The Microfracture Technique for the Treatment of Full-Thickness Articular Cartilage Lesions of the Knee: Midterm Results

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Purpose: The purpose of this study was to determine the effectiveness of the microfracture technique in the treatment of full-thickness articular cartilage lesions of the knee. **Methods:** In this study the midterm results of 90 patients (47 women and 43 men) with focal full-thickness articular cartilage lesions who had been managed with the microfracture technique are presented. The mean age of our patients was 34.5 years (range, 20 to 58), and 51 right and 39 left knees were treated. All of the articular lesions involved medial femoral condyles. **Results:** On the basis of follow-up at a mean of 68 months (range, 24 to 108 months), mean improvements in Lysholm knee scores (from 54.2 to 84.6 points), Tegner activity scale scores (from 2.6 to 5.2 points), and Oxford knee interrogation scores (from 23.1 to 44.8 points) were observed ($P < .0001$). Moreover, there was a strong and significant correlation between functional results and age younger than 35 years, size of defect less than 2 cm^2, non–weight-bearing surface, and body mass index lower than 25 kg/m^2, respectively ($P < .001$). **Conclusions:** According to our midterm results, the microfracture technique is quite effective with regard to the improvement of daily activities with a favorable impact on pain relief and better functional results. Furthermore, we found that there was a correlation between functional results and age, size of defect, location of defect, and body mass index as prognostic parameters. **Level of Evidence:** Level IV, therapeutic case series. **Key Words:** Cartilage—Defect—Knee—Treatment—Microfracture.

Full-thickness articular cartilage lesions of the knee are among the important problems in current orthopaedic surgery for which there is no definite consensus regarding the preferred surgical management. Because healing potential of these articular lesions is limited, osteoarthritis develops with time. Full-thickness articular cartilage lesions of the knee can manifest many symptoms such as articular pain, swelling, crepitation, and instability. Cartilage lesions can be managed with a wide spectrum of treatment modalities ranging from conservative methods to arthroplasty. The target of surgical treatment is to fill the cartilage defect with newly formed cartilaginous tissue or similar structures and achieve normal knee functions with establishment of integrity of this new regenerate with adjacent cartilage and subchondral bony structure.[1-5]

In young and middle-aged persons who are active with a higher quality of life, articular repair procedures such as abrasion arthroplasty, drilling and microfractures that stimulate regeneration of the cartilage, and articular reconstructive procedures with autologous chondrocyte implantation and mosaicplasty with autografts or allografts have been preferred.[1-13]

In this study the midterm results of 90 patients with full-thickness articular cartilage lesions who we man-

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aged with the microfracture technique were analyzed in light of the literature. The purpose of this study was to demonstrate the effectiveness of a simple and less expensive microfracture technique in the treatment of full-thickness articular cartilage lesions. We hypothesize that the microfracture technique yields satisfactory results.

METHODS

In this study, between October 1998 and January 2006, in 2 different centers, 246 patients with full-thickness articular cartilage lesions of the knee were treated by the microfracture technique. We excluded 28 patients who were lost to regular follow-up and 30 patients (16 anterior cruciate ligament [ACL] ruptures, 13 meniscus ruptures, and 1 posterior cruciate ligament rupture) who had undergone a secondary surgical intervention after the index operation. In addition, 98 of remaining 188 patients were excluded from the study because an ACL rupture, meniscal lesion, patellofemoral problems, plica lesion, other location of defect, or more than 1 location of defect was observed at our index operation. Therefore this study only included 90 patients with focal full-thickness cartilage defects of the medial femoral condyle who have a stable knee joint and are without any concomitant pathology. Furthermore, patients were divided into 2 subgroups depending on age (<35 years or ≥35 years), size of defect (<2 cm^2 or ≥2 cm^2), location of defect (weight-bearing or non–weight-bearing surface), and body mass index (BMI) (<25 kg/m^2 or ≥25 kg/m^2) for intergroup evaluation. The details about our patients are given in Table 1. The microfracture technique was applied in the patients with grade IV full-thickness articular cartilage lesions of the medial femoral condyle categorized according to the Outerbridge classification.[14]

