



## Improvement in Bone Homeostasis Following Autologous Chondrocyte Implantation of the Knee

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### Abstract

This retrospective review and clinical follow-up demonstrates the effectiveness of autologous chondrocyte implantation of the knee. From September 1995 to June 2001, 24 patients with average follow-up of 26.5 months were evaluated. The mean Lysholm score improved from 43.58 before surgery to 71.42 at most recent follow-up, the modified Cincinnati knee score for overall clinician evaluation improved from 2.96 to 6.92, and the mean modified Cincinnati knee score for overall patient evaluation improved from 3.21 to 6.13 at  $P < .05$ . Seventy-nine percent of patients responded that they would have the same knee surgery again and 83% rated the results of their knee surgery as good to excellent. Limited radionuclide bone scans with single photon emission computed tomography were completed in 11 of the patients to assess the physiology and homeostasis of subchondral bone adjacent to treated articular cartilage defects. A trend was identified suggesting improvement in subchondral bone scores at a mean of 29.6-months follow-up compared to preoperative bone scan assessment. There also was a trend towards greatest improvement correlating with the patients with the best clinical scores. The results of this study suggest that autologous chondrocyte implantation of the knee can be successful in improving pain and function in patients with articular cartilage defects.

Until recently, the most common method for repairing cartilage damage on the articular surface of the knee joint has been debridement and lavage, subchondral drilling, microfracture, spongyalization, and abrasion arthroplasty.<sup>1-7</sup> Each of these surgical techniques may help to relieve clinical symptoms of pain, locking, and swelling, but the long-term clinical outcomes have been shown to be unpredictable.

Treatment of cartilage defects with autologous tissue or mesenchymal cells has also been explored. The autologous chondrocyte implantation technique was developed to treat focal articular cartilage knee defects. The procedure was initially studied in different rabbit models<sup>8-13</sup> and then further developed using human subjects<sup>14</sup> in an effort to provide a treatment option for people with full thickness chondral defects of the knee joint.

Early outcomes of the technique were reported by Brittberg et al.<sup>14</sup> This two-year follow-up study reviewed outcomes of the technique in 23 patients (16 with femoral condylar defects and 7 with patellar defects). Fourteen of the 16 patients treated for femoral condyle defects had good to excellent results. The two remaining patients suffered poor results with further treatment required. Seven patients were treated for patellar defects, with two patients reporting good or excellent results.

This initial study of autologous chondrocyte implantation for articular cartilage defects of the knee yielded promising results, especially for femoral condyle defects. Since then, Peterson et al.<sup>15</sup> and Peterson et al.<sup>16</sup> have confirmed these findings.

The purpose of the current study is twofold: 1) to evaluate the effectiveness of autologous chondrocyte implantation of the knee, through a retrospective clinical review and 2) to perform a pilot study to assess the benefit of this procedure on the physiology and homeostasis of the subchondral bone adjacent to the treated articular cartilage defects by the use of limited radionuclide bone scan with single photon emission computed tomography (CT).

We hypothesize that patients who have undergone autologous chondrocyte implantation to repair focal defects of the articular cartilage surface of the knee joint will have improved subjective and objective knee function as well as improvement in subchondral bone homeostasis.

### Materials and Methods

#### Patient Selection

The data used in this study were obtained from a total of 77 patients with articular cartilage defects. Biopsy specimens were obtained from each patient from September 1995 to June 2001 for autologous chondrocyte implantation. Thirty-four implantations in 31 patients were completed. The remaining 46 patients either improved with alternative treatment methods, chose not to proceed with surgery, or were denied approval for this procedure by their insurance company.

Thirty-one patients who received autologous chondrocyte implantation were assessed by a retrospective chart review and attempts were made to contact these patients through mail or by phone for a follow-up visit. Twenty-four (77%) patients agreed to return for clinical evaluation and documentation of adverse events, and to complete questionnaires regarding their clinical course. Two patients lived outside the United States and were not able to return for follow-up. One patient died of an unrelated cause. Four patients did not respond. Eleven of the 24 patients also agreed to undergo a follow-up limited radionuclide bone scan with single photon emission CT examinations of the treated knee. All patients provided informed consent for study participation, and the study design was approved by the medical center IRB committee.

