

Comparison of Magnetic Resonance Observation of Cartilage Repair Tissue Score and Functional Outcomes between Microdrilling and Microfracture for Cartilage Lesions of Distal Femur: A Retrospective Comparative Study

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Abstract

Objective. This study aimed to compare the clinical outcomes of microdrilling and microfracture for unipolar cartilage lesions of the distal femur. **Design.** Patients who underwent either microfracture or microdrilling and had postoperative magnetic resonance imaging (MRI) at 1 year were retrospectively reviewed. The morphology of the repaired cartilage tissue was evaluated using Magnetic Resonance Observation of Cartilage Repair Tissue (MOCART) 2.0 score. Functional outcomes were assessed using the International Knee Documentation Committee (IKDC) subjective, Lysholm scores, and Visual Analog Scale (VAS). In addition, the proportion of patients achieving improvement beyond the minimal clinically important difference (MCID) was analyzed. **Results.** The MOCART score was significantly higher in the microdrilling group. Among the variables, volume fill of the cartilage defect and integration into the adjacent cartilage showed significantly better results in favor of the microdrilling group. A higher proportion of patients achieved improvement in the IKDC subjective score beyond the MCID in the microdrilling group, whereas no significant differences were observed between the groups in Lysholm score and VAS. **Conclusion.** Microdrilling showed better outcomes in terms of the MOCART and IKDC subjective scores than microfracture, whereas Lysholm and VAS showed no significant differences. Further prospective studies are required to evaluate the results of these 2 procedures.

Keywords

marrow stimulation procedure, microdrilling, microfracture, cartilage defect

Introduction

Articular cartilage has limited natural healing potential and hence, cartilage restoration procedures are commonly performed.¹⁻⁵ Various surgical modalities have been used, including marrow stimulation procedures (MSPs), cell-based therapies, and whole-tissue transplantation. Among these procedures, MSPs are the most cost-effective for cartilage restoration.⁶⁻¹¹ MSPs involve multiple penetrations of the subchondral bone, which facilitates the recruitment of various cytokines and autologous pluripotent mesenchymal stem cells from the bone marrow, leading to the formation of superclots that cover the defect.¹² Although regenerated cartilage is thought to be more akin to fibrous cartilage than

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normal hyaline cartilage, improved clinical outcomes have been reported in multiple studies.^{1,13-16}

MSPs include microfracturing and microdrilling, which differ in their methods of subchondral bone penetration. Microfracturing involves impacting a microfracture awl to create channels in the bone marrow, whereas microdrilling involves drilling of the subchondral bone. Owing to the different methods of penetrating the subchondral bone, each procedure has its own limitations. Microfractures, which affect the subchondral bone more severely than microdrilling, are thought to alter the normal structure whereas microdrilling poses a risk of thermal damage. Regarding the potential differences due to discrepancies between the 2 surgical modalities, several animal studies have advocated microdrilling over microfractures.¹⁷⁻¹⁹

Although Beletsky *et al.*²⁰ reported superior functional outcomes with microdrilling at short-term follow-up, there is a paucity of clinical studies comparing the clinical outcomes of microdrilling and microfracture. Considering that marrow stimulation is a widely used surgical technique, a comparison of the clinical outcomes could provide valuable insights into the selection of the 2 procedures, especially on the perspective of the structure of the regenerated cartilage.

Therefore, the aim of our study was to compare the clinical outcomes of microdrilling and microfracture for unipolar cartilage lesions in the distal femur using a Magnetic Resonance Observation of Cartilage Repair Tissue (MOCART) 2.0 score as a primary outcome measure. We hypothesized that microdrilling would result in superior results compared with microfractures.

Methods

Patient Enrollment

This was a retrospective study of patients who underwent MSPs performed by a single surgeon who had performed both microdrilling and microfracture within the period of interest, with a prospective collection of pre- and postoperative patient-reported outcome scores and imaging studies, including 1-year postoperative magnetic resonance imaging (MRI) and a minimum 2-year follow-up of functional outcomes. This study was approved by the Institutional Review Board, and the requirement for informed consent was waived because of the retrospective nature of the study (Gangnam Severance Hospital, 3-2024-0251). The medical records of patients who underwent MSPs for unipolar cartilage defects of the distal femur between March 2010 and February 2022 performed by the single surgeon at the single institute were analyzed. The inclusion criteria were as follows: patients with (1) follow-up MRI at 1 year postoperatively and (2) minimum follow-up duration of 2 years with data of patient-reported outcome measures, including the

Visual Analog Scale (VAS), International Knee Documentation Committee (IKDC) subjective score, and Lysholm score. The exclusion criteria were as follows: patients who had (1) concomitant osteotomy, (2) concomitant ligament reconstruction, (3) enhanced MSPs, (4) concomitant stem cell implantation, (5) combined procedures for cartilage restoration, (6) concomitant procedures involving the subchondral bone of the articular surface, (7) a history of previous surgery of the ipsilateral knee, and (8) nonfunctional meniscus defined as subtotal or total meniscectomy of the affected compartment.

The patients were divided into 2 groups according to MSPs: the microfracture group (group 1) and the microdrilling group (group 2).

Surgical Indication, Technique, and Rehabilitation

The indications for MSP without limb realignment procedure at our institute were as follows: patients with (1) no advanced osteoarthritis defined as Kellgren–Lawrence grade ≥ 3 , (2) cartilage lesion grade $\geq 3b$ according to the International Cartilage Repair Society (ICRS) grading system, (3) no definite malalignment of the affected lower limb (hip-knee-ankle angle within 5° of valgus or varus alignment), and (4) the willingness to complete a strict postoperative rehabilitation program. Although MSP was planned for cartilage lesions sized 2–3 cm², patients with cartilage lesions >3 cm² after debridement of the unstable margin were evaluated intraoperatively and underwent MSP as planned. Patients were informed about the clinical routine for MRI follow-up at 1-year postoperatively. The surgical procedure was performed using an arthroscopic gouge to create a stable vertical margin of the cartilage lesion, and a ring curette was used to remove tissues, including the calcified area, which has been reported to affect the MSP results.^{21,22}

