Improvement of Full-Thickness Chondral Defect Healing in the Human Knee After Debridement and Microfracture Using Continuous Passive Motion

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ABSTRACT: ***Since 1985, 298 patients have been studied after treatment of full-thickness articular surface defects of the knee. Most of these defects were found at the time of arthroscopy for other soft-tissue injuries, and all were treated with debridement and microfracture of the exposed subchondral bone. Seventy-seven patients underwent second-look arthroscopy. Lesions were graded from 1 to 5 at the initial surgery and at second look, with grade 5 being a chronic "bare-bone" lesion and grade 1 being normal-appearing cartilage. All of the patients but one had a score of 5 initially.***

Although continuous passive motion (CPM) was recommended for 8 weeks postoperatively for all patients, only 46 of the sample of 77 were able to comply, primarily because of insurance restrictions. Patients were assigned to groups based on whether CPM was part of their postoperative rehabilitation. The mean improvement in grade for patients in the CPM group (46 patients) was 2.67 compared with 1.67 for those in the non-CPM group (31 patients) (P=.003). Only 15% of the CPM group had no improvement in grade, whereas 45% of the non-CPM group exhibited no improvement (P=.0065). The improvement in the CPM group over the non-CPM group was the same whether the lesion was patellofemoral or tibiofemoral, large or small, or in a young individual or older individual. We conclude that CPM for 6 hours daily for 8 weeks postdebridement and microfracture for full-thickness cartilage defects in the knee appears to result in better gross healing of the lesion when evaluated by arthroscopic visualization compared with the same treatment without CPM. This is not a functional outcome study and extrapolation to the functional outcome status of the patients cannot be made.

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INTRODUCTION

Biological resurfacing of joint surface defects has been a goal of orthopedic surgeons for decades. Attempts at resurfacing have included subchondral abrasion,[1,7,11,12,17]

subchondral abrasion plus drilling,[4,7,15] perichondral autograft,[13,29,30] subchondral abrasion plus continuous passive motion (CPM),[25,26] subchondral abrasion plus periosteal resurfacing plus CPM,[21] plug autografts,[22,28] and shell allografts.[6,9,10,16,19,20,23] With the advent of arthroscopy, the techniques that involve chondral debridement and drilling have become much easier to perform and entail less morbidity than open procedures performed prior to arthroscopy. Because cartilage has limited capacity to heal and regenerate,[2,3,5,8,18,27] it is not expected that debridement and drilling procedures would always yield a durable fibrocartilage. However, it would seem logical that such arthroscopic techniques should be performed first in attempting biological resurfacing, and only in those cases that failed would more extensive open procedures be needed.

Chondroplasties of varying depths and debridement were popularized in the late 1940s and early 1950s. Haggart[11] originally described a procedure for the older age group that involved debridement of all degenerative tissue including osteophytes, partial or complete patellectomy, and a synovectomy. Of 20 patients treated, eight (40%) had an excellent result, six (30%) had a good result, four (20%) had a fair result, and two (10%) had a poor result. One year later, Magnuson[17] described a similar procedure that differed from Haggart's procedure in that a synovectomy was not routinely performed. Haggart[12] gave an update of his procedure, noting that he needed to manipulate 75% of the knees under general anesthesia at about 3 weeks postoperatively. Insall[14] reported on the Pridie operation of intra-articular debridement of the chronic degenerated knee in the elderly patient. He noted that Pridie had done a subchondral abrasion in approximately half of the knees while the other half received a subchondral abrasion plus drilling. The clinical outcomes and postoperative manipulation rates of the two subgroups were approximately the same. Examination of a few autopsy specimens revealed a fibrocartilaginous surface covering the area of subchondral abrasion and drilling.

