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# THE MICROFRACTURE TECHNIQUE FOR THE TREATMENT OF ARTICULAR CARTILAGE LESIONS IN THE KNEE

## A PROSPECTIVE COHORT STUDY

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**Background:** Microfracture is a frequently used technique for the repair of articular cartilage lesions of the knee. Despite the popularity of the technique, prospective information about the clinical results after microfracture is still limited. The purpose of our study was to identify the factors that affect the clinical outcome from this cartilage repair technique.

**Methods:** Forty-eight symptomatic patients with isolated full-thickness articular cartilage defects of the femur in a stable knee were treated with the microfracture technique. Prospective evaluation of patient outcome was performed for a minimum follow-up of twenty-four months with a combination of validated outcome scores, subjective clinical rating, and cartilage-sensitive magnetic resonance imaging.

**Results:** At the time of the latest follow-up, knee function was rated good to excellent for thirty-two patients (67%), fair for twelve patients (25%), and poor for four (8%). Significant increases in the activities of daily living scores, International Knee Documentation Committee scores, and the physical component score of the Short Form-36 were demonstrated after microfracture ( $p < 0.05$ ). A lower body-mass index correlated with higher scores for the activities of daily living and SF-36 physical component, with the worst results for patients with a body-mass index of  $>30 \text{ kg/m}^2$ . Significant improvement in the activities of daily living score was more frequent with a preoperative duration of symptoms of less than twelve months ( $p < 0.05$ ). Magnetic resonance imaging in twenty-four knees demonstrated good repair-tissue fill in the defect in thirteen patients (54%), moderate fill in seven (29%), and poor fill in four patients (17%). The fill grade correlated with the knee function scores. All knees with good fill demonstrated improved knee function, whereas poor fill grade was associated with limited improvement and decreasing functional scores after twenty-four months.

**Conclusions:** Microfracture repair of articular cartilage lesions in the knee results in significant functional improvement at a minimum follow-up of two years. The best short-term results are observed with good fill grade, low body-mass index, and a short duration of preoperative symptoms. A high body-mass index adversely affects short-term outcome, and a poor fill grade is associated with limited short-term durability.

**Level of Evidence:** Therapeutic Level IV. See Instructions to Authors for a complete description of levels of evidence.

Articular cartilage defects of the knee are frequently observed. Curl et al. described 53,569 hyaline cartilage lesions in 19,827 patients undergoing knee arthroscopy<sup>1</sup>. Similarly, a more recent prospective survey of 993 consecutive knee arthroscopies demonstrated evidence of articular cartilage abnormality in 66%<sup>2</sup>. Articular cartilage defects of the femoral condyles have also been observed in up to 50% of athletes undergoing anterior cruciate ligament reconstruction<sup>3</sup>. Because of their poor spontaneous repair po-

tential, these articular cartilage lesions present a clinical treatment dilemma, particularly in young and active individuals<sup>4,6</sup>. Several techniques for the treatment of articular cartilage defects have been described recently with varying results and indications<sup>5-11</sup>. Microfracture represents a frequently used technique used to attempt repair of symptomatic articular cartilage defects of the knee<sup>12-15</sup>. Penetration of the subchondral bone plate in these defects leads to clot formation in the defect. This clot contains pluripotent, marrow-derived mesen-

chymal stem cells, which produce a fibrocartilage repair with varying amounts of type-II collagen content<sup>10-19</sup>. Because of the technical simplicity, low morbidity, and cost-effectiveness of microfracture, it is frequently used as a first-line treatment option. Despite the popularity of the technique, few studies are available on the clinical results after microfracture repair of knee articular cartilage. Moreover, the factors relevant to the functional outcome following microfracture are poorly understood. We hypothesized that microfracture would result in improved functional outcome scores at a minimum two-year follow-up and that functional scores would correlate positively with the percentage of the lesion filled. Using a combination of validated outcome instruments and high-resolution, cartilage-specific magnetic resonance imaging, we prospectively studied the results of repair of knee articular cartilage with microfracture to identify factors influencing the clinical outcome.

### Materials and Methods

Data collection was performed as part of an institutional cartilage repair registry. The registry was approved by the institutional review board, and all patients signed an informed consent form before participation. Patients included in the registry were evaluated preoperatively and were prospectively followed for three, six, twelve, twenty-four, thirty-six, or forty-eight months postoperatively. Two hundred and fifty-four patients were treated for symptomatic articular cartilage lesions at our institution and were entered into the cartilage repair registry. One hundred and forty-four of the 254 patients had been treated with the microfracture technique. From these 144 patients, all those with clinical evidence of a fixed flexion deformity, ligamentous instability, genu varum or valgum malalignment, generalized osteoarthritis, multiple lesions, patellar or tibial lesions, concomitant ligamentous stabilizations, or follow-up of less than twenty-four months were excluded from the study. Fifty-two patients who lacked these exclusion criteria were identified. They had been treated for single Outerbridge grade-3 or 4 lesions of the medial or lateral femoral condyle or trochlea with a minimum follow-up of twenty-four months. Forty-eight patients (92%) were available for follow-up, while four were lost to follow-up.