After the preparation, arthroscopic microfracturing or microdrilling was performed. Until February 2019, microfracturing with an awl was performed, whereas microdrilling was initiated in March 2019 regarding previous studies.¹⁷⁻¹⁹ Additional portals for direct access to the cartilaginous lesions were made if needed. For microfracturing, angled awls were used to penetrate the subchondral bone, and each hole was made with a width of 2 to 3 mm and a depth of 5 to 8 mm at an interval of 3–4 mm (**Fig. 1**). For microdrilling, a 1.5-mm drill bit (ECT Internal Fracture Fixation Drill Bits; Zimmer Biomet, Warsaw, IN, USA) and pneumatic power drill with a reamer (PowerPro Pneumatic Single Trigger Modular Handpiece; ConMed, Largo, FL, USA) were used. The drill bit was locked to the drill chuck at a length at which the drill bit was exposed from the guide at 15 mm when fully engaged, leading to a unified penetration depth. Subchondral bone perforation was performed vertically at 2 mm intervals between each drill hole, using

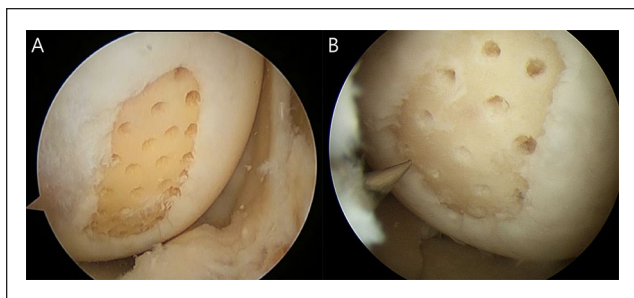


Figure 1. Arthroscopic image of (A) microdrilling and (B) microfracture.

the diameter of the perforated hole as a reference (**Fig. 1**). The aim of both the microfracture and microdrilling procedures was to create as many channels as possible to the bone marrow.

Passive range of motion exercises were initiated immediately after the surgery. A hinged knee brace and crutches were typically applied for 6–10 weeks, in accordance with the location of the cartilage defect and meniscus procedure. During this period, limited weightbearing was implemented with the knees fully extended. After discontinuation of crutches and braces, closed-chain exercises were recommended.

Patient Evaluation

Demographic data, such as age, sex, laterality of the affected knee, and body mass index (BMI) were also collected. The presence of preoperative subchondral bone marrow edema adjacent to the cartilage lesion was analyzed, and the highest grade of the preoperative bone marrow edema among the subregions evaluated by MOAKS was used for analysis.²³ Intraoperative data assessing the cartilage lesion were documented by the attending surgeon immediately after the surgical procedure, including the location and grade of the lesion in accordance with the ICRS grading system and the size of the lesion after preparation. The location of the cartilage lesion was classified as the medial femoral condyle, lateral femoral condyle, or trochlea. Considering that MSP results in poor outcomes for large cartilage lesions and that the current literature suggests against MSP for large lesions typically defined as lesions of size $>2.5 \text{ cm}^2$, a subgroup analysis was performed with cartilage lesion sizes $\leq 2.5 \text{ cm}^2$.^{24–26}

Clinical Evaluation

To assess the subjective outcomes, the VAS, IKDC, and Lysholm scores were analyzed. Each score was prospectively recorded preoperatively and at 1 and 2 years postoperatively. The minimal clinically important difference (MCID) values of each variable, which were reported as

16.7, 10.1, and 27 in previous studies for the IKDC subjective, Lysholm scores, and VAS, respectively, were used in the analyses.^{27,28}

The radiological outcomes were retrospectively analyzed. Radiological outcomes included the Kellgren–Lawrence grade of the affected compartment on standing anteroposterior (AP) radiographs of the medial and lateral compartments. For trochlear lesions, the Kellgren–Lawrence grade was analyzed using Merchant radiography.

A follow-up MRI was performed with a minimum 1.5 tesla unit at 1 year postoperatively. A Magnetic Resonance Observation of Cartilage Repair Tissue (MOCART) 2.0 score, which is reported to be a reliable method for evaluating the morphology of regenerated cartilage tissue, was analyzed using MRI conducted 1 year postoperatively.^{29,30} The MOCART score was evaluated by 2 experienced orthopedic surgeons who were blinded to the group allocation and results. For patients who underwent concomitant meniscal repair, the healing status was evaluated according to the method reported in previous studies.^{31,32}

Statistical Analysis

Prior to the study, an a priori power analysis was performed to determine an adequate sample size. Owing to the lack of a reference study for each variable and total MOCART score, a preliminary pilot study was performed with 10 patients in each group. Using these data as a reference value, a power analysis was performed for each variable, and the total MOCART score with the significance level (α) and power ($1 - \beta$) was set as 0.05 and 0.8, respectively. As a result, the largest value of the required sample size in each group was 21 for the total MOCART score, which was 53.0 ± 20.6 and 68.0 ± 14.2 for groups 1 and 2, respectively.

All statistical analysis was performed with IBM SPSS (version 26.0). Normality was analyzed using the Kolmogorov–Smirnov test. For continuous variables, an independent t-test or Mann–Whitney U test was performed according to the normality of each variable. For categorical values, the chi-square test was performed. Fisher's exact test was performed when $\geq 20\%$ of the expected cell counts were <5 . To measure the MOCART score, the interobserver reliability was evaluated using intraclass correlation coefficients with 95% confidence intervals (CI). The level of significance was set at $P < 0.05$.