In a follow-up report, Insall[15] recommended this type of procedure and its use for the appropriate middle-aged patient rather than the elderly patient. In 1979, Childers and Ellwood[4] reported on their series of subchondral abrasions and bone drilling for chondromalacia with a high success rate in the under-30 age group (20/21 good or excellent) compared with a high failure rate in the over-30 age group (2/4). In 1984, Friedman[7] reported a comparison of the results of debridement with and without subchondral abrasion. He found 53% improvement in the group that had debridement plus abrasion compared with 32% improvement in the group that had debridement alone. More recent investigations have not confirmed the findings of Friedman in that the results of subchondral abrasion were no better than those of debridement alone.[1] Neither of the latter two articles detailed the associated lesions of the knee (meniscus tears, etc). Moreover, the average age appeared to be higher in the study by Bert and Maschka.[1]

Beginning in the late 1970s, experimental investigations in animals revealed that full-thickness defects created in articular cartilage could achieve a good cartilage-like surface if CPM was applied to the joint postoperatively.[25] Continuous passive motion was needed for 8 to 24 hours per day for at least 1 week to stimulate the tissue repair; 2 hours per day was insufficient.[26] Periods of immobilization were allowed if the 8 hours per day CPM was used. If CPM was delayed for a week following immobilization, the effect of CPM on the cartilage was reduced. Continuous passive motion also was beneficial in increasing range of motion and improving ligament repair. The beneficial effects of CPM have been well summarized by Salter.[24]

The purpose of the study was to describe the appearance of the healing tissue in full-thickness chondral defects of the knee in two groups of patients: one group used CPM postoperatively, the other did not. The healing of these defects was evaluated by a second-look arthroscopy. The hypothesis of this study was that postoperative CPM would improve the appearance of the fibrocartilage formed in healing full-thickness chondral defects of the knee.

METHODS

Since 1985, 295 patients in our practices have undergone debridement with microfracture. Of these, 77 underwent second-look arthroscopy for reasons such as persistent pain, another complication, or evaluation of healing of the defect in order to advise the patient whether to resume strenuous activities. Forty-six of the patients had CPM postoperatively as part of their routine postoperative care and 31 did not. At follow-up examinations, patients were asked whether they used CPM as advised, and if so, for how long. Of those who used CPM, the overwhelming majority used it for 8 weeks (range: 1 to 16 weeks). The average time of use was 7.83 weeks. Continuous passive motion was recommended postoperatively, but some patients were unable to comply, usually because of lack of insurance coverage. Most of the initial procedures were performed to treat multiple soft-tissue injuries to the knee, such as anterior cruciate ligament tears (acute and chronic), meniscal tears (acute and chronic), patellar malalignment problems (acute and chronic), and other partial-thickness chondral defects. It was not uncommon for the full-thickness chondral defect to be discovered at arthroscopy for one of the other soft-tissue injuries.

After diagnosis of the full-thickness chondral defect,

the following surgical procedure was carried out. The exposed bone was cleaned of remaining cartilage tags using a full radius resector, and a perpendicular edge was created on the remaining healthy cartilage to allow blood to pool in the defect. To avoid thermal damage to the subchondral bone, neither abrasion nor burring with power tools was used. A full-radius resector usually was sufficient to debride the lesion. An awl was used to create multiple holes in the exposed subchondral bone. It was assumed that an awl would create less heat in the bone than either a hand-driven or motor-driven drill. This resulted in multiple "microfractures" at the base of the defect. Fat usually was seen coming from the subchondral marrow. The rationale for creating microfractures is to allow good adhesion of the blood clot that forms in the immediate postoperative period.

Immediately after awakening from general anesthesia, the patient was started on a CPM machine and maintained on the machine until discharge (usually the next day for extensive surgical repairs about the knee, but often the same day in the more simple repairs). The patient was advised preoperatively to rent a CPM machine and use it for 8 weeks postoperatively for 6 to 8 hours per 24-hour period, usually at night. The rate was one cycle per minute, and the range of motion was the largest range that the patient found to be comfortable. It also was recommended that the patient be touchdown (flat-footed) weightbearing on crutches for the full 8-week period. Patients who did not have access to a CPM machine (usually because they did not have insurance coverage for it) were advised to undertake a physical therapy program that included intermittent active motion of their knees. The usual regimen recommended was active flexion and extension of the operated knee for several hundred times three times a day.