TABLE 1. *Data of Study Population*

No. of patients	90 (47 women and 43 men)
Age (yrs) (range)	34.5 (20-58)
<35 yrs	42
≥35 yrs	48
Follow-up period (mo) (range)	62 (24-108)
Knee operated	51 right and 39 left
Size of defect	
<2 cm^2	68
≥2 cm^2	22
Location of defect	
Weight-bearing surface	42
Non–weight-bearing surface	48
BMI	
<25 kg/m^2	52
≥25 kg/m^2	38

In all of our patients anteroposterior radiographs of both knees were taken in a weight-bearing position, and lateral knee and skyline radiographs of the knee were also obtained. All patients excluding 16 cases underwent magnetic resonance imaging (MRI) examinations. Postoperatively, at the end of twelfth month, MRI examinations were performed in 29 patients by use of the technique recommended by Brown et al.[15]

Detailed information on surgical interventions was provided to all patients. An informed consent form concerning the operative technique to be performed was signed by all patients. The patients were enlightened about the rehabilitation program to be instituted.

Moreover, second-look arthroscopy was performed in 6 patients because of a postoperative traumatic episode after the informed consent form had been obtained. Ruptures of the medial and lateral menisci in 3 patients and ruptures of the ACL in 3 patients were detected, and surgical interventions were performed.

Surgical Technique and Rehabilitation

After routine diagnostic arthroscopy, in case of focal full-thickness articular cartilage defect, cartilaginous remnants on the subchondral bone were debrided fully with an arthroscopic curette and shaver (Fig 1A). Debridement was continued until steep and intact surrounding cartilaginous tissue was obtained. Removal of the calcified cartilaginous layer and achievement of a steep wall adhering closely to the subchondral bone are very important to establish an intact surface for the attachment of fibrous tissue. Elimination of the calcified zone is also important for the nourishment of the cartilage from the subchondral region through diffusion.

After preparation of the bed of the lesion, the microfracture procedure was performed. For this procedure, microfracture awls were used. Holes were created in the defective lesion by use of instruments from appropriate angles. Creation of holes was started from the periphery to the center of the lesion at the demarcation line of the intact cartilage. The holes should be as close to each other as possible; however, a hole should not extend into adjacent holes. Care was taken to create holes of 3 to 4 mm in depth at 3- to 4-mm intervals (Fig 1B).

After creation of microfractures, the tourniquet was loosened, pressures of intra-articular fluids were re-