Results

A total of 68 patients were enrolled, with 43 patients classified into group 1 (microfracture) and 25 into group 2 (microdrilling) (**Fig. 2**). Demographic data, the proportion of patients with preoperative subchondral edema, and intraoperative data showed no significant differences between the 2 groups (**Table 1**). With no repaired meniscus non-healed,

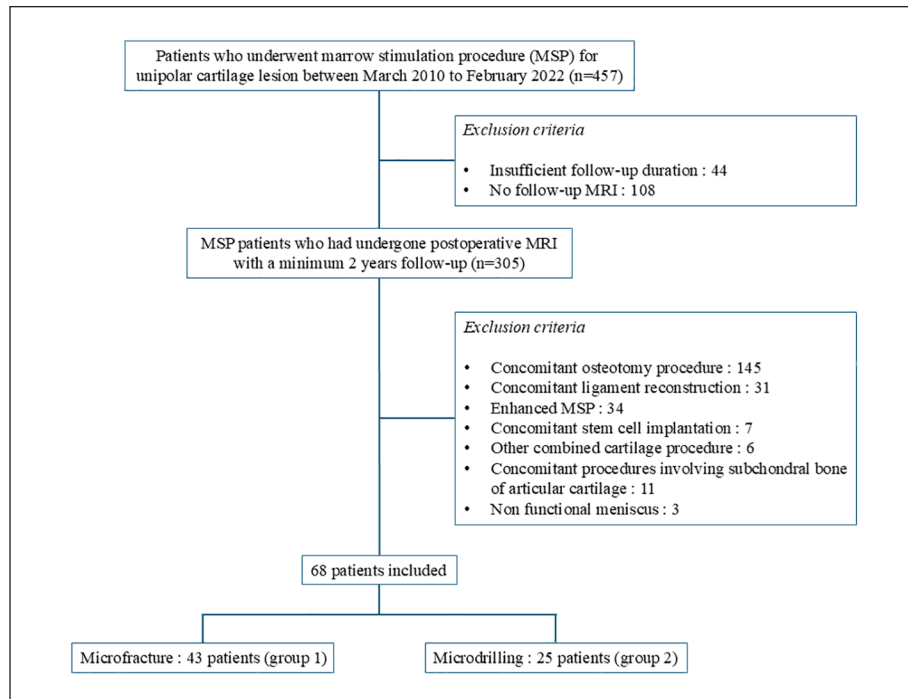


Figure 2. Flow chart of patient inclusion and exclusion criteria. MSP = marrow stimulation procedure; MRI = magnetic resonance imaging.

24 and 8 patients in groups 1 and 2, respectively, had a completely healed meniscus, as assessed by 1-year postoperative MRI, showing no significant difference between the 2 groups ($P > 0.999$). One patient in the microfracture group underwent revision autologous chondrocyte implantation at 15 months postoperatively, whereas no patient in the microdrilling group underwent revision surgery during the 2-year follow-up period.

Comparison of MOCART Scores

Among the variables of the MOCART 2.0 score, volume fill of cartilage defect, integration to adjacent cartilage, and total MOCART scores were significantly higher in group 2, while other variables showed no significant difference. Although the mean score for subchondral changes showed no significant difference, the proportion of patients with severe edema-like marrow signals was significantly higher in group 1 (**Table 2**). The measurement reliability for MOCART score in the present study showed “good” to “excellent” reliability (intraclass correlation coefficient, 0.837–0.935).³³

Comparison of Objective and Subjective Variables

The preoperative Kellgren-Lawrence (KL) grade of the compartment involving the cartilage defect was not significantly different between the 2 groups. At 1 and 2 years

postoperatively, the KL grades showed no significant differences between the 2 groups (**Table 3**).

The preoperative IKDC subjective, Lysholm scores, and VAS were not significantly different between the 2 groups. Each variable at 1 and 2 years postoperatively also showed no significant differences between the 2 groups for any of the IKDC subjective, Lysholm scores, or VAS, except for the IKDC subjective score at 2 years postoperatively. The proportion of patients whose scores improved beyond the MCID was higher in the microdrilling group whereas no difference was observed in the Lysholm score and VAS (**Table 3**).

Subgroup Analysis for Cartilage Lesions Sized $\leq 2.5 \text{ cm}^2$

Notably, 33 patients in group 1 and 22 patients in group 2 had MSP for cartilage defect sizes $\leq 2.5 \text{ cm}^2$. No significant differences were observed in the demographic and intraoperative data between the 2 groups (**Table 4**). The volume of the cartilage defect, integration into the adjacent cartilage, and total MOCART scores were also higher in group 2, which was consistent with the results obtained regardless of the lesion size (**Table 5**). The mean IKDC subjective score at 2 years postoperatively and the proportion of patients who showed an improvement in the IKDC subjective score beyond the MCID were significantly higher in group 2, which was also consistent with the results for whole cartilage lesion size (**Table 6**).

Table 1. Demographic and Intraoperative Data.

Demographic and Intraoperative Data ^a	Group 1 (n = 43)	Group 2 (n = 25)	P value
Age (years)	56.0 ± 11.7	57.7 ± 10.2	0.548
Sex ^b			>0.999
Male	8 (18.6%)	4 (16.0%)	
Female	35 (81.4%)	21 (84.0%)	
Laterality ^b			0.448
Right	17 (39.5%)	13 (52.0%)	
Left	26 (60.4%)	12 (48.0%)	
BMI	25.5 ± 3.1	26.4 ± 4.6	0.430
Preoperative bone marrow edema, yes/ no ^b	15 (34.9%)/28 (65.1%)	8 (32.0%)/17 (68.0%)	>0.999
Grade 1	5	3	>0.999
Grade 2	5	2	
Grade 3	5	3	
Cartilage lesion size (cm ²)	2.0 ± 1.0	1.8 ± 0.8	0.430
Cartilage location ^b			0.662
Medial femoral condyle	33 (76.7%)	18 (72.0%)	
Lateral femoral condyle	3 (7.0%)	1 (4.0%)	
Trochlea	7 (16.3%)	6 (24.0%)	
ICRS grade ^b			>0.999
IIIb, c, and d	40 (93.1%)	24 (96.0%)	
IV	3 (6.9%)	1 (4.0%)	
Meniscus procedure of affected compartment ^b			0.185
None	12 (27.0%)	10 (40.0%)	
Partial meniscectomy	6 (14.0%)	6 (24.0%)	
Meniscus repair	25 (58.1%)	9 (36.0%)	

BMI = body mass index; ICRS = International Cartilage Repair Society.