Operation reports and video recordings were used to grade the initial lesion and the lesion at second-look arthroscopy using the following grading system:

- grade 1—firm, normal-appearing articular cartilage,
- grade 2—soft, yellowish cartilage or mild fibrillation,
- grade 3—deep fissure or cobblestone surface with no exposed bone,
- grade 4—recent full-thickness cartilage loss with exposure of subchondral bone and sharp edges, and
- grade 5—chronic full-thickness cartilage loss with exposure of subchondral bone and deep fissures or cobblestone edges.

Because the repair process is not always uniform, parts of the grade 5 lesion may have healed to a grade 2, while others healed to a grade 3. The grade assigned to the healing lesion at second look was the grade of the worst part of the lesion if the repair process was not uniform.

Although two centers were involved in contributing the cases to the study, only one surgeon graded the patients' lesions before treatment and at second look. The scoring was based on the operation reports and videos.

TABLE 1
IMPROVEMENT IN ARTICULAR CARTILAGE AFTER CHONDROPLASTY

	CPM Group (n=46)	Non-CPM Group (n=31)	*P* Value
Cartilage grade at second look	2.15	2.73	.05
Improvement in grade	2.67	1.67	.003

Abbreviations: CPM = continuous passive motion.

The records also were reviewed for other factors that might foretell chondral healing. These factors included:

- size of the lesion in millimeters squared,
- age of the patient,
- interval in weeks from initial operation to second-look arthroscopy,
- number of hours per day CPM was used,
- lesion locations,
- total number of lesions in the knee (including other soft-tissue injuries), and
- stability of the knee.

Patients in the CPM group (46 patients) used the CPM machine an average of 7.83 weeks for 6 to 8 hours per day (usually at night) while patients in the non-CPM group (31 patients) did not use the machine.

RESULTS

Preoperatively, all but three of the patients in the CPM group had grade 5 lesions (three were grade 4 lesions), and all of the patients in the non-CPM group had grade 5 lesions. If a lesion was grade 5 preoperatively and grade 2 at second look, the improvement in the grade was scored as 3. In the patients who used CPM postoperatively, the improvement in the cartilage was 2.7 on average, compared with 1.67 in the patients who did not use CPM ($P = .003$) (Table 1). Another way to look at these data is to examine the number of patients who showed no improvement after chondroplasty (they remained a grade 5 at second look). Seven (15%) patients in the CPM group and 13 (45%) patients in the non-CPM group showed no improvement on second look ($P = .0065$ using chi-square analysis). A breakdown of the range of postoperative scores compared with preoperative scores is given in Table 2.

Parameters beyond our control—the size of the lesion, the time from initial operation to second look, the age of the patient, knee stability, the number of lesions in the knee, and the location of the lesion—are listed in Table 3.

TABLE 2
RANGE OF POSTOPERATIVE GRADES

Lesion Grade	CPM Group		Non-CPM Group	
	Preop	Postop	Preop	Postop
1	—	17	—	5
2	—	18	—	8
3	—	4	—	6
4	3	1	—	0
5	43	6	31	12

TABLE 3
UNCONTROLLED PARAMETERS

	CPM Group (n=46)	Non-CPM Group (n=31)	P Value
No. of lesions	3.63	3.4	.27
Lesion size (mm^2)	322	210	.012
No. unstable knees	3 (13.6%)*	2 (18%)	.75
Interval to second look (weeks)	64	73	.34
Age (years)	30	37	.01
Lesion location			
Medial	25 (54%)	15 (48%)	.61
Lateral	21 (46%)	8 (26%)	.32
Patellofemoral	8 (17%)	14 (39%)	.03

*n = 41; five knees had no record of stability testing.

There was no difference in the number of lesions in either group, the number of unstable knees, and the interval to second look. However, CPM patients had slightly larger lesions than non-CPM patients. Non-CPM patients also had a significantly higher incidence of patellofemoral lesions than CPM patients. Finally, non-CPM patients were older than CPM patients. To control for these variables, patients were stratified into subsets.