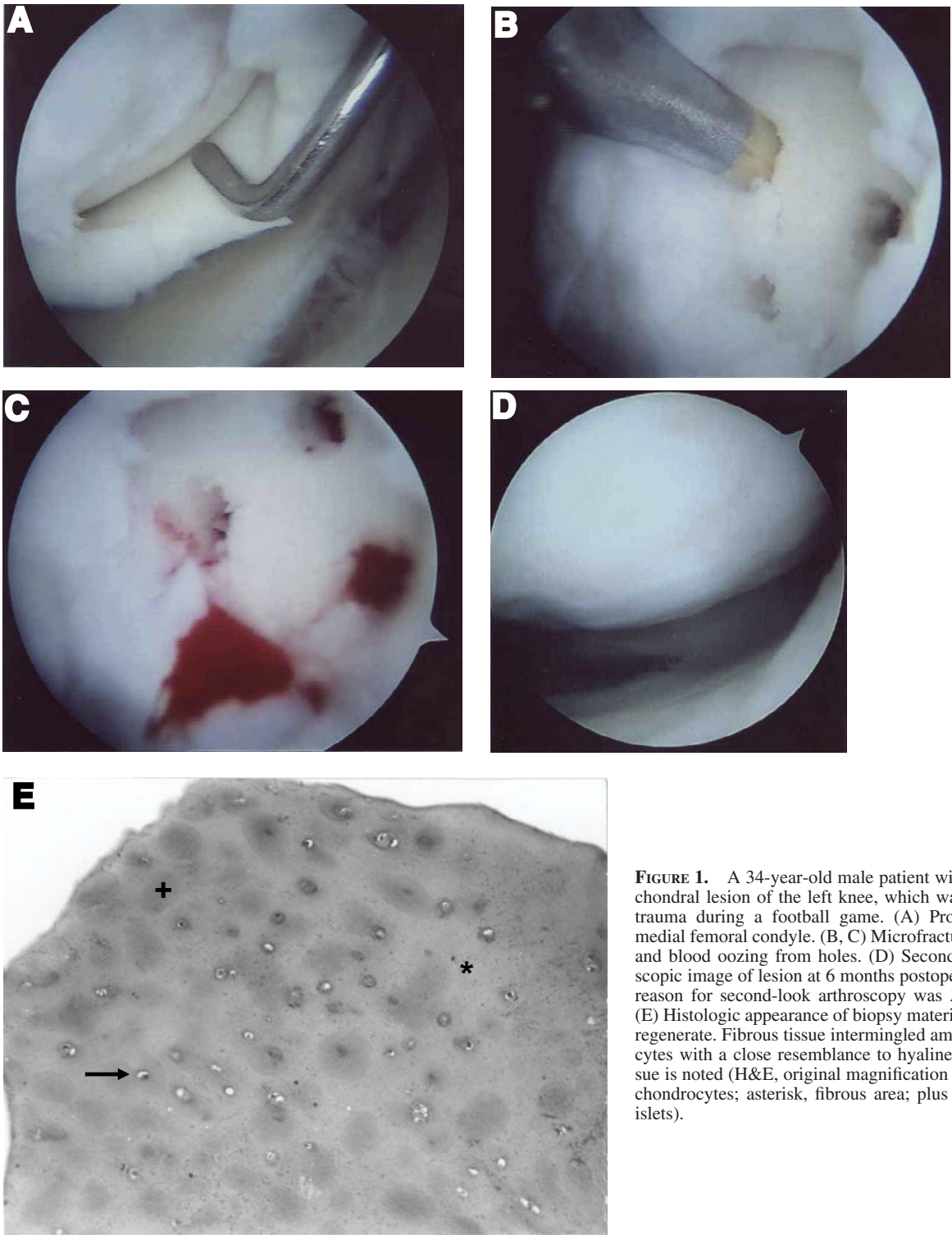

Figure 1. A 34-year-old male patient with a grade IV chondral lesion of the left knee, which was exposed to trauma during a football game. (A) Probe defect of medial femoral condyle. (B, C) Microfracture procedure and blood oozing from holes. (D) Second-look arthroscopic image of lesion at 6 months postoperatively. The reason for second-look arthroscopy was ACL rupture. (E) Histologic appearance of biopsy material taken from regenerate. Fibrous tissue intermingled among chondrocytes with a close resemblance to hyaline cartilage tissue is noted (H&E, original magnification ×40) (arrow, chondrocytes; asterisk, fibrous area; plus sign, hyaline islets).

duced, and fat droplets and blood oozing from the drilled holes were observed (Fig 1C). The portals were closed, and the procedure was terminated.

Postoperative rehabilitation plays a vital role in obtaining favorable outcomes from the microfracture technique. The patients were told to perform certain

TABLE 2. *Preoperative and Postoperative Functional Variables of Patients*

Functional Assessment	Preoperative [Mean ± SD (Range)]	Postoperative [Mean ± SD (Range)]	*P* Value
Lysholm knee score	52.4 ± 6.2 (38-70)	84.6 ± 7.8 (68-100)	<.0001
Tegner activity scale	2.6 ± 1.5 (2-5)	5.2 ± 1.3 (4-9)	<.0001
Oxford knee questionnaire	23.1 ± 4.8 (12-30)	44.8 ± 5.7 (24-48)	<.0001

rehabilitative exercises using a continuous passive motion (CPM) device, 4 to 8 hours per day for 6 to 8 weeks. For patients without this facility, flexion-extension exercises were repeated 1,500 times during 3 sessions per day. Ice packs were applied during postoperative days 1 to 7. All patients performed quadriceps and hamstring strengthening exercises.

The patients were allowed to bear weight at 20% to 30% of their body weight on their tiptoes for 6 to 8 weeks. After 8 weeks, full weight bearing was permitted. Athletes were permitted to return to their training and intensive exercises at 4 months postoperatively and to sporting activities at 6 to 8 months.

