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High-Impact Athletics After Knee Articular Cartilage Repair

A Prospective Evaluation of the Microfracture Technique

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Background: Knee articular cartilage injuries in athletes present a therapeutic challenge and have been identified as an important cause of permanent disability because of the high mechanical joint stresses in athletes.

Purpose: To determine whether microfracture treatment of knee articular cartilage injuries can return athletes to high-impact sports and to identify the factors that affect the ability to return to athletic activity.

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

Methods: Thirty-two athletes who regularly participated in high-impact, pivoting sports before articular cartilage injury were treated with microfracture for single articular cartilage lesions of the knee. Functional outcome was prospectively evaluated with a minimum 2-year follow-up by subjective rating, activity-based outcome scores, and the ability for postoperative participation in high-impact, pivoting sports.

Results: At last follow-up, 66% of athletes reported good or excellent results. Activity of daily living, Marx activity rating scale, and Tegner activity scores increased significantly after microfracture. After an initial improvement, score decreases were observed in 47% of athletes. Forty-four percent of athletes were able to regularly participate in high-impact, pivoting sports, 57% of these at the preoperative level. Return to high-impact sports was significantly higher in athletes with age <40 years, lesion size <200 mm², preoperative symptoms <12 months, and no prior surgical intervention.

Conclusion: Microfracture is an effective first-line treatment to return young athletes with short symptomatic intervals and small articular cartilage lesions of the knee back to high-impact athletics.

Keywords: articular cartilage; injury; repair; return to sport; microfracture

Injuries of knee articular cartilage surfaces in athletes are observed with increasing frequency.^{1,16,21,26,37,39} Because of poor spontaneous repair potential, these injuries frequently lead to severe limitation of athletic participation and predispose the athlete to early degenerative changes and disability.^{4-8,14,21,22} Traditional treatment methods, such as abrasion chondroplasty and drilling, have not produced reliable cartilage repair, but newer techniques such as

mosaicplasty, autologous chondrocyte transplantation, and osteochondral allograft transplantation have produced encouraging results.^{3,17,18,27,34-36} Microfracture is frequently used to repair symptomatic articular cartilage defects of the knee. By penetrating the subchondral bone, clot formation is induced that contains marrow-derived mesenchymal stem cells, which produce a mixed fibrocartilage repair tissue that contains varying amounts of type II collagen.^{2,9-11,40-43} Because of its technical simplicity, limited invasiveness, low associated morbidity, and short postoperative rehabilitation, microfracture has become a popular treatment option for articular cartilage lesions in the athlete's knee. However, despite its obvious advantages for the athletic population, limited information is available on the results of this cartilage repair technique under the marked mechanical demands associated with high-impact athletics. Because previous reports have pointed out the detrimental effect of excessive loading for articular cartilage repair with marrow-stimulating

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techniques,^{5,28} we aimed to investigate the efficacy of microfracture to produce a successful repair of full-thickness articular cartilage lesions in the knee, even under the increased mechanical demands in high-impact sports. The combination of validated outcome scores and postoperative return to high-impact sport was used to assess function after microfracture, and the factors affecting the athlete's ability to return to high-demand sports after microfracture were investigated.

MATERIALS AND METHODS

The study was approved by the institutional review board. Prospective data collection was performed by an independent observer using an institutional cartilage repair registry. We have previously reported on a large cohort of patients treated with microfracture from our registry,²⁸ and the patients included in this study represent a subgroup of those patients who regularly participated in high-impact, pivoting sports before articular cartilage injury. Athletic participation before injury was at the recreational (38%), competitive (59%), and professional (3%) levels. All patients included in the study were symptomatic with single cartilage lesions of the femur, had follow-up greater than 2 years, and lacked lower extremity malalignment, ligamentous instability, or simultaneous ligamentous stabilization. Thirty-two patients were included in the study based on these criteria.

Eighty-four percent of the athletes were male, and 16% were female. The mean age was 38 ± 2 years (range, 16-54 years). The patients had undergone a mean of 0.9 ± 0.3 surgical procedures before microfracture (range, 0-7 procedures). Fifty-six percent of the patients had no prior surgery to the affected knee, and only 6% had 3 or more prior procedures. Preoperative duration of symptoms averaged 28 ± 12 months (range, 0.5-372 months). Lesion size averaged 492 mm^2 (range, 24-2000 mm^2). Lesions were located on the medial femoral condyle (53%), lateral femoral condyle (22%), and trochlea (25%). Fifty-nine percent reported a traumatic cause of the cartilage defect, whereas a nontraumatic cause was reported in 41%. None of the patients with a nontraumatic cause had osteochondral lesions. Eighty-four percent of all lesions were chondral lesions, whereas the remaining 16% were osteochondral lesions.