Thirty-seven patients (77%) were male and eleven (23%) were female, with an average age (and standard deviation) of  $41 \pm 12$  years (range, sixteen to sixty years). The patients had undergone an average of 0.8 surgical procedure (range, zero to seven procedures) before microfracture, with thirty-two (66%) of the patients presenting without prior surgery on the affected knee. The preoperative duration of symptoms averaged  $28 \pm 60$  months (range, one to 375 months). The mean body-mass index was  $26 \pm 4.3$  kg/m<sup>2</sup> (range, 20 to 40 kg/m<sup>2</sup>). The lesion size averaged 482 mm<sup>2</sup> (range, 24 to 2000 mm<sup>2</sup>; median, 275 mm<sup>2</sup>) (Table I). The lesions were located on the medial femoral condyle (54%), lateral femoral condyle (23%), and trochlea (23%). The etiology of the defect was traumatic in 56% and nontraumatic in 44%, and it was

**TABLE I** Distribution of the Articular Cartilage Lesions According to Size Among the Forty-eight Patients

Size of Lesion (mm <sup>2</sup> )	No. (%) of Patients
0-100	6 (13)
101-400	25 (52)
401-1000	9 (19)
>1000	8 (17)

independent of age ( $r = 0.227$ ,  $p = 0.121$ ). Eighty-four percent of the defects were chondral lesions, while the remaining 16% were osteochondral lesions without cavitation.

### Surgical Procedure

Surgery was performed only by surgeons who were well trained and experienced with the microfracture technique. A thorough diagnostic arthroscopy was performed in all patients to identify any additional intra-articular abnormality. A partial tear in the white-white zone of the meniscus was found in ten patients (21%) and was the only concomitant lesion included in the study. Six meniscal tears were located in the same compartment as the cartilage lesion. All meniscal tears were treated with partial meniscectomy. Microfracture of the isolated femoral cartilage lesion was then performed according to the method described by Steadman et al.<sup>15</sup>. This included débridement of the cartilage lesion to stable cartilage margins, careful removal of the calcified cartilage layer, and micropenetration of the subchondral bone with use of commercially available instrumentation (Linvatec, Largo, Florida). The 4-mm-wide subchondral bone bridges were carefully maintained between each microfracture hole to ensure the preservation of subchondral bone-plate integrity and function. Release of blood and marrow fat droplets from the microfracture holes was confirmed by eliminating arthroscopic pump pressure. In patients with femoral condylar lesions, continuous passive motion was started in the recovery room at 0° to 60° and was gradually increased until full passive motion was achieved. It was continued for six hours per day for six weeks. Avoidance of weight-bearing was maintained for six weeks. Patients with trochlear lesions were allowed to bear weight as tolerated, and motion was avoided for forty-eight hours. Thereafter, full weight-bearing was allowed, although active flexion was limited to 0° to 20°; however, the continuous passive motion from 0° to 80° was used for six weeks. Stationary bicycling was allowed as soon as range of motion permitted. Full weight-bearing was usually introduced between seven and eight weeks after surgery, and a return to regular activities was generally achieved six to eight months postoperatively<sup>15,20</sup>.

### Functional Outcome Evaluation

Clinical outcome was evaluated at a minimum of two years after the index procedure. The average time from the index procedure to the latest evaluation was forty-one months (range,

twenty-four to fifty-four months). Postoperative data collection was performed by an independent observer at three, six, twelve, twenty-four, thirty-six, or forty-eight months after microfracture. A follow-up evaluation was carried out in all forty-eight patients at twenty-four months. Follow-up evaluations were completed in thirty-four patients at thirty-six months and in five patients at forty-eight months. Instruments for outcome evaluation included a preoperative and postoperative subjective clinical rating of knee function by the patient as excellent, good, fair, or poor<sup>9</sup>; the activities of daily living scale of the Knee Outcome Survey<sup>21</sup>; and the Medical Outcome Study 36-Item Short Form Health Survey (SF-36) physical component scale (version 1.0)<sup>22</sup>; and the International Knee Documentation Committee (IKDC) score. These knee-specific outcome instruments have been previously validated at our institution and have been previously used for prospective evaluation of knee articular cartilage repair<sup>9,10,13,14,19,23</sup>. Treatment durability was defined as the ability of patients to maintain improvement of functional scores for more than two years after microfracture.

