reported on a series of 5 patients treated with microfracture in combination with periosteal flap coverage for a humeral head defect. All patients had grade IV cartilage lesions of the humeral head. All had significant postoperative pain relief and increased functionality, at a mean follow-up of 25 months. The short-term results were satisfactory, but the authors noted that imaging studies showed progression of osteoarthritis in 2 patients, and 2 of 3 patients who underwent second-look arthroscopy had significantly reduced cartilage lesions.

Kerr and McCarty[24] compared patients with unipolar and bipolar shoulder cartilage lesions. They evaluated 19 patients aged younger than 55 years with Outerbridge grade II to IV articular changes who were treated with glenohumeral debridement. Of the 19 patients, 2 received microfracture in conjunction with debridement. At 1 year, 3 patients had progressed to shoulder arthroplasty despite reporting better shoulder function after debridement. The authors found that the lesion grade did not influence outcome scores, but patients with unipolar lesions had higher outcome scores than patients with bipolar lesions. Our results did show a trend that patients with bipolar lesions did not improve as much as patients with unipolar lesions. However, 3 of the 5 patients with bipolar lesions also had a capsular release or manipulation under anesthesia versus 4 of 20 in patients with unipolar defects. It might be that patients benefited more from the capsular release than the microfracture. In this series patients who had a capsular release in combination with microfracture had the most substantial increase in their ASES scores.

Perhaps one of the most important findings in this study was that the microfracture technique did not compromise future shoulder resurfacing or reconstructive options. Microfracture may be an effective tool in managing painful shoulder cartilage defects and delaying the need for invasive resurfacing or arthroplasty. In the future, histology and mechanical properties of the repair tissue in the microfractured lesion should be evaluated. More research is needed to determine how early arthroscopic microfracture of shoulder chondral defects may alter the cascade of joint degeneration and affect long-term outcomes. Finally, a larger population of patients is needed to assess the difference in healing and outcomes in patients with acute versus chronic chondral defects.

Our study was limited by the retrospective design, the small number of patients, the lack of a control group, and the relatively short follow-up periods. The study conclusions are limited by the fact that only 67% of the patients were able to be followed up. Another weakness of this study group was that only 4 patients had an isolated microfracture procedure, which limits generalizations. It is important to note that a variety of other pathologies were addressed during the index arthroscopies, and the degree to which the ASES scores can be attributed to the microfracture procedure is unclear.

CONCLUSIONS

Failure occurred in 6 of the 31 shoulders (19%). In the remaining patients there was an overall significant improvement of 20 points (range, −11 to 45 points) in the ASES score. In those patients in whom just the humerus was treated, the greatest improvement was seen, with an increase of 32 points (range, 3 to 87 points). There was a negative correlation between the size of the lesion and ASES improvement ($r = -0.351$, $P = .124$). Our early results have shown that microfracture, combined with other indicated procedures, is able to significantly increase patients' ability to perform activities of daily living and to participate in athletics. Our data showed the greatest improvement for smaller lesions of the humerus with the worst results in patients with bipolar lesions.

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