^aThe values are given as the mean and standard deviation, otherwise noted separately.

^bThe values are given as the number and proportion of patients.

Table 2. Comparison of MOCART Score.

MOCART Variables ^a	Group 1 (n = 43)	Group 2 (n = 25)	P value
Volume fill of cartilage defect ^b	12.6 ± 7.4	17.2 ± 3.3	0.017
(20) Complete filling or minor hypertrophy	16 (37.2%)	13 (52.0%)	0.021
(15) Major hypertrophy of 75%~99% filling	8 (18.6%)	10 (40.0%)	
(10) 50%~74% filling	7 (16.3%)	2 (8.0%)	
(5) 25%~49% filling	6 (14.0%)	0 (0.0%)	
(0) 50%~74% filling	6 (14.0%)	0 (0.0%)	
Integration into adjacent cartilage ^b	9.2 ± 5.7	12.0 ± 4.8	0.019
(15) Complete integration	13 (30.2%)	16 (64.0%)	0.041
(10) Split-like defect ≤ 2 mm	18 (41.9%)	5 (20.0%)	
(5) Defect > 2 mm but <50% of repair tissue length	3 (7.0%)	2 (8.0%)	
(0) Defect ≥50% of repair tissue length	9 (20.9%)	2 (8.0%)	
Surface of the repair tissue ^b	4.8 ± 4.1	5.4 ± 3.8	0.525
(10) Surface intact	13 (30.2%)	8 (32.0%)	0.665
(5) Surface irregular <50% of repair tissue diameter	15 (34.9%)	11 (44.0%)	
(0) Surface irregular ≥50% of repair tissue diameter	15 (34.9%)	6 (24.0%)	
Structure of the repair tissue ^b	0.5 ± 2.1	0.4 ± 2.0	0.900
(10) Homogenous	2 (4.7%)	1 (4.0%)	>0.999
(0) Inhomogenous	41 (95.3%)	24 (96.0%)	

(continued)

Table 2. (continued)

MOCART Variables ^a	Group 1 (n = 43)	Group 2 (n = 25)	P value
Signal intensity of the repair tissue ^b	9.8 ± 1.5	10.2 ± 1.0	0.145
(15) Normal	0 (0.0%)	1 (4.0%)	0.604
(10) Minor abnormal	42 (97.7%)	24 (96.0%)	
(0) Severely abnormal	1 (2.3%)	0 (0.0%)	
Bony defect or bony overgrowth ^b	7.1 ± 4.1	6.6 ± 3.7	0.449
(10) No bony defect or bony overgrowth	27 (62.8%)	12 (48.0%)	0.193
(5) Bony defect < thickness of adjacent cartilage OR overgrowth < 50% of adjacent cartilage	7 (16.3%)	9 (36.0%)	
(0) Bony defect ≥ cartilage thickness OR overgrowth ≥ 50% of adjacent cartilage	9 (20.9%)	4 (16.0%)	
Subchondral changes ^b	13.3 ± 4.1	14.2 ± 4.5	0.144
(20) No major change	9 (20.9%)	5 (20.0%)	0.043
(15) Minor edema-like marrow signal	10 (23.3%)	13 (52.0%)	
(10) Severe edema-like marrow signal	23 (53.5%)	6 (24.0%)	
(0) Subchondral cyst ≥ 5 mm or osteonecrosis-like signal	1 (2.3%)	1 (4.0%)	
Total ^b	56.9 ± 16.6	66.0 ± 12.0	0.022

MOCART = Magnetic Resonance Observation of Cartilage Repair Tissue.

^aThe values are given as the number and proportion of patients, otherwise noted separately.

^bThe values are given as the mean and standard deviation.

Table 3. Comparison of Subjective and Objective Outcomes Between 2 Groups.

Subjective and Objective Variables ^a	Group 1 (n = 43)	Group 2 (n = 25)	P value
Kellgren-Lawrence grade ^b			
Preoperative			
0/1/2	6/32/5	5/17/3	0.247
1 year postoperative			
0/1/2/3	1/32/9/1	3/17/5/0	0.775
2 year postoperative			
0/1/2/3	1/17/21/4	2/14/9/0	0.848
IKDC subjective			
Preop	37.7 ± 13.9	40.5 ± 16.5	0.458
1 year postoperative	50.9 ± 14.0	55.9 ± 14.9	0.183
2 year postoperative	53.2 ± 14.0	61.7 ± 15.2	0.023
MCID achievement ^c	17 (39.5%)	18 (72.0%)	0.013
Lysholm			
Preop	46.6 ± 21.3	54.6 ± 21.8	0.142
1 year postoperative	65.3 ± 23.2	69.7 ± 22.8	0.461
2 year postoperative	68.7 ± 20.0	75.0 ± 18.3	0.196
MCID achievement ^c	28 (65.1%)	17 (68.0%)	>0.999
VAS			
Preop	54.4 ± 24.0	44.6 ± 28.4	0.136
1 year postoperative	22.5 ± 20.2	16.5 ± 13.2	0.203
2 year postoperative	26.0 ± 22.8	21.6 ± 26.3	0.470
MCID achievement ^c	25 (58.1%)	12 (48.0%)	0.458

IKDC = International Knee Documentation Committee; VAS = Visual Analogue Scale; MCID = minimal clinically important difference.

^aThe values are given as the mean and standard deviation, otherwise noted separately.

^bThe values are given as number of patients.

^cThe values are given as the number and proportion of patients.

Table 4. Subgroup Analysis of Demographic and Intraoperative Data for Cartilage Lesion Sized ≤ 2.5 cm².