#### Magnetic Resonance Imaging

Of the forty-eight patients treated with the microfracture technique in our study, twenty-four (50%) agreed to participate in a follow-up magnetic resonance imaging evaluation. Magnetic resonance imaging was performed for study purposes only and not on the basis of clinical symptoms, and it was acquired at an average of  $12 \pm 2$  months (range, three to thirty-eight months) after surgery. Imaging was performed at less than six months for three patients (13%), at six to twelve months for fifteen (61%), and at more than twelve months for six patients (26%) after microfracture (Fig. 1). Six patients had serial magnetic resonance imaging scans with an average of  $1.3 \pm 0.1$  scans (range, one to three scans) per patient. In these six patients, the findings of the most re-

cent magnetic resonance imaging evaluation were used for the functional outcome analysis. No significant difference between the patients with or without follow-up magnetic resonance imaging studies was found with regard to demographic data ( $p > 0.650$ ); lesion characteristics ( $p > 0.450$ ); preoperative duration of symptoms ( $p = 0.793$ ); body-mass index ( $p = 0.217$ ); length of postoperative follow-up ( $p = 0.902$ ); and preoperative and postoperative scores for the activities of daily living ( $p = 0.250$ ), SF-36 physical component ( $p = 0.250$ ), IKDC ( $p = 0.820$ ), and subjective ratings ( $p = 0.867$ ). Magnetic resonance imaging was performed in a 1.5-T magnet (Signa Horizon LX; General Electric Medical Systems, Milwaukee, Wisconsin) with use of either a linear receive-only knee extremity coil or a transmit-and-receive phased-array coil. Fast-spin-echo images were acquired in three planes to assess articular cartilage with use of a previously validated cartilage-sensitive pulse sequence<sup>24</sup>. This technique uses moderate echo time fast-spin-echo imaging and provides high contrast resolution between articular cartilage, subchondral bone, and joint fluid while avoiding the susceptibility artifacts of postoperative knee gradient-echo imaging techniques<sup>24</sup>. All images were acquired with a repetition time of 3500 to 500 msec, an echo time of 34 msec (effective), a field of view of 13 to 16 cm<sup>2</sup>, a matrix of  $512 \times 256$  to  $354$ , providing a maximum in-plane resolution of  $254 \mu\text{m}$  in the frequency direction by  $406$  in the phase direction by a slice resolution of 3 to 3.5 mm with no gap. A wider receiver bandwidth of 31.2 kHz was used over the entire frequency range to minimize chemical shift misregistration. To assess for the presence of subchondral bone marrow edema, an additional sagittal image was performed with frequency-selective fat suppression (ChemSat; General Electric Medical Systems).

Image assessment was performed by a senior musculoskeletal radiologist who had no knowledge of the patient or

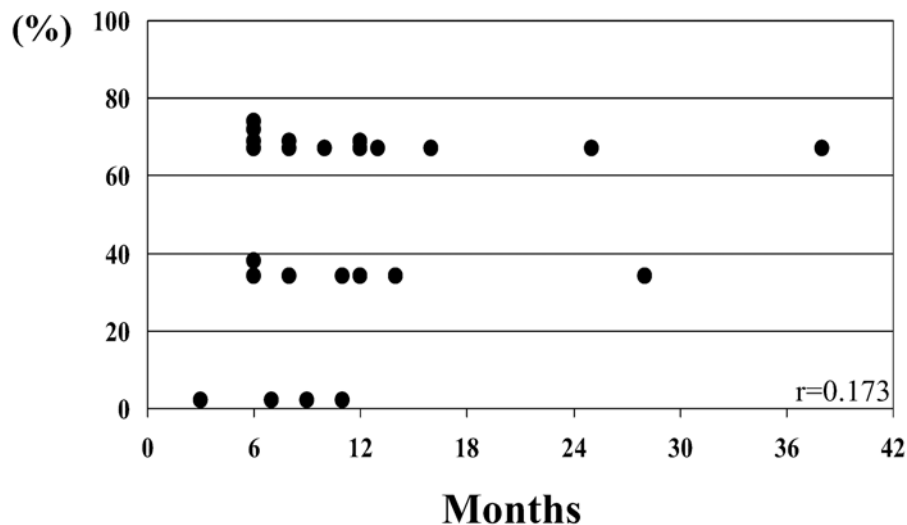


Fig. 1

Scattergraph showing repair cartilage fill volume, detected with use of cartilage-sensitive magnetic resonance imaging, as a function of the postoperative interval after microfracture arthroplasty ( $r = 0.173$ ,  $p = 0.420$ ).