Our patients were assessed according to 3 different evaluation methods: Lysholm knee evaluation scale,[16] Tegner activity scale,[17] and Oxford knee questionnaire.[18] Assessments were performed preoperatively; at 1.5, 3, 6, and 12 months postoperatively; and at the last control visit.

Evaluation of Statistical Data

Two paired sample test, two independent sample *t* test, and χ^2 test were used for statistical analysis. Nonparametric Spearman correlation analysis was used for the evaluation of age, size of defect, location of defect, and BMI in terms of intergroup evaluation. $P < .05$ was considered statistically significant. All analyses were performed with a commercially available software package (SPSS 15.0 demo; SPSS, Chicago, IL).

RESULTS

The mean age of the patients on the day of surgery was 34.5 years (range, 20 to 58 years). The mean follow-up was 68 months (range, 24 to 108 months). In patients who underwent second-look arthroscopy, the area of cartilaginous defect was examined arthroscopically and biopsy materials were taken. We observed that cartilaginous defect was filled completely with healing tissue (Fig 1D). Our biopsy results confirmed that healing tissue was of intermediate histologic structure between fibrocartilaginous and hyaline cartilage tissue, known as hybrid tissue (Fig 1E).

Preoperative and postoperative functional outcomes of our patients are given in Table 2. There was a significant improvement in all scores between those obtained preoperatively and those obtained at last follow-up. Accordingly, mean increases of 30.4 ± 4.2 points, 2.6 ± 0.8 points, and 21.7 ± 3.8 points were achieved in Lysholm knee scores, Tegner activity scale scores, and Oxford knee questionnaire scores, respectively ($P < .0001$). Furthermore, we investigated the relation between functional results and prognostic factors (Table 3). There was a strong and significant correlation between functional results and age younger than 35 years, size of defect less than 2 cm^2, non–weight-bearing surface, and BMI lower than 25 kg/m^2, respectively ($P < .001$) (Table 4). Furthermore, we observed that the patients who underwent surgery within 12 months healed better than those having surgery at more than 12 months. However, there was no significant difference on statistical analysis ($P > .05$).

Moreover, we performed MRI in 29 patients at the end of the twelfth month postoperatively. We ob-

TABLE 3. *Relation Between Prediction Criteria and Functional Scores*

	Lysholm Score	Tegner Activity Scale	Oxford Knee Questionnaire
Age			
<35 yrs	36.2 ± 5.8	2.6 ± 0.8	21.7 ± 3.4
≥35 yrs	24.3 ± 6.1	2.1 ± 0.4	16.5 ± 2.8
Statistical significance	$P < .001$	$P < .001$	$P < .001$
Size of defect			
<2 cm^2	37.4 ± 5.9	2.8 ± 0.6	22.2 ± 3.6
≥2 cm^2	26.9 ± 4.7	2.0 ± 0.4	15.8 ± 2.8
Statistical significance	$P < .001$	$P < .001$	$P < .001$
Location of defect			
Weight bearing	26.8 ± 5.3	2.2 ± 0.5	16.2 ± 2.7
Non–weight bearing	37.3 ± 6.4	2.6 ± 0.6	23.2 ± 2.4
Statistical significance	$P < .001$	$P < .001$	$P < .001$
BMI			
<25 kg/m^2	38.2 ± 5.4	2.8 ± 0.4	22.8 ± 2.1
≥25 kg/m^2	26.2 ± 4.8	2.0 ± 0.3	16.3 ± 2.4
Statistical significance	$P < .001$	$P < .001$	$P < .001$

TABLE 4. *Relation Between Prediction Criteria and P Values*

Prediction Criteria	Lysholm Knee Score	Tegner Activity Scale	Oxford Knee Questionnaire
Age	$P < .001$	$P < .001$	$P < .001$
	$r = 0.623$	$r = 0.612$	$r = 0.615$
Size of defect	$P < .001$	$P < .001$	$P < .001$
	$r = 0.538$	$r = 0.562$	$r = 0.576$
Location of defect	$P < .001$	$P < .001$	$P < .001$
	$r = 0.658$	$r = 0.629$	$r = 0.618$
BMI	$P < .001$	$P < .001$	$P < .001$
	$r = 0.547$	$r = 0.589$	$r = 0.572$

served filling of defect, fissures, depression of defect with respect to adjacent normal cartilage, and bony overgrowth.