Demographic and Intraoperative Data ^a	Group 1 (n = 33)	Group 2 (n = 22)	P value
Age (Years)	57.1 $\pm$ 10.8	57.9 $\pm$ 10.7	0.795
Sex ^b			>0.999
Male	6 (18.2%)	4 (18.2%)	
Female	27 (81.8%)	18 (81.8%)	
Laterality ^b			0.580
Right	12 (36.4%)	10 (45.5%)	
Left	21 (63.6%)	12 (54.5%)	
BMI	25.5 $\pm$ 3.1	26.2 $\pm$ 4.6	0.537
Preoperative bone marrow edema, yes/no ^b	9 (27.3%) / 24 (72.7%)	7 (31.8%) / 15 (68.2%)	0.768
Grade 1	2	3	0.563
Grade 2	4	1	
Grade 3	3	3	
Cartilage lesion size (cm ²)	1.6 $\pm$ 0.7	1.6 $\pm$ 0.4	0.911
Cartilage location ^b			>0.999
Medial femoral condyle	25 (75.8%)	17 (77.3%)	
Lateral femoral condyle	1 (3.0%)	0 (0.0%)	
Trochlea	7 (21.2%)	5 (22.7%)	
ICRS grade ^b			0.511
IIIb, c, and d	31 (93.9%)	22 (100.0%)	
IV	2 (6.1%)	0 (0.0%)	
Meniscus procedure of affected compartment ^b			0.257
None	11 (33.3%)	8 (36.4%)	
Partial meniscectomy	4 (12.1%)	6 (27.3%)	
Meniscus repair	18 (54.6%)	8 (36.4%)	

BMI = body mass index; ICRS = International Cartilage Repair Society.

^aThe values are given as the mean and standard deviation, otherwise noted separately.

^bThe values are given as the number and proportion of patients.

Table 5. Subgroup Analysis of MOCART Score for Cartilage Lesion Sized ≤ 2.5 cm².

MOCART Variables ^a	Group 1 (n = 33)	Group 2 (n = 22)	P value
Volume fill of cartilage defect ^b	13.1 $\pm$ 7.0	17.3 $\pm$ 3.4	0.031
(20) Complete filling or minor hypertrophy	13 (39.4%)	12 (54.5%)	0.047
(15) Major hypertrophy of 75%~99% filling	5 (15.2%)	8 (36.4%)	
(10) 50%~74% filling	7 (21.2%)	2 (9.1%)	
(5) 25%~49% filling	5 (15.2%)	0 (0.0%)	
(0) 50%~74% filling	3 (9.1%)	0 (0.0%)	
Integration into adjacent cartilage ^b	9.7 $\pm$ 5.6	12.1 $\pm$ 5.0	0.034
(15) Complete integration	11 (33.3%)	15 (68.2%)	0.039
(10) Split-like defect $\leq$ 2 mm	14 (42.4%)	3 (13.6%)	
(5) Defect > 2 mm but <50% of repair tissue length	2 (6.1%)	2 (9.1%)	
(0) Defect $\geq$ 50% of repair tissue length	6 (18.2%)	2 (9.1%)	
Surface of the repair tissue ^b	4.9 $\pm$ 4.2	5.5 $\pm$ 3.8	0.591
(10) Surface intact	11 (33.3%)	7 (31.8%)	0.457
(5) Surface irregular <50% of repair tissue diameter	10 (30.3%)	10 (45.5%)	
(0) Surface irregular $\geq$ 50% of repair tissue diameter	12 (36.4%)	5 (22.7%)	
Structure of the repair tissue ^b	0.6 $\pm$ 2.4	0.0 $\pm$ 0.0	0.244
(10) Homogenous	2 (6.1%)	0 (0.0%)	0.511
(0) Inhomogenous	31 (93.9%)	22 (100.0%)	

(continued)

Table 5. (continued)

MOCART Variables ^a	Group 1 (n = 33)	Group 2 (n = 22)	P value
Signal intensity of the repair tissue ^b	9.7 ± 1.7	10.2 ± 1.1	0.153
(15) Normal	0 (0%)	1 (4.5%)	0.644
(10) Minor abnormal	32 (97.0%)	21 (95.5%)	
(0) Severely abnormal	1 (3.0%)	0 (0%)	
Bony defect or bony overgrowth ^b	7.0 ± 4.1	6.8 ± 4.0	0.801
(10) No bony defect or bony overgrowth	20 (60.6%)	12 (54.5%)	0.746
(5) Bony defect < thickness of adjacent cartilage OR overgrowth <50% of adjacent cartilage	6 (18.2%)	6 (27.3%)	
(0) Bony defect ≥ cartilage thickness OR overgrowth ≥50% of adjacent cartilage	7 (21.2%)	4 (18.2%)	
Subchondral changes ^b	13.0 ± 4.7	14.1 ± 4.5	0.220
(20) No major change	7 (21.2%)	4 (18.2%)	0.080
(15) Minor edema-like marrow signal	8 (24.2%)	12 (54.5%)	
(10) Severe edema-like marrow signal	17 (51.5%)	5 (22.7%)	
(0) Subchondral cyst ≥5 mm or osteonecrosis-like signal	1 (3.0%)	1 (4.5%)	
Total ^b	57.9 ± 15.9	65.9 ± 12.2	0.039

MOCART = Magnetic Resonance Observation of Cartilage Repair Tissue.

^aThe values are given as the number and proportion of patients, otherwise noted separately.

^bThe values are given as the mean and standard deviation.

Table 6. Subgroup Analyses of Subjective and Objective Outcomes for Cartilage Lesion Sized ≤ 2.5 cm².

Subjective and Objective Variables ^a	Group 1 (n = 33)	Group 2 (n = 22)	P value
Kellgren-Lawrence grade ^b			
Preoperative			
0/1/2	3/28/2	5/14/3	0.247
1 year postoperative			
0/1/2/3	1/25/7	2/16/4	0.775
2 year postoperative			
0/1/2/3	1/14/16/2	2/12/8/0	0.436
IKDC subjective			
Preop	37.3 ± 13.8	41.7 ± 16.1	0.282
1 year postoperative	51.3 ± 14.6	58.8 ± 11.6	0.052
2 year postoperative	53.1 ± 14.2	63.2 ± 14.2	0.013
MCID achievement ^c	13 (39.4%)	16 (72.7%)	0.027
Lysholm			
Preop	46.6 ± 21.2	56.5 ± 20.8	0.092
1 year postoperative	65.5 ± 23.3	73.0 ± 18.8	0.228
2 year postoperative	66.7 ± 21.3	76.5 ± 18.8	0.084
MCID achievement ^c	19 (57.6%)	15 (68.2%)	0.573
VAS			
Preop	51.9 ± 24.6	42.1 ± 27.9	0.177
1 year postoperative	21.3 ± 20.6	16.0 ± 12.7	0.300
2 year postoperative	26.5 ± 21.2	21.8 ± 27.9	0.484
MCID achievement ^c	18 (54.5%)	10 (45.5%)	0.587

IKDC = International Knee Documentation Committee; VAS = Visual Analogue Scale; MCID = minimal clinically important difference.