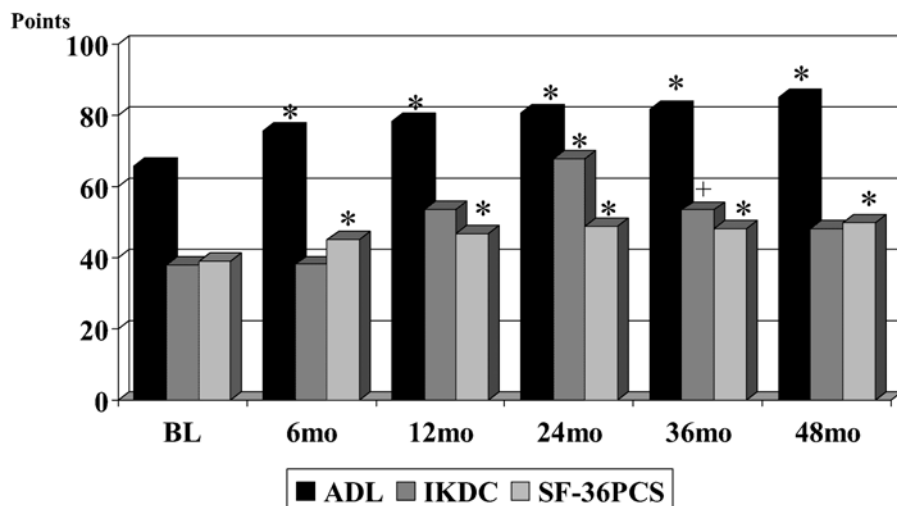


Fig. 2

Histogram showing the development of the activities of daily living (ADL) score, International Knee Documentation Committee (IKDC) score, and Short Form-36 physical component score (SF-36 PCS) following microfracture of femoral articular cartilage lesions in the knee. Significant increases in all scores were observed within the first twenty-four months (forty-eight patients), and a decrease in IKDC scores was noted after twenty-four months (thirty-four patients who were followed for thirty-six months and five patients who were followed for forty-eight months). An asterisk indicates a significant difference compared with baseline (BL) ( $p < 0.05$ ), and a plus sign indicates a significant difference compared with results at twenty-four months ( $p < 0.05$ ).

the treating surgeon. The images were assessed for signal of the repair cartilage with use of a region-of-interest analysis on a workstation (Advantage Windows; General Electric Medical Systems) compared with the native cartilage. Repair morphology was described as depressed, flush, or proud compared

with the surrounding native cartilage. Volume filling of the defect by repair cartilage was measured with use of coronal and sagittal images and was graded as good (67% to 100%), moderate (34% to 66%), or poor (0% to 33%) on the basis of the percentage of the defect that was filled. The interface with

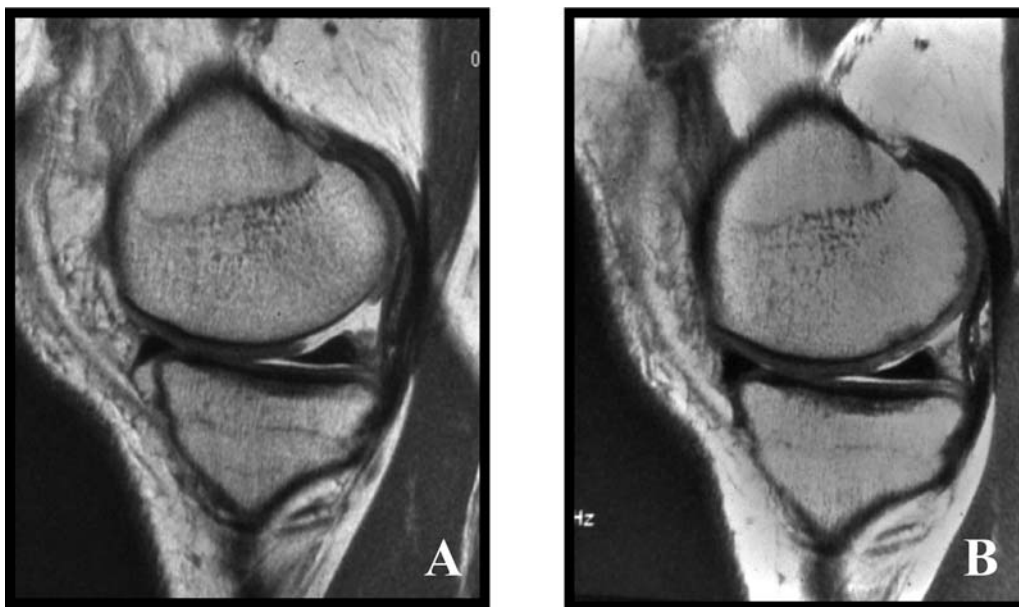


Fig. 3

Sagittal fast-spin-echo magnetic resonance imaging scans of the knee in a thirty-year-old patient with a full-thickness lesion of the medial femoral condyle. A: Scan acquired before microfracture. B: Scan acquired four months after microfracture, demonstrating moderate fill of the defect with hyperintense repair tissue signal and smooth peripheral integration.



Fig. 4-A



Fig. 4-B

**Figs. 4-A, 4-B, and 4-C** Serial coronal fast-spin-echo magnetic resonance imaging scans of the knee in a thirty-three-year-old woman who had a full-thickness articular cartilage defect of the medial femoral condyle, demonstrating progressive increase fill volume over time (arrows). **Fig. 4-A** Three months after microfracture. **Fig. 4-B** Eighteen months after microfracture.

the adjacent native cartilage surface was evaluated and graded as small (a gap of  $\leq 2$  mm) or large (a gap of  $>2$  mm). Subchondral bone-marrow edema was graded as mild ( $<1$  cm<sup>2</sup>), moderate (1 to 3 cm<sup>2</sup>), or severe ( $>3$  cm<sup>2</sup>), and the presence or absence of osseous overgrowth was carefully recorded<sup>25</sup>.