Microfracture arthroplasty was performed by fellowship-trained orthopaedic surgeons well experienced with the operative technique. A partial tear of the meniscus was present in 7 patients and was located in the same compartment as the cartilage lesion in 4 patients. All meniscal tears were treated with partial meniscectomy. Microfracture of the isolated femoral cartilage lesion was then performed as described by Steadman et al⁴² by debridement of the cartilage lesion to stable cartilage margins, careful removal of the calcified cartilage layer using a curette, and micropenetration of the subchondral bone in 3- to 4-mm intervals using commercially available instrumentation (Linvatec, Largo, Fla) to maintain the integrity of the subchondral bone plate.

In patients with femoral condyle lesions, continuous passive motion was started in the recovery room. Range of

motion was gradually increased until full passive motion was achieved. Continuous passive motion was used for 6 hours per day, and weightbearing was protected for 6 weeks. Full weightbearing was normally introduced between 7 and 8 weeks after surgery. In patients with lesions of the trochlea, weightbearing was allowed in a knee brace 48 hours after surgery, but active flexion was limited to 0° to 20° . In addition, continuous passive motion from 0° to 80° was used for 6 weeks. Stationary bicycling was allowed as soon as range of motion was permitted. Patients usually returned to running at 3 to 4 months and to cutting and pivoting at 4 to 6 months after microfracture.⁴² The exact timing of return to high-impact sports was not recorded.

Functional outcome was evaluated at a minimum of 2 years after microfracture, with a mean follow-up time of 41 months (range, 24-54 months). Prospective follow-up evaluation was performed at 3, 6, 12, 24, 36, and 48 months postoperatively. Instruments for outcome evaluation included preoperative and postoperative subjective clinical rating of knee function with the patient-based Brittberg rating^{35,36} and the activity-based Marx activity rating scale,²⁵ Tegner score,⁴⁵ and activities of daily living (ADL) scale of the Knee Outcome Survey.¹³ These outcome instruments have been previously used for evaluation of cartilage injuries of the knee.^{11,18,24,36,40,41} The Marx activity rating scale has been recently developed and places specific emphasis on athletic activities that are difficult to perform with chondral injuries such as running, cutting, decelerating, and pivoting.

Intragroup comparison between parameters before and after microfracture were tested by paired *t* test. Intergroup comparison was performed by Student *t* test. Differences between variable proportions were evaluated by χ^2 analysis. Values are presented as mean \pm standard error of the mean. $P < .05$ was considered statistically significant.

RESULTS

At last follow-up, 21 (66%) of the athletes reported good or excellent results on the Brittberg rating (Figure 1). Good or excellent results were reported for 65% of lesions located on the medial femoral condyle, 71% on the lateral femoral condyle, and 63% on the trochlea. Activity of daily living scores ($P = .001$), Marx activity rating scale results ($P = .001$), and Tegner activity scores ($P = .001$) improved significantly after microfracture (Figures 1 and 2). Improvement of ADL, Marx scale, and Tegner scores was observed in 71%, 58%, and 72% of athletes, respectively. Although significant increases in functional outcome scores were observed in patients returning to high-impact athletics, functional increases were lower in patients who failed to return to the sport (Figures 1 and 2). After an initial increase, a decline of the activity scores was observed in 15 athletes (47%). Age, duration of symptoms, or lesion size or type did not affect the incidence of decreasing functional scores.

All patients regularly participated in one or more high-impact sports before cartilage injury (Table 1). Fourteen athletes (44%) were able to return to regular participation in high-impact, pivoting sports after microfracture: 10 (71%) at the competitive level and 4 (29%) at the recreational

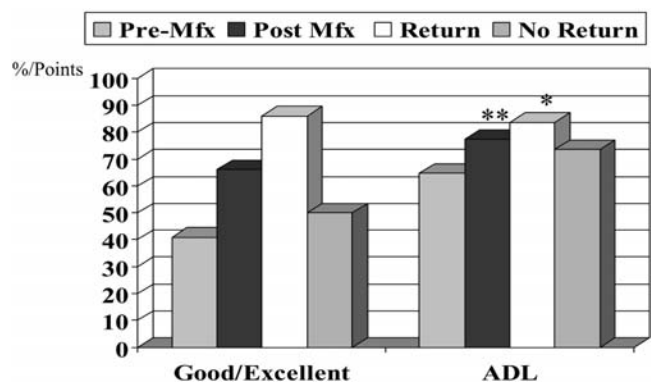


Figure 1. Changes in activities of daily living (ADL) score and good or excellent Brittberg rating before microfracture (light gray), after microfracture in all patients (black), and in athletes who returned (white) and athletes who did not return (dark gray) to high-demand sports after microfracture. * $P < .05$ return versus no return. ** $P < .001$ premicrofracture versus postmicrofracture. Mfx, microfracture.