^aThe values are given as the mean and standard deviation, otherwise noted separately.

^bThe values are given as number of patients.

^cThe values are given as the number and proportion of patients.

Discussion

The principal finding of our study was that microdrilling has advantages over microfractures in terms of the radiologic evidence of regeneration, as indicated by the superior MOCART score. Among these variables, volume filling and integration into the adjacent cartilage showed higher scores in the microdrilling group. Regarding clinical outcomes, a higher proportion of patients in the microdrilling group achieved improvements beyond the MCID in the IKDC subjective score.

The superiority of microdrilling in volume filling and integration into the adjacent tissue, which were the variables that showed significant differences, could stem from the advantages reported in previous animal studies.^{17,34-38} Previous studies have reported that deep drilling (6 mm) resulted in a superior outcome compared to shallow drilling (2 mm) or microfracture in a rabbit model.^{35,36} In addition, microdrilling resulted in less osteocyte necrosis than microfracture in rabbits, which was performed with continuous saline irrigation, while an animal study conducted on sheep reported that microfractures resulted in trabecular bone impaction and regularity of the channel surface, leading to channel sealing.^{17,37} Another animal study comparing the effect of the drilling diameter on the subchondral bone reported that a smaller diameter resulted in a superior histological component of repaired cartilage and better reconstitution of the subchondral bone.³⁸ Specifically, drilling with a smaller diameter resulted in higher immunoreactivity for type 2 collagen and lower immunoreactivity for type 1 collagen. Furthermore, considering that more channels can penetrate per unit area in microdrilling because of the smaller diameter of each channel, it seems reasonable that microdrilling, which enables a greater number of well-communicating channels, results in superior outcomes in terms of volume filling and integration with adjacent cartilage.

When it comes to the previous concerns on the thermal damage of microdrilling,^{35,39} it is noteworthy that structural evaluation of the subchondral bone using the mean value of MOCART score variables showed no significant difference between the 2 procedures. Bone overgrowth or defects, another variable reported to be inferior to other cartilage regeneration procedures, also showed no significant differences between the 2 groups.⁴⁰ Rather, the proportion of severe edema-like signals in the subchondral bone was significantly higher in the microfracture group, although it was not significant for the cartilage defect size ≤ 2.5 cm². This could be explained by the results of a previous animal study conducted with continuous cooled saline irrigation, which counteracted possible thermal damage to the surrounding tissue.¹⁷ Although the temperature of the saline used in the clinical field at our institute is not as cold as the cooled saline used in the animal study, continuous saline inflow

itself could be inferred to be sufficient to counteract potential thermal damage. Thus, microdrilling should not be avoided because of the unsubstantiated concern of thermal damage. Further basic scientific studies analyzing the independent role of saline irrigation could yield a well-founded explanation of our results and provide guidance for other procedures, such as enhanced MSP or stem cell implantation for cartilage regeneration, which are commonly performed as open procedures.

Most previous studies comparing microfracturing and microdrilling were performed in animals, and there is a paucity of clinical studies. Beletsky *et al.*²⁰ reported that microdrilling resulted in a significantly higher IKDC subjective score at 1 year postoperatively and a lower risk of revision surgery. Although no significant difference in the mean functional outcome scores except IKDC subjective score at 2 years postoperatively was found in our study, our study is in line with a previous study regarding the superiority of the microdrilling group for the proportion of patients achieving improvement beyond the MCID and the mean value at 2 years postoperatively for IKDC subjective score and could be a clinically relevant result.

This study had some limitations. First, there is a possible risk of bias owing to the retrospective nature of our study. Due to the retrospective nature, potential selection bias could not be excluded, and further prospective studies could yield better results between the 2 methods. Second, owing to the different periods of each surgical procedure, differences in surgical experience could result in performance bias. However, all surgical procedures were reviewed, and basic principles, such as the formation of a rigid shoulder and curettage of the calcified layer, as well as the concomitant procedure and function of the meniscus were confirmed, which could reduce the possibility of bias. Third, meniscal healing in patients who underwent concomitant meniscal repair was only analyzed by MRI and not by second-look arthroscopy. Because meniscal function affects cartilage regeneration, the limitation of MRI in assessing meniscal healing could be a confounding variable. Fourth, this study included patients who underwent concomitant meniscal procedures. Although patients with nonfunctional menisci were excluded and the healing status of meniscus repair was also analyzed, the possible discrepancy in the function between the intact and healed menisci could not be excluded. However, we analyzed the proportion of meniscal procedures performed in each group and found no significant differences. Further studies comparing patients without concomitant meniscal procedures may provide a more precise understanding of the effects of MSPs.

Conclusions

Microdrilling showed better outcomes in terms of the MOCART and IKDC subjective scores than microfracture,

whereas Lysholm and VAS showed no significant differences. Further prospective studies are required to evaluate the results of these 2 procedures.

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Ethical Considerations

This study was ethically approved by the institutional review board from Gangnam Severance hospital.

Informed Consent

Not applicable.

Permission to Reproduce Material From Other Sources

Not applicable.