#### Statistical Analysis

Intragroup comparison between parameters before and after microfracture was tested with use of the paired t test. Differences between variable proportions were evaluated with chi-square analysis. For testing relationships between variables, linear regression and correlation analysis were used. P values of  $<0.05$  were considered significant.

#### Results

At a mean follow-up of  $41 \pm 7$  months after microfracture, thirty-two patients (67%) reported good or excellent subjective results, twelve (25%) had fair knee function, and only four (8%) reported poor function. Ten of the eleven poor preoperative ratings improved following microfracture ( $p < 0.05$ ). The activities of daily living scores, SF-36 physical component scores, and IKDC scores increased significantly following microfracture ( $p < 0.05$ ) (Fig. 2). Thirty-three patients (69%) showed decreases in the IKDC scores after twenty-four months ( $p < 0.05$ ) (Fig. 2). Decreasing IKDC scores were seen in all patients with poor repair cartilage fill compared with only three of thirteen patients with good fill grade ( $p < 0.05$ ). With the numbers available, the average lesion size, patient age, preoperative interval, and body-mass index for patients with decreasing IKDC scores were not different from those for patients without decreasing scores.

Magnetic resonance imaging demonstrated a hyperintense signal in the repair cartilage in twenty-two (92%) of the twenty-four patients and mild subchondral edema in



Fig. 4-C

Thirty-eight months after microfracture.

seventeen (71%). Repair cartilage fill was graded as good (67% to 100%) in the majority of patients, but most treated lesions demonstrated depressed repair cartilage morphology relative to the adjacent hyaline cartilage (Table II, Fig. 3). For six patients, sequential magnetic resonance imaging studies were available and all demonstrated at least moderate fill volume. There was no deterioration of fill volume in these patients, but one patient showed improvement of fill over time (Figs. 4-A, 4-B, and 4-C). No statistical correlation was detected between repair cartilage volume and the time since microfracture ( $r = 0.173$ ,  $p = 0.420$ ) (Fig. 1). Osseous overgrowth was demonstrated in six patients (25%) (Fig. 5). Two-thirds of the patients with osseous overgrowth showed a good fill grade. All thirteen patients with a good fill grade

demonstrated an improvement in the scores for the activities of daily living, whereas only three patients with moderate defect fill and only one patient with poor defect fill had improved scores ( $p < 0.05$ ). Similarly, the SF-36 physical component scores and subjective ratings significantly increased for patients with a good fill grade on magnetic resonance imaging ( $p < 0.05$ ) (Fig. 6). Decreasing functional scores after twenty-four months were observed for all patients with a poor fill grade after microfracture, for two patients with a moderate fill grade ( $p = 0.097$ ), and for three patients with a good fill grade ( $p < 0.05$ ). The activities of daily living score ( $p < 0.05$ ,  $r = 0.385$ ) and the SF-36 physical component score ( $p < 0.05$ ,  $r = 0.388$ ) obtained at the time of magnetic resonance imaging demonstrated a positive statistical correlation with fill grade.

Patients with good repair fill had a lower body-mass index than did the patients with poor fill grade ( $p < 0.05$ ). A lower body-mass index was associated with a better fill grade on magnetic resonance imaging ( $p < 0.05$ ,  $r = 0.520$ ). Persistent gap formation at the interface with the surrounding native cartilage was observed in twenty-two (92%) of the twenty-four patients who had magnetic resonance imaging, with most gaps measuring  $\leq 2$  mm (Table II). Peripheral interfacing correlated well with the fill grade ( $p < 0.0001$ ,  $r = 0.778$ ), with twelve of the thirteen repairs with good fill demonstrating interfaces of  $< 2$  mm. Interfacing did not correlate with the outcome scores ( $p = 0.279$ ,  $r = 0.230$ ). Three of the four patients with poor fill were more than thirty years old. However, with the numbers available, age, gender, preoperative duration of symptoms, defect location, defect type (chondral compared with osteochondral), defect size, number of prior operations, and concomitant meniscectomy were not



Fig. 5

Sagittal fast-spin-echo magnetic resonance imaging scan acquired twelve months after microfracture treatment of a cartilage defect of the lateral femoral condyle, demonstrating prominent osseous overgrowth of the subchondral bone (arrow) with resultant relative thinning of the overlying repair cartilage.

**TABLE II** Magnetic Resonance Imaging Findings in Twenty-four Knees After Microfracture

Finding	No. (%) of Knees
Repair cartilage signal	
Hyperintense	22 (92)
Isointense	1 (4)
Hypointense	1 (4)
Repaired lesion morphology	
Proud	2 (8)
Flush	9 (38)
Depressed	13 (54)
Repair cartilage fill	
Good (67%-100%)	13 (54)
Moderate (34%-66%)	7 (29)
Poor (0%-33%)	4 (17)
Peripheral repair cartilage integration	
No gap	2 (8)
Small (gap of $\leq 2$ mm)	12 (50)
Large (gap of $> 2$ mm)	10 (42)
Subchondral edema	
Mild ( $< 1$ cm <sup>2</sup> )	17 (71)
Moderate (1-3 cm <sup>2</sup> )	7 (29)
Severe ( $> 3$ cm <sup>2</sup> )	0 (0)
Osseous overgrowth	6 (25)

found to be significantly related to magnetic resonance imaging parameters.