In none of the patients was infectious complications encountered. In 9 patients recurrent painless articular effusions were seen. With conservative treatment, the symptoms regressed within a few weeks.

DISCUSSION

For the management of full-thickness articular cartilage lesions of the knee, many treatment modalities have been defined. Hypoactive patients with few symptoms and incidental chondral lesions less than 2 to 3 cm^2 should be managed with palliative methods such as debridement and lavage.[1-5,10]

In hyperactive patients with cartilaginous lesions measuring 1 to 5 cm^2, techniques stimulating subchondral bone tissue have been used. First, in 1959, Pridie[19] reported abrasion arthroplasty as an open surgical modality. Abrasion arthroplasty is applied for focal chondral lesions in patients with extremely knee arthritis. Recurrence of symptoms 2 to 3 years later has been observed in patients treated with this technique. According to the results of these studies, the success rate for functional outcomes was about 50%.[2,6,7,10]

Currently, among techniques stimulating subchondral bone, the most popular is the microfracture technique.[8,11,13,20-28] Drilling of the subchondral bone leads to ingress of pluripotential mesenchymal stem cells, which arise from the vascular system, and growth factors into the defective region, and thus adherence to the surface of the bone is achieved. Bleeding occurring after the procedure leads to the formation of a hematoma, which fills the defective region. Hematoma forms a fibrin plug in the area of the defect. The development of the fibrovascular repair tissue (i.e., granulation tissue) ensues. Mesenchymal stem cells stemming from the subchondral bone proliferate and transform into chondrocytes under the influence of local growth and environmental factors. Any fibrocartilaginous tissue within the tissue formed was not detected with histomorphometric measurements performed at 2 to 4 weeks postoperatively.[20] At 6 to 8 weeks, fibrocartilaginous and hyaline-like tissue emerges. During these weeks, numerous chondrocytes in repair tissue are present. The cartilage tissue formed can fill the defect partially or completely.[3,20] When the healing tissue was analyzed at 8 weeks, it was observed that it consisted of fibrous tissue (29%), fibrocartilaginous tissue (30%), granulation tissue (12%), bone tissue filling the defect (10%), and hyaline-like cartilage tissue (12%).[20]

When we consulted histologists regarding our biopsy materials taken during second-look arthroscopy in our series, we noted that although the repair tissue resembled hyaline cartilage tissue, it also contained fibroblasts. When the literature and our experiences are taken into consideration, it will be accurate to say that healing tissue achieved after the microfracture procedure has the characteristics of hybrid tissue. On the other hand, it is not feasible to perform second-look arthroscopy in every patient because of ethical and economic considerations. Postoperative evaluation of patients who underwent microfracture procedures with MRI is also possible. In a study done by Brown et al.[15] patients who had undergone autologous chondrocyte implantation or microfracture procedures were compared postoperatively by use of MRI, and the authors stated that MRI provided more valuable information in patients treated with autologous chondrocyte implantation procedure. In addition, it was concluded that MRI examination combined with the evaluation of clinical outcomes would portend more significant implications for the assessment of these cases.[15] In our series only 29 patients could be investigated by MRI. Improvements observed on MRI studies of our patients were in compliance with functional outcomes. However, we believe that definite conclusions on this issue require an increasing number of MRI examinations and evaluation of them by experienced radiologists.