Author Contributions

The project was coordinated by JB and S-HK. JB drafted the manuscript, together with KC and S-HJ. JB and S-HK generated the concept of the study. The acquisition of data and analysis was done by SH Jung and J-KK. MJ, and H-SM provided supervision and guidance throughout the research process. The design of the study and interpretation of data were all done jointly by all authors. JB and S-HK revised the final draft critically for important intellectual content and approved the version to be submitted. All of the authors agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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References

1. Moran CJ, Pascual-Garrido C, Chubinskaya S, Potter HG, Warren RF, Cole BJ, *et al.* Restoration of articular cartilage. *J Bone Joint Surg Am.* 2014;96(4):336-44. doi:10.2106/JBJS.L.01329.
2. Pearle AD, Warren RF, Rodeo SA. Basic science of articular cartilage and osteoarthritis. *Clin Sports Med.* 2005;24(1):1-12. doi:10.1016/j.csm.2004.08.007.
3. Mostowy M, Ruzik K, Ebisz M, LaPrade RF, Malinowski K. Impaction fractures of the lateral femoral condyle related to anterior cruciate ligament injury: a scoping review concerning diagnosis, prevalence, clinical importance, and management. *Clin Orthop Surg.* 2023;15(5):781-92. doi:10.4055/cios22278.
4. Moran CJ, Shannon FJ, Barry FP, O'Byrne JM, O'Brien T, Curtin W. Translation of science to surgery: linking emerging concepts in biological cartilage repair to surgical intervention. *J Bone Joint Surg Br.* 2010;92(9):1195-202. doi:10.1302/0301-620X.92B9.23651.
5. McCormick F, Harris JD, Abrams GD, Frank R, Gupta A, Hussey K, *et al.* Trends in the surgical treatment of articular cartilage lesions in the United States: an analysis of a large private-payer database over a period of 8 years. *Arthroscopy.* 2014;30(2):222-6. doi:10.1016/j.arthro.2013.11.001.
6. Orth P, Gao L, Madry H. Microfracture for cartilage repair in the knee: a systematic review of the contemporary literature. *Knee Surg Sports Traumatol Arthrosc.* 2020;28(3):670-706. doi:10.1007/s00167-019-05359-9.
7. Gou GH, Tseng FJ, Wang SH, Chen PJ, Shyu JF, Weng CF, *et al.* Autologous chondrocyte implantation versus microfracture in the knee: a meta-analysis and systematic review. *Arthroscopy.* 2020;36(1):289-303. doi:10.1016/j.arthro.2019.06.033.
8. Lim HC, Park YB, Ha CW, Cole BJ, Lee BK, Jeong HJ, *et al.* Allogeneic umbilical cord blood-derived mesenchymal stem cell implantation versus microfracture for large, full-thickness cartilage defects in older patients: a multicenter randomized clinical trial and extended 5-year clinical follow-up. *Orthop J Sports Med.* 2021;9(1):2325967120973052. doi:10.1177/2325967120973052.
9. Knutsen G, Engebretsen L, Ludvigsen TC, Drogset JO, Grøntvedt T, Solheim E, *et al.* Autologous chondrocyte implantation compared with microfracture in the knee. A randomized trial. *J Bone Joint Surg Am.* 2004;86(3):455-64. doi:10.2106/00004623-200403000-00001.
10. Goyal D, Keyhani S, Lee EH, Hui JH. Evidence-based status of microfracture technique: a systematic review of level I and II studies. *Arthroscopy.* 2013;29(9):1579-88. doi:10.1016/j.arthro.2013.05.027.
11. Park JY, Kim JH, Cho JW, Kim MS, Choi W. Clinical and radiological results of high tibial of osteotomy over the age of 65 are comparable to that of under 55 at minimum 2-year follow-up: a propensity score matched analysis. *Knee Surg Relat Res.* 2024;36(1):10. doi:10.1186/s43019-024-00214-9.
12. Steadman JR, Rodkey WG, Singleton SB, Briggs KK. Microfracture technique for full-thickness chondral defects: technique and clinical results. *Oper Tech Orthop.* 1997;7(4):300-4. doi:10.1016/S1048-6666(97)80033-X.
13. Han JH, Jung M, Chung K, Jung SH, Choi CH, Kim SH. Effects of concurrent cartilage procedures on cartilage regeneration in high tibial osteotomy: a systematic review. *Knee Surg Relat Res.* 2024;36(1):13. doi:10.1186/s43019-024-00221-w.
14. Negrin L, Kutscha-Lissberg F, Gartlehner G, Vecsei V. Clinical outcome after microfracture of the knee: a meta-analysis of before/after-data of controlled studies. *Int Orthop.* 2012;36(1):43-50. doi:10.1007/s00264-011-1364-x.
15. Suh JW, Kwon JH, Lee DH, Jung JU, Park HW. Outcomes of osteochondral autologous transplantation with ipsilateral lateral talar autograft for medial osteochondral lesions of the talus. *Clin Orthop Surg.* 2024;16(4):620-7. doi:10.4055/cios23327.