Body-mass index was inversely correlated with the activities of daily living score ( $p < 0.05$ ,  $r = -0.330$ ) and the SF-36 physical component subscore ( $p < 0.05$ ,  $r = -0.343$ ). Patients with a body-mass index of  $> 30$  kg/m<sup>2</sup> demonstrated the lowest outcome scores and the worst subjective rating (Fig. 7). The preoperative duration of symptoms also significantly affected outcome, as twenty-two (76%) of the twenty-nine patients with a preoperative interval of less than twelve months showed improvement in the activities of daily living scores compared with seven of the nineteen patients with a longer preoperative interval ( $p < 0.05$ ). A similar trend was noted for the SF-36 physical function subscore ( $p = 0.08$ ). A trend toward better scores on the activities of daily living scale was also observed for patients who were less than thirty years old when they had microfracture repair compared with patients who were older when they had the procedure ( $p = 0.072$ ). With the numbers available, gender, defect size, defect location, defect type, prior operations, and presence or absence of concomitant partial meniscectomy also did not appear to influence outcome scores.

## Discussion

This study demonstrated that microfracture arthroplasty resulted in increased functional scores in patients treated for symptomatic cartilage lesions at a minimum follow-up of

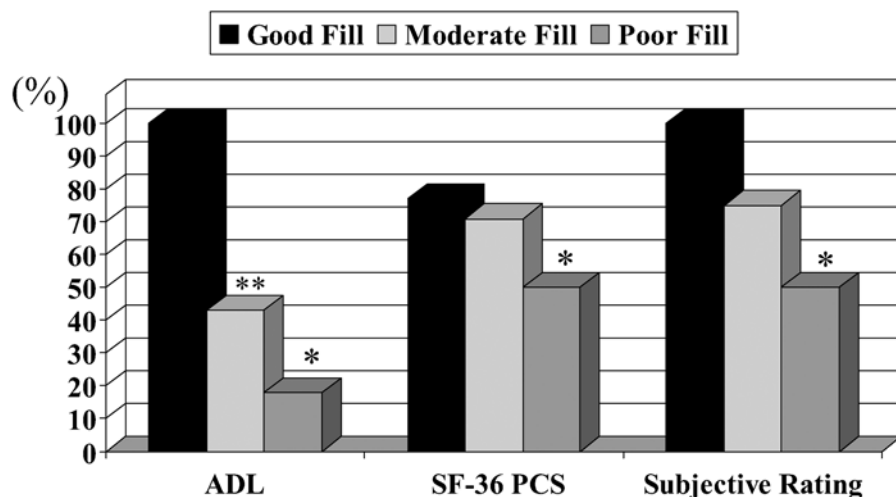


Fig. 6

Histogram demonstrating the rate of improvement in the activities of daily living (ADL) score, SF-36 physical component subscale (SF-36 PCS), and subjective rating for the patients in whom the repair cartilage provided good fill (black), moderate fill (light gray), or poor fill (dark gray). A single asterisk indicates a significant difference between knees with good fill and those with poor fill ( $p < 0.05$ ). A double asterisk indicates a significant difference between knees with good fill and those with moderate fill ( $p < 0.05$ ).

two years. The overall clinical results with microfracture in our study are comparable with those in previous reports, which have shown improved knee function in 70% to 95% of patients<sup>10,12,14,19,26</sup>. Steadman et al. reported that their patients had substantial increases in the ability to perform the activities of daily living, strenuous work, and sports after microfracture<sup>14</sup>. This finding is consistent with the significant in-

crease in the activities of daily living scores observed in our study. Besides the changes in the activities of daily living score, we also observed significant increases in the SF-36 physical component subscale and the IKDC scores after microfracture. Increases in the IKDC and SF-36 physical component scores have been reported after microfracture by other authors, attesting to the reproducibility of these results<sup>10,19</sup>.