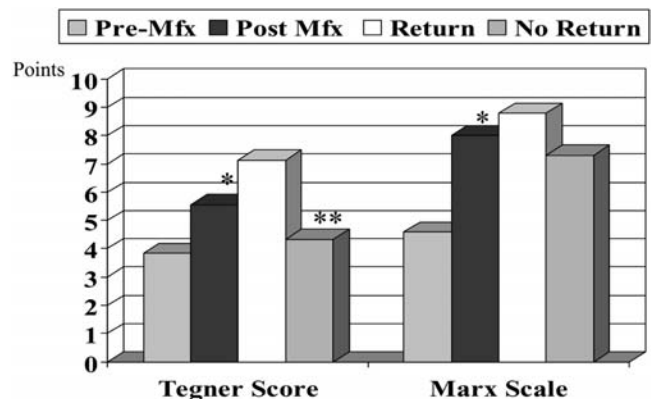


Figure 2. Changes in Tegner activity scores and Marx activity rating scale results before microfracture (light gray), after microfracture in all patients (black), and in athletes who returned (white) and athletes who did not return (dark gray) to high-demand sports after microfracture. * $P < .05$ premicrofracture versus postmicrofracture. ** $P < .05$ return versus no return. Mfx, microfracture.

level. Eight (57%) of the returning athletes participated at the preoperative athletic level. Athletes who were able to return to high-impact sports had good or excellent Brittberg ratings (86%), compared with 50% of athletes who were unable to return ($P = .08$). Patients returning to high-impact athletics also had higher activity scores than did athletes who did not return (Figures 1 and 2).

Although the mean duration of symptoms in players who returned to high-impact sports was markedly shorter than in athletes who were unable to return, this difference did not reach statistical significance ($P = .153$) (Table 2). Of the players who were symptomatic for 12 months or less before microfracture, 67% were able to return to high-impact sports, whereas only 14% of players with symptoms for more than 12 months returned to demanding athletic activity



Figure 3. Sagittal fast-spin-echo magnetic resonance images in the knee of a 30-year-old patient with an Outerbridge IV articular cartilage lesion of the trochlea before (A) and after (B) microfracture treatment.

($P = .009$). Along with the lower preoperative duration of symptoms, the mean number of surgeries before microfracture was lower in athletes who returned to their sports ($P = .014$) (Table 2). In fact, 86% of athletes who returned to high-impact sports underwent microfracture as their first-line procedure, whereas 67% of patients who had undergone prior surgeries failed to return ($P = .009$). Concomitant

TABLE 1
High-Impact Athletic Activity Before Cartilage
Injury and After Microfracture^a

	Before Cartilage Injury		After Microfracture	
	n	%	n	%
Overall	32	100	14	44
Football	9	28	3	9
Soccer	5	6	1	3
Basketball	14	44	7	22
Tennis	13	41	4	13
Squash	1	3	1	3
Downhill skiing	7	22	6	19

^aSeveral athletes participated in multiple sports.

TABLE 2
Demographic Parameters, Lesion Characteristics,
and Ability to Return to High-Impact
Athletics After Microfracture

Demographic Data	All Athletes	Returning	Not Returning
Gender, male:female, %	84:16	79:21	89:11
Age, y	38 ± 2.0	33 ± 2.6 ^a	41 ± 2.5
Previous surgeries, no.	0.9 ± 0.3	0.3 ± 0.2 ^a	1.3 ± 0.4
Meniscectomy, %	22	14	27
Symptom duration, mo	27.9 ± 11.8	8.6 ± 2.5	42.9 ± 20.4
Lesion size, mm ²	492 ± 98	342 ± 132	610 ± 137
Lesion type, %			
Chondral	84	79	89
Osteochondral	16	21	11
Lesion location, %			
Medial femoral condyle	53	50	56
Lateral femoral condyle	22	29	17
Trochlea	25	21	27

^a $P < .05$.

meniscectomy did not significantly influence the ability to return to high-impact sport ($P = .628$) (Table 2).