In the first subset examined, the lesion size was held constant. Lesions between 100 and 400 mm^2 were chosen as those to be studied from each group (Table 4). The improvement in grade was 2.77 in the CPM group compared with 1.9 in the non-CPM group. This pattern paralleled the results seen in the overall study group. The statistical significance was slightly less compared with the overall group ($P = .013$ versus $P = .003$). In CPM patients, there was a trend toward better healing of the smaller lesions compared with the larger lesions, but the correlation was not strong ($r = .19$), nor was there statistical significance ($P = .21$).

The next subset to be studied were those lesions in which the location of the lesion was held constant (Table 4). Patients who had medial and lateral defects were studied, and all patellofemoral lesions were omitted. Again, there was significant improvement in CPM patients compared with non-CPM patients.

Next, patients were stratified by age: those under 25 years old, those between 25 and 40 years old, and those over 40 years old. There were not enough patients in the non-CPM group to allow a good comparison of the younger age group; however, there were adequate numbers in the middle and older age groups. Again, there was more improvement in the CPM group compared with the non-CPM group, with age held constant. A trend toward better healing in the younger age group was revealed; however, the correlation coefficient was not strong ($r = .15$) nor were the data statistically significant ($P = .31$).

To determine if the number of lesions was a predictor of success or failure of healing, data from CPM patients were entered into a scatterplot correlating the number of lesions in the knee and the success of healing. The lesions in the knee were counted whether they were acute or chronic lesions and whether they were partial or complete lesions. Lesions of the following areas in the knee were identified in the study: patella articular cartilage; trochlear articular cartilage; mediofemoral condyle articular cartilage; laterofemoral condyle articular cartilage; mediotibial plateau articular cartilage; laterotibial plateau articular cartilage; medial meniscus; lateral meniscus; anterior cruciate ligament; posterior cruciate ligament; posterolateral ligamentous structures; posteromedial ligamentous structures; anterolateral ligamentous structures; anteromedial ligamentous structures; medial collateral ligament; and lateral collateral ligament. If a lesion was encountered in any of these locations, it was scored as one lesion. It appears that there is a trend toward better healing in those knees that had fewer lesions, but again, the correlation was not strong nor was the statistical significance great ($r = .16$; $P = .28$).

Finally, the interval to second look was broken down for the CPM and non-CPM groups and compared with the improvement scores for each interval (Table 5). Whether the lesion was seen within 6 months after surgery or at intervals up to 2 years after surgery, the CPM group always showed more improvement than the non-CPM group. It also appeared that the improvement obtained within the first 6 months would be maintained for at least 2 years.

Evaluation by second-look arthroscopy of healing chondral defects demonstrates superior healing in knees that have had CPM as part of their postoperative regimen. The CPM treatment was started immediately after debridement and microfracture and was continued for 8 weeks postoperatively. This regimen should provide sufficient CPM to improve chondral healing, as suggested by animal studies.[26] Although the two samples

TABLE 4
IMPROVEMENT IN ARTICULAR CARTILAGE AFTER CHONDROPLASTY AFTER CONTROLLING FOR VARIABLES

	CPM Group		Non-CPM Group		
Variable	No. Patients	Improvement in Grade	No. Patients	Improvement in Grade	*P* Value
Lesion size held constant	31	2.77	21	1.90	.013
Medial and lateral locations only	37	2.64	16	1.71	.017
Age held constant					
<25 years	14	2.78	—	—	—
25 to 40 years	25	2.60	17	2.10	.08
>40 years	7	2.40	10	0.80	.02