Rodrigo et al.[29] reported marked improvement in healing of cartilage postoperatively with CPM, partial weight-bearing, and isometric exercises. Therefore reconstitution of durable fibrous cartilage requires a moderate range-of-motion and weight-bearing program to stimulate the repair process, along with a

sustained exercise program. Steadman et al.[25] pointed out the significant role of the rehabilitation program instituted during the postoperative period in patients managed with the microfracture method, and they stated that rehabilitation plays a vital role in the transformation of mesenchymal stem cells into cartilage cells. In our study, for 6 to 8 weeks postoperatively, patients performed exercises using a CPM device. After 3 postoperative weeks, active range-of-motion exercises were started. In addition, all patients performed a quadriceps and hamstring strengthening program. During this period, the patients were allowed to bear partial loading. At the end of 8 weeks, full weight bearing was permitted. In our study we believe that this rehabilitation program is successful in consideration of the relatively higher functional values obtained postoperatively.

In 2003 Steadman et al.[26] used the microfracture technique in 71 patients aged under 45 years with traumatic chondral defects without any concomitant lesion and found increases in mean Lysholm scores (from 59 to 89 points) and mean Tegner scores (from 3 to 6 points) after approximately 11 years of follow-up. In another study published in 2003 Steadman et al.[27] reported application of the microfracture technique in 25 athletes with full-thickness articular cartilage lesions and indicated that 19 of them returned to their active sports during the next season. This study with a follow-up period of 4.5 years showed that the microfracture technique is appropriate in patients performing high-level sports activities. In this study the authors stated that the microfracture technique is a safe and less costly treatment modality providing satisfactory symptomatic and functional improvement. According to the midterm results of a study by Gill et al.,[21] who applied the microfracture technique for full-thickness articular cartilage lesions, painful sensations reportedly regressed by more than 70%. As for the outcomes of 109 patients followed up for a mean of 72 months by Gobbi et al.,[22] despite generally satisfactory results, the authors reported that the activity levels of athletes decreased with time, which might necessitate application of other modalities for athletes.

When the results of our 90 patients who had undergone microfracture procedures with a mean follow-up period of 62 months are evaluated, we observed symptomatic and functional improvements in most of our patients. On second-look arthroscopy in 6 patients, we observed complete filling of cartilage defects with healing tissue. When our functional results were evaluated, mean increases in Lysholm knee scores (30.4 points), Tegner activity scale scores (2.6 points), and Oxford knee questionnaire scores (21.7 points) were noted ($P < .0001$). In our series 29 patients had postoperative MRI examinations, but the results obtained are not suitable for generalizations encompassing all of our series. However, according to outcomes obtained, we believe that the microfracture technique we applied is quite successful in the management of full-thickness articular cartilage lesions.

In addition, we detected a correlation between functional results and outcome parameters. Steadman et al.[26] found that more improvement was achieved in patients aged less than 35 years than in patients aged between 35 and 45 years. Mithoefer et al.,[24] in their analysis of 48 patients with full-thickness articular cartilage lesions whom they treated with the microfracture technique, reported that optimal results were obtained in patients with lower BMIs having a short period of preoperative symptoms, being aged less than 30 years, and having defects that filled fully during the postoperative period. Knutsen et al.[12] found that better results were obtained in patients who were aged less than 30 years and were more active. In another study, Kreuz et al.[28] showed that the best prognostic factors were age less than 40 years and lesions on the femoral condyles. In our study we found that there was a strong and significant positive correlation between functional results and age less than 35 years, size of defect less than 2 cm^2, non–weight-bearing surface, and BMI less than 25 kg/m^2, respectively ($P < .001$). Therefore we consider that age, size of defect, location of defect, and BMI are prognostic factors for functional results in the treatment of full-thickness cartilage defects of the femoral condyles.

The weak points of this study are the lack of comparison with another method and paucity of cases in which biopsy had been performed during second-look arthroscopy. Because this is a retrospectively designed study, comparative studies were not performed. However, we believe that this technique is a successful and time-saving procedure because of our large series and quite satisfactory functional results with a mean of 5 years' follow-up. On the other hand, for ethical and economic reasons, second-look arthroscopy was reserved for a limited number of patients. However, analytic results of biopsied materials suggest the usefulness of the microfracture technique.

CONCLUSIONS

According to the midterm results of this study, the microfracture technique is quite effective with regard to the improvement of daily activities with a favorable

impact on pain relief and better functional results. Furthermore, we found that there was a correlation between functional results and age, size of defect, location of defect, and BMI as prognostic parameters.

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