Athletes who returned to high-impact sports were younger than were patients who did not return ($P = .03$) (Table 2). Sixty-five percent of athletes younger than 40 years returned to demanding high-impact sports, whereas only 20% of athletes older than 40 years were able to return ($P = .029$).

The mean lesion size in athletes who failed to return was larger than that of patients who were able to return, but this difference was not statistically significant ($P = .176$) (Table 2). However, we found that athletes with lesion size ≤ 200 mm² had a significantly higher return rate (64%) to high-impact sports than did athletes with lesions > 200 mm² (22%, $P = .04$).

Lesion location did not affect outcome, as good and excellent outcomes were similar for lesions located on the medial femoral condyle (65%), lateral femoral condyle (71%), and

trochlea (62%). There was also no difference in the rate of return to demanding athletics between the different lesion locations (Table 2). In addition, we were unable to detect an effect of gender ($P = .812$) or lesion type ($P = .389$) on the ability to return to high-impact sports after microfracture in our study cohort (Table 2).

DISCUSSION

Increasing participation in organized high-impact sports such as soccer, basketball, and football has been associated with a growing incidence of knee articular cartilage injuries in these high-demand athletes.^{1,16,21,26,31,37,39} Injuries to the articular cartilage surfaces of the knee present a therapeutic challenge and often limit participation in athletic activity while predisposing the athlete to early joint degeneration and disability.^{4-6,14,20-22,30,33} Recent data indicate effective and durable improvement of knee function after articular cartilage restoration with microfracture in the general population.⁴⁰ Despite these promising results, limited information is available on the ability of microfracture to return athletes to demanding high-impact sports. Extreme mechanical joint stresses such as those from repetitive joint impact, rapid deceleration, and frequent pivoting in high-impact athletics are detrimental to articular cartilage repair and have been shown to increase the risk of osteoarthritis.^{5,20,38} Thus, evaluation of microfracture in high-impact athletes provides critical information about the ability of this technique to restore articular cartilage in the knee to the degree that it can withstand maximum mechanical demands.

Steadman et al⁴⁰ reported significant increases in their patients' ability to perform ADL, strenuous work, and sports after microfracture, results similar to ours. Besides changes in ADL scores, we also observed significant increases in Marx activity scale results and Tegner scores after microfracture, which is consistent with improved functional scores reported after microfracture by other authors.^{11,18} The improvement rate of 58% to 72% in our study is lower than the results from previous reports, which have shown improved knee function in 70% to 95%.^{2,11,18,40,43} This lower functional improvement rate likely resulted from the focus of our study on a population with higher mechanical demands on the repaired cartilage. The specific emphasis of the Marx rating scale on demanding activities, such as cutting, pivoting, and decelerations, can explain the relatively lower improvement rate of this instrument in our study. The high demand in our study population is also reflected by the fact that only 44% of our athletes were able to return to high-impact, pivoting athletics. Similarly, only 33% of soccer players were able to return to their demanding sport after autologous chondrocyte transplantation.³⁰ In comparison, Blevins et al² and Steadman et al⁴¹ reported 76% to 77% of their elite athletes were able to return to competition after microfracture. These rates are comparable with the higher return rate of 83% observed in elite athletes after autologous chondrocyte transplantation.³⁰ Blevins et al² noted that high-level athletes had better filling of their repaired cartilage defects than did recreational athletes and attributed this result to the higher portion of acute

lesions, younger age, and differences in postoperative rehabilitation. This finding is consistent with the better results after microfracture in younger athletes and with shorter preoperative duration of symptoms observed in our study. The better results reported by Blevins et al² and Steadman et al⁴¹ may also be explained by their smaller mean lesion size of 223 mm² and 380 mm², respectively, compared with the mean size of 492 mm² in our study. This finding is supported by our finding that defect size less than 200 mm² was associated with a significantly higher rate of return to high-impact athletics and by previous clinical and experimental studies that have shown better articular cartilage repair in smaller cartilage defects.^{12,22,27}