TABLE 5
INTERVAL TO SECOND LOOK AS COMPARED WITH IMPROVEMENT IN SCORES

	CPM Group		Non-CPM Group	
No. Weeks to Second Look	No. (%)	Average Improvement	No. (%)	Average Improvement
<25	22 (47)	2.8	10 (32)	1.9
25 to 50	14 (31)	2.9	6 (20)	1.5
50 to 100	5 (11)	2.0	6 (20)	1.5
>100	5 (11)	2.4	9 (28)	1.7

differed in several variables, control of these by stratification still showed a positive effect of CPM. Unlike controlled animal studies, human clinical studies always have other predictors of success or failure that are mixed with the particular predictor under examination. Sometimes, this can be dealt with by a randomized control study, but such a study was not possible here because our study was retrospective. Our method to deal with other possible predictors was to subset; the results were not changed when using this method. Sometimes randomized studies for one predictor do not result in randomization of other predictors, and further subsets are necessary. The quality of the cartilaginous material that was observed in the second-look arthroscopy appeared to be better in the patients receiving CPM. In addition, the number of patients who had no improvement in their grade of lesion was considerably higher in the non-CPM group compared with the CPM group (Table 1). This last observation is the most important observation from this study.

The 77 patients who underwent second-look arthroscopy were not selected randomly as these patients had a need for a second look (complaints, persistent pain, or desire for return to vigorous activity). However, it is believed that groups that could be achieved by a randomized study could be created by subsetting the CPM versus non-CPM groups in this retrospective study.

It would have been ideal to do biopsies at second look; however, only a small biopsy would have been possible to eliminate risk to the healing tissue and most likely would not have been representative of the entire healing surface of fibrocartilage. In addition, only histology could have been studied by such a biopsy. Although the grading system was somewhat arbitrary and subjective, it did use palpation and visualization of the entire healing area. Perhaps the most sound and important observation of the study was that 45% of patients not using CPM had persistence of a grade 5 lesion, while only 15% of those using CPM had no improvement. Because grade 5 at second look means there was exposed bone present, this was a reliable observation. Even if all of the grading scores were not considered in this study, the percentage of knees with persisting exposed bone is important.

This result substantiates Salter's conclusions from animal experimental investigations[25] that CPM resulted in better healing than intermittent active motion. We also agree with Salter that younger patients of either group tended to heal better than older patients. However, CPM helped both the older and younger patients in the healing of their defects.

The effect of improved cartilage healing on functional outcome was not evaluated in this study. This leaves

several questions unanswered. Will a knee with a grade 3 lesion have better function and longevity than a knee with a grade 5 lesion? If the patients who did not use CPM could not afford it, were they also less able to heal their lesions? Could the slight increase in age have been responsible for less healing in the non-CPM group? Could the smaller lesions and more patellofemoral involvement have been responsible for poor healing in the non-CPM group? This heterogeneity between the groups was addressed by creating subsets, but there are still some unanswered questions, particularly with respect to functional outcome. In our series, only about 25% of patients had isolated chondral defects. Because most of the patients had other lesions about the knee, it is extremely difficult to find knees that are comparable to evaluate functional outcome. For example, a knee that has had a partial meniscectomy and anterior cruciate ligament repair as well as chondral defect cannot be compared with a knee that has had a meniscus repair and chondral defect. Nonetheless, functional studies are underway that compare knees stratified into identified subsets. Particular attention is being paid to the group of knees that have isolated chondral defects and were treated with or without CPM.

It would seem logical that the improvement in chondral healing obtained by the immediate postoperative regimen of CPM should be sustained with an exercise program on a permanent basis that also involves a considerable amount of motion. After the CPM regimen is completed, we recommend a program of progressive bicycling or deep-water running for these patients. In general, these patients are advised to avoid exercises that entail running, cutting, or jumping. It is our clinical impression that those patients who maintain the bicycling exercise program on a daily or every-other-day basis do better than those patients who try to get back to a running, cutting, or jumping exercise or similar sports program.

CONCLUSIONS

We recommend that a full-thickness chondral lesion discovered during arthroscopic surgery should be treated with debridement and microfracture, followed by 8 weeks of postoperative CPM (6 to 8 hours per day, one cycle per minute). The patients should remain touchdown weightbearing on crutches during this 8-week period. At the end of 8 weeks, it is recommended that patients progress to a bicycling exercise program that would start

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