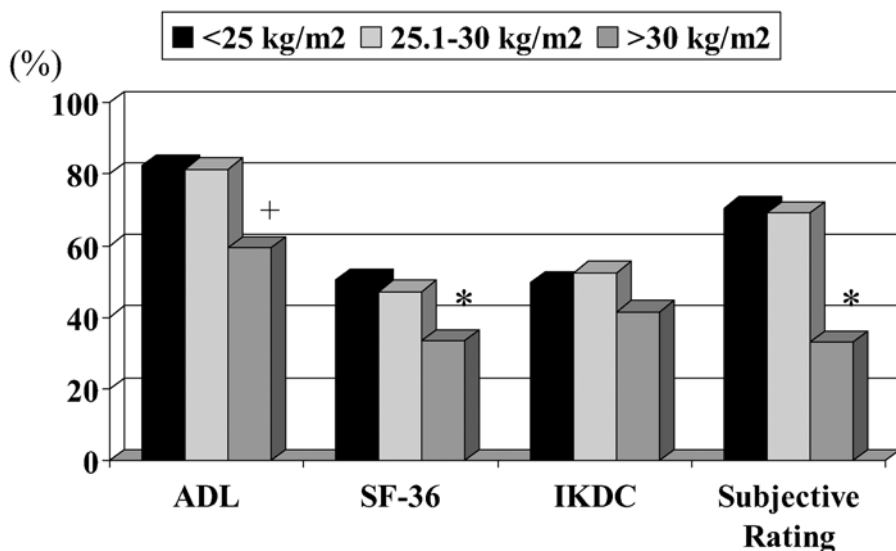


Fig. 7

Histogram showing the rate of improvement in the activities of daily living (ADL) scores, SF-36 physical component subscales (SF-36 PCS), International Knee Documentation Committee (IKDC) scores, and subjective ratings in patients with a body-mass index of >30kg/m<sup>2</sup> (dark gray), 25 to 30 kg/m<sup>2</sup> (light gray), and <25 kg/m<sup>2</sup> (black). The lowest improvement rate is consistently observed with a body-mass index of >30 kg/m<sup>2</sup>. An asterisk indicates a significant difference ( $p < 0.05$ ). A plus sign indicates a significant difference ( $p < 0.01$ ).

Similar to our findings, the most substantial improvement after microfracture has been shown to occur within the first two postoperative years in several other studies<sup>10,12,14,19,26</sup>. This may be due to the continued qualitative and quantitative maturation of the repair cartilage tissue<sup>14,16,17</sup>. Increasing cartilage fill was demonstrated on serial magnetic resonance imaging studies in one of our patients and may explain why maximum improvement was described only after two to three years by Steadman et al.<sup>14</sup>. In contrast to some other studies, our findings indicated a deterioration of knee function after two years<sup>10,14</sup>. The limitation of follow-up to two years or less may have prevented this observation by some authors<sup>10</sup>. As we found in our patients, other investigators have observed that pain scores decreased in recreational athletes three years after microfracture<sup>26</sup> and Tegner scores declined in 80% of the patients two years after microfracture<sup>19</sup>. The reason for this decline in functional score has not yet been identified. While some patients may simply change their interest in a given sport, Steadman et al.<sup>14</sup> observed that deterioration of knee function occurred in some patients who did not demonstrate repair cartilage fill at second-look arthroscopy. Since the decrease in knee function after twenty-four months was primarily observed in patients with a poor fill grade after cartilage repair, our study provides the first clinical evidence that repair cartilage volume plays a critical role in the durability of functional improvement in the knee after microfracture repair. Similar to the 17% rate of poor fill (four of twenty-four patients) in our study, Blevins et al.<sup>26</sup> described the persistence of subchondral bone exposure in 8% to 35% of the lesions treated with microfracture at the time of second-look arthroscopy. Poor filling may explain the decrease in function observed in some of the athletes in that study. While deterioration was seen in all patients with poor fill in our study, our data indicated that deterioration of knee function is not limited to patients with a poor fill grade and that other factors must be considered. In addition, our results indicated that postoperative magnetic resonance imaging, with use of a previously described cartilage-sensitive pulse sequence with high contrast resolution<sup>24</sup>, can be useful to differentiate between patients who will show durable improvement of knee function after microfracture and those who will not. Finally, these results suggest that there is a subgroup of patients who do not form a sufficient repair cartilage volume after microfracture and experience only temporary functional improvement, while patients with a high fill volume have superior functional results and durability. Due to the limited number of serial magnetic resonance imaging scans in our investigation, additional studies are necessary to better describe the changes of repair cartilage fill over time.

Our study demonstrated the clinical importance of body-mass index on functional outcome after microfracture repair of articular cartilage in the knee. In particular, a high body-mass index (>30 kg/m<sup>2</sup>) was associated with a significantly poor functional outcome after microfracture. Increased cartilage degradation has been shown in osteoarthritic patients with a body-mass index in excess of 25 kg/m<sup>2</sup>. This is thought

to result from increased cartilage matrix catabolism in that patient population, and the same mechanism may be at work affecting the repair cartilage after microfracture<sup>27-29</sup>. As in previous reports, which have noted that excessive loading may be detrimental for articular cartilage repair with marrow-stimulation techniques<sup>5</sup>, our observation that the most significant effect occurred in subjects with a body-mass index of >30 kg/m<sup>2</sup> suggests that an excessive body-mass index may present a relative contraindication for microfracture repair in the knee.

Previous studies have shown that articular cartilage repair after microfracture in patients who are less than thirty years old had better clinical outcomes<sup>10,14</sup>. A trend toward better functional scores in patients who were younger than thirty years was also observed in our patients and may be attributed to an age-dependent qualitative and quantitative difference in metabolic activity in the repair cartilage<sup>5,6,30</sup>. However, we were unable to detect a statistical correlation between age and repair tissue fill volume in the cartilage defect. This may be due to the fact that magnetic resonance imaging studies were available for only half of our patients.