16. Jarecki J, Wasko MK, Widuchowski W, Tomczyk-Warunek A, Wojciak M, Sowa I, *et al.* Knee cartilage lesion management-current trends in clinical practice. *J Clin Med.* 2023;12(20):6434. doi:10.3390/jcm12206434.
17. Chen H, Sun J, Hoemann CD, Lascau-Coman V, Ouyang W, McKee MD, *et al.* Drilling and microfracture lead to different bone structure and necrosis during bone-marrow stimulation for cartilage repair. *J Orthop Res.* 2009;27(11):1432-8. doi:10.1002/jor.20905.
18. Meyer LE, Danilkowicz RM, Hinton ZW, Crook BS, Abar B, Allen NB, *et al.* Microdrilling resulted in less subchondral bone destruction than a traditional microfracture awl for articular cartilage defect bone marrow stimulation. *Arthrosc Sports Med Rehabil.* 2023;5(5):100786. doi:10.1016/j.asmr.2023.100786.
19. Pohlig F, Wittek M, von Thaden A, Lenze U, Glowalla C, Minzlaff P, *et al.* Biomechanical properties of repair cartilage tissue are superior following microdrilling compared to microfracturing in critical size cartilage defects. *In Vivo.* 2023;37(2):565-73. doi:10.21873/in vivo.13115.
20. Beletsky A, Naveen NB, Tauro T, Southworth TM, Chahla J, Verma NN, *et al.* Microdrilling demonstrates superior patient-reported outcomes and lower revision rates than traditional microfracture: a matched cohort analysis. *Arthrosc Sports Med Rehabil.* 2021;3(3):e629-e638. doi:10.1016/j.asmr.2020.10.006.
21. Frisbie DD, Morisset S, Ho CP, Rodkey WG, Steadman JR, McIlwraith CW. Effects of calcified cartilage on healing of chondral defects treated with microfracture in horses. *Am J Sports Med.* 2006;34(11):1824-31. doi:10.1177/0363546506289882.
22. Theodoropoulos J, Dwyer T, Whelan D, Marks P, Hurtig M, Sharma P. Microfracture for knee chondral defects: a survey of surgical practice among Canadian orthopedic surgeons. *Knee Surg Sports Traumatol Arthrosc.* 2012;20(12):2430-7. doi:10.1007/s00167-012-1925-6.
23. Hunter DJ, Guermazi A, Lo GH, Grainger AJ, Conaghan PG, Boudreau RM, *et al.* Evolution of semi-quantitative whole joint assessment of knee OA: MOAKS (MRI osteoarthritis knee score). *Osteoarthritis Cartilage.* 2011;19(8):990-1002. doi:10.1016/j.joca.2011.05.004.
24. Mithoefer K, McAdams T, Williams RJ, Kreuz PC, Mandelbaum BR. Clinical efficacy of the microfracture technique for articular cartilage repair in the knee: an evidence-based systematic analysis. *Am J Sports Med.* 2009;37(10):2053-63. doi:10.1177/0363546508328414.
25. Shah SS, Lee S, Mithoefer K. Next-generation marrow stimulation technology for cartilage repair: basic science to clinical application. *JBJS Rev.* 2021;9(1):e2000090. doi:10.2106/JBJS.RVW.20.00090.
26. Steinwachs MR, Guggi T, Kreuz PC. Marrow stimulation techniques. *Injury.* 2008;39(1 Suppl):26-31. doi:10.1016/j.injury.2008.01.042.
27. Greco NJ, Anderson AF, Mann BJ, Cole BJ, Farr J, Nissen CW, *et al.* Responsiveness of the international knee documentation committee subjective knee form in comparison to the Western Ontario and McMaster Universities osteoarthritis index, modified Cincinnati knee rating system, and short form 36 in patients with focal articular cartilage defects. *Am J Sports Med.* 2010;38(5):891-902. doi:10.1177/0363546509354163.
28. Jones KJ, Kelley BV, Arshi A, McAllister DR, Fabricant PD. Comparative effectiveness of cartilage repair with respect to the minimal clinically important difference. *Am J Sports Med.* 2019;47(13):3284-93. doi:10.1177/0363546518824552.
29. Trattng S, Winalski CS, Marlovits S, Jurvelin JS, Welsch GH, Potter HG. Magnetic resonance imaging of cartilage repair: a review. *Cartilage.* 2011;2(1):5-26. doi:10.1177/1947603509360209.
30. Schreiner MM, Raudner M, Marlovits S, Bohndorf K, Weber M, Zalaudek M, *et al.* The MOCART (magnetic resonance observation of cartilage repair tissue) 2.0 knee score and atlas. *Cartilage.* 2021;13(1 Suppl):571S-587S. doi:10.1177/1947603519865308.
31. Kim SB, Ha JK, Lee SW, Kim DW, Shim JC, Kim JG, *et al.* Medial meniscus root tear refixation: comparison of clinical, radiologic, and arthroscopic findings with medial meniscectomy. *Arthroscopy.* 2011;27(3):346-54. doi:10.1016/j.arthro.2010.08.005.
32. Hatayama K, Terauchi M, Saito K, Takase R, Higuchi H. Healing status of meniscal ramp lesion affects anterior knee stability after ACL reconstruction. *Orthop J Sports Med.* 2020;8(5):2325967120917674. doi:10.1177/2325967120917674.
33. Koo TK, Li MY. A guideline of selecting and reporting intra-class correlation coefficients for reliability research. *J Chiropr Med.* 2016;15(2):155-63. doi:10.1016/j.jcm.2016.02.012.
34. Kraeutler MJ, Aliberti GM, Scillia AJ, McCarty EC, Mulcahey MK. Microfracture versus drilling of articular cartilage defects: a systematic review of the basic science evidence. *Orthop J Sports Med.* 2020;8(8):2325967120945313. doi:10.1177/2325967120945313.
35. Chen H, Chevrier A, Hoemann CD, Sun J, Ouyang W, Buschmann MD. Characterization of subchondral bone repair for marrow-stimulated chondral defects and its relationship to articular cartilage resurfacing. *Am J Sports Med.* 2011;39(8):1731-40. doi:10.1177/0363546511403282.
36. Chen H, Hoemann CD, Sun J, Chevrier A, McKee MD, Shive MS, *et al.* Depth of subchondral perforation influences the outcome of bone marrow stimulation cartilage repair. *J Orthop Res.* 2011;29(8):1178-84. doi:10.1002/jor.21386.
37. Zedde P, Cudoni S, Giachetti G, Manunta ML, Masala G, Brunetti A, *et al.* Subchondral bone remodeling: comparing nanofracture with microfracture. *Joints.* 2016;4(2):87-93. doi:10.11138/jts/2016.4.2.087.
38. Eldracher M, Orth P, Cucchiari M, Pape D, Madry H. Small subchondral drill holes improve marrow stimulation of articular cartilage defects. *Am J Sports Med.* 2014;42(11):2741-50. doi:10.1177/0363546514547029.
39. Augustin G, Zigman T, Davila S, Udilljak T, Staroveski T, Brezak D, *et al.* Cortical bone drilling and thermal osteonecrosis. *Clin Biomech (Bristol).* 2012;27(4):313-25. doi:10.1016/j.clinbiomech.2011.10.010.
40. Brown WE, Potter HG, Marx RG, Wickiewicz TL, Warren RF. Magnetic resonance imaging appearance of cartilage repair in the knee. *Clin Orthop Relat Res.* 2004;(422):214-23. doi:10.1097/01.blo.0000129162.36302.4f.