As in our study, some investigators have observed deterioration of knee function with decreasing pain scores, Tegner scores, and International Knee Documentation Committee scores after microfracture.^{11,18,28,40} Clinical evidence suggests that repair cartilage volume plays a critical role for durability of functional improvement after microfracture, as deterioration of knee function occurred primarily in patients with lack of repair cartilage fill at second-look arthroscopic evaluation or poor fill grade on postoperative MRI (Figure 3).^{28,40} Because mechanical stress is known to be detrimental for cartilage repair with bone marrow-stimulating techniques,⁵ the excessive loading in our demanding athletic population may have resulted in more limited filling of the repaired defects and contributed to the functional deterioration observed in our study. Systematic study with scheduled second-look arthroscopic evaluation or follow-up MRI would be needed to confirm this assumption. Excessive loading from high body mass index has also been implicated as a cause for inferior results after microfracture.²⁸

The preoperative duration of symptoms was found to be an important factor for cartilage repair with microfracture in our study. Our data indicate that the longer the interval between injury and microfracture, the lower the rate of return to high-impact athletics. In our study, the successful return rate increased from 44% to 67% if microfracture was performed within 1 year after articular cartilage injury. Similar to our findings with microfracture, prolonged preoperative morbidity resulted in decreased return to athletics after autologous chondrocyte transplantation and mosaicplasty.^{17,29,30,34} The inferior macroscopic grading of the repaired cartilage associated with longer preoperative intervals observed at second-look arthroscopic evaluation after microfracture offers a possible explanation for the inferior results in our study.² Development of early degenerative joint changes could explain the inferior results observed with late surgical cartilage repair in our study and others.¹⁷ Prolonged absence from sports-associated joint loading and its positive effect on the articular cartilage metabolism may have contributed to the failure to return to the preinjury athletics.¹⁵ Furthermore, prolonged absence from athletic activity promotes chronic deconditioning and makes returning to competitive sports more unlikely. Thus, early surgical treatment of articular cartilage lesions is critical for the return of the injured athlete to demanding sports.

Athletes with no prior surgical intervention had a better rate of return to high-impact athletics than did those who had undergone knee surgery before microfracture. This finding

suggests that microfracture is most effective as a first-line procedure in athletes, whereas the results from this technique in a salvage situation are less predictable. The use of microfracture as a first-line procedure has also been advocated by other authors.²⁷ In accordance with our observation, previous studies found that athletes with prior surgical interventions are less likely to return to preinjury sports and pointed out that the treatment options for patients who failed multiple surgeries are limited and that results are often poor.^{29,30} Patients with prior procedures may also carry biologic characteristics that predispose them to failure. The detrimental effect of prior surgeries in our study may also be related to the more chronic preoperative intervals in athletes who had failed surgical intervention before microfracture. Other cartilage repair techniques, such as autologous chondrocyte transplantation, may be considered in patients after unsuccessful prior surgical treatment.^{27,29,30,35,36}

Athletes returning to high-impact sports after microfracture were younger than were athletes who failed to return to their demanding sport. Younger age has been previously associated with better functional outcome after microfracture.^{18,30,40} The benefit of young age was also observed for mosaicplasty,¹⁷ with 90% of athletes younger than 30 years returning to full athletic participation, whereas only 23% of athletes older than 30 years were able to return to competition. Those authors suggested that the lower return rate in the older athletes was related to a slower rehabilitation and overall recovery in that subgroup. Younger age has also been shown to improve outcome from autologous chondrocyte transplantation.^{29,30} Age-dependent qualitative and quantitative differences in metabolic activity in the repair cartilage offer a plausible explanation for the better functional outcome observed in younger athletes.^{23,32,44,46} Besides clinical and biologic factors related to the injury, natural causes and changing social and professional demands may have contributed to the decreased return to competitive sports in older athletes.

Limitations of our study included the nonrandomized, uncontrolled study design; short follow-up; and inability to measure compliance with the postoperative rehabilitation. Randomized, controlled studies with long-term follow-up will certainly be beneficial but may be difficult to achieve. Despite our study limitations, we were able to show significant improvement of knee function in our athletes and were able to determine several factors that affect the ability to return to demanding high-impact athletic activity after microfracture.

This study demonstrates that microfracture results in increased functional scores in high-demand athletes treated for symptomatic cartilage lesions at a minimum 2-year follow-up. Our data demonstrate a better return to high-impact athletic activity if athletes are younger than 40 years of age, have small lesions less than 200 mm², have short preoperative intervals less than 12 months, and have had no prior surgical interventions. Decreasing function after initial improvement is observed in a considerable number of the athletes. Long-term evaluation will help to determine the long-term durability of articular cartilage restoration with microfracture and whether this technique can reduce the high incidence of osteoarthritis in this demanding population.

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