The preoperative duration of symptoms was found to be an important factor for cartilage repair with microfracture in our study, as significantly fewer patients with preoperative intervals of more than twelve months showed improved activities of daily living scores. Similarly, prolonged preoperative intervals also have been associated with an inferior grade of repair cartilage at second-look arthroscopy after microfracture<sup>26</sup>. A worse functional outcome has also been observed for both autologous chondrocyte transplantation and mosaicplasty after a prolonged preoperative duration of symptoms<sup>9,11</sup>. Cartilage defects left untreated for prolonged periods may lead to the development of early degenerative joint changes, particularly at the margin of the defects, perhaps explaining the inferior results that have been observed with late repair in our study and other investigations. Our findings, therefore, further emphasize the importance of early surgical treatment of articular cartilage lesions.

Magnetic resonance imaging demonstrated a primarily hyperintense signal in the repair tissue, which is consistent with a less organized cartilage repair<sup>24,25,31</sup>, allowing for increased mobility of water, and confirms previous histological findings in clinical and experimental studies that have demonstrated a predominantly fibrocartilaginous repair after microfracture<sup>10</sup>. Experimental studies with use of an equine model have shown that the volume of the repair tissue after microfracture averaged 64% and an average of 59% of the filling contained fibrous-like tissue or fibrocartilage<sup>15,16,32</sup>. This is consistent with our magnetic resonance imaging findings that most patients had moderate-to-good filling but persistent depression of the defect. However, despite incomplete filling, all patients with a fill volume of more than two-thirds of the defect demonstrated significant improvement in knee function after microfracture. This suggests that complete filling of the lesion may not be necessary at least for short-term functional improvement, but enhancing the filling increases the opportunity for clinical improvement.

Persistent gaps between the native and repair cartilage were observed in 92% of the microfracture repairs. This finding is consistent with observations in previous clinical and laboratory studies, which have demonstrated failure of peripheral integration of the repair cartilage after microfracture in as much as 53% of the repairs<sup>16,25</sup>. This failure of peripheral integration is believed to increase the vertical shear stresses between repair and native cartilage, thereby promoting micro-motion and degenerative changes<sup>32,33</sup>. Failure of peripheral integration is also observed with other cartilage repair techniques<sup>10,11</sup>. The magnitude of the persistent gap in our study correlated with the overall grade of the repair cartilage fill. This suggests that peripheral integration depends on other factors involved in cartilage repair and could explain the absence of a statistical effect of persistent gaps alone on functional outcome in our study.

Osseous overgrowth following microfracture has not been well described and was observed in 25% of the patients who had magnetic resonance imaging in our study. This phenomenon is thought to result from metaplasia of the deep layer of the repair cartilage after microfracture stimulation<sup>32</sup> and has been demonstrated in up to 49% of patients after microfracture in the knee<sup>25</sup>. The factors responsible for the development of osseous overgrowth have not been defined, but excessive removal of the subchondral bone plate during débridement or removal of the calcified cartilage layer may promote vascularization of the base of the repair tissue and provide a stimulus for endochondral ossification<sup>34</sup>. Magnetic resonance imaging studies in this series demonstrated that osseous overgrowth results in a relative thinning of the overlying repair cartilage, which may have biomechanical implications for the repair cartilage and its function and durability<sup>35,36</sup>. A longer duration of follow-up and a larger number of patients are needed to further evaluate this finding.

The limitations of our study included the lack of a control group, the short-to-mid-term follow-up interval, and the absence of clinical examination data. Despite these shortcomings, we were able to demonstrate significant changes in knee function and were able to identify several factors that influence functional outcome after microfracture by using outcome instruments that have been previously validated for the knee<sup>21-23</sup>. With regard to the morphology of the repair, only 50% of our patients agreed to a follow-up magnetic resonance imaging study. However, no significant differences between

the patients with or without a follow-up magnetic resonance imaging study were found with respect to demographic data or the preoperative and postoperative outcome scores. This suggests that the findings in the subgroup of patients with follow-up magnetic resonance imaging studies may be representative of the entire study group. Since magnetic resonance imaging was used in our study for noninvasive evaluation of the repair cartilage, no histologic or biochemical analysis of the repair tissue was available. While magnetic resonance imaging is not able to replace a tissue biopsy, a recent study has demonstrated a good correlation between visual scores at second-look arthroscopy, histological findings of repair cartilage, and magnetic resonance imaging scores after autologous chondrocyte transplantation<sup>37</sup>.

In summary, microfracture provides subjective functional improvement and significantly increased activity levels in patients with isolated articular cartilage lesions of the femur. The best functional results are observed in patients with a good repair cartilage volume on magnetic resonance imaging, patients with a lower body-mass index, and those with a shorter preoperative duration of symptoms. Poor defect filling frequently results in limited functional improvement and durability of the repair. ■

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