Collected patient characteristics included age, gender, duration of symptoms from time of onset to implantation, follow-up time from implantation to June 2001, previous operations on the ipsilateral knee, cause of injury, completion of follow-up limited radionuclide bone scan with single photon emission CT, and presence of workman's compensation coverage. Defect characteristics including location of defect, size of defect, associated operations at time of biopsy or implantation, and grade of defect at time of biopsy also were recorded.

All the patients included in this study underwent an autologous chondrocyte implantation procedure by the senior author (J.L.H.). Thirty-four implantations in 31 patients were completed. All patients had moderate-to-large, full-thickness (Outerbridge<sup>17</sup> grade IV) defects located on the femoral condyle, patella, or trochlea.

## **Clinical Evaluation**

Clinical examinations before and after autologous chondrocyte implantation included assessment of alignment, anteroposterior stability, mediolateral stability, crepitus, effusion, joint line pain, atrophy, and patella tracking. Two scoring systems were used to quantify the clinical status of the patients: the methods described by Lysholm and Gillquist<sup>18</sup> and modified Cincinnati knee score.<sup>19</sup> Lysholm scores and the modified Cincinnati knee scores were obtained prior to biopsy, as well as at follow-up visits for all 24 patients in June 2001.

In addition, a follow-up questionnaire regarding patient perception of surgical outcome was completed for all 24 patients in June 2001.

## **Bone Scan Assessment**

Limited radionuclide bone scans with single photon emission CT were performed to assess bone activity and state of joint homeostasis. The goal of the single photon emission CT scanning was to determine the ability of chondral resurfacing using autologous chondrocytes to restore joint homeostasis. Single photon emission CT provided increased contrast resolution over standard (planar) imaging and was useful in more accurately localizing abnormalities in radiotracer distribution.

Single photon emission CT examination of the treated knee joint was based on the recommended protocol used at the Nuclear Medicine Division, Department of Radiology, California Pacific Medical Center (San Francisco, Calif) (Table 1). Evaluations of the single photon emission CT examinations were completed by a nuclear medicine specialist through a blinded scoring system (Table 2). Single photon emission CT examinations were performed prior to implantation and at the most recent follow-up visit in June 2001 in 11 patients. Bone scan scoring was based on a scale of 0 (normal) to 3 (most severe).

Table 1

### Protocol Used for Limited Radionuclide Bone Scan With Single Photon Emission Computed Tomography Examinations

**The radiopharmaceutical:**  $^{99m}\text{Tc}$ -MDP or  $^{99m}\text{Tc}$ OHDP, dose 20-25 mCi (740-925 MBq)IV

**Patient preparation:** hydration, voiding prior to imaging

**Imaging:** 2.5-3 hours after tracer injection

**Technique:** LFOV camera, LEHR collimator, 20% window at 140 keV

**Planar image acquisition**

Views: anterior, posterior, lateral, medial

Digital Matrix: 256×512 preferred

Time: 480 s/view

Counts: 500K per view

**SPECT acquisition**

Zoom: 1

Matrix: 128×128

64 steps (single head camera), 360° acquisition, 30 s/step

120 steps (multi head camera), 3°/step, 20 s/step

**Image display format**

Standard coronal, axial, parasagittal slices. Slice thickness 1-2 pixels maximum

*Abbreviations: LEHR=low-energy high-resolution and LFOV=large field-of-view.*

Table 2

### Subchondral Bone Scoring System, Using SPECT Scanning (Limited Radionuclide Bone scan With Single Photon Emission CT)

0-Normal (n=0*, 0†)	1-Minor Change (n=2*,3†)	2-Moderate Changes (n=3*,5†)	3-Severe Changes (n=6*,3†)
	Unicompartmental involvement	1-2 compartments involvement	Multicompartmental involvement
	Increased uptake relative to normal	Increased uptake relative to normal	Increased uptake relative to normal
	<30% of ipsilateral plateau/condyle	30%-50% compartmental involvement	>50% compartmental involvement

\*Number of patients preoperatively.

†Number of patients at most recent follow-up visit.

## Data Analysis

Clinical baseline scores were compared with follow-up data and manually recorded onto data logs and then entered on computer into Excel worksheets where tables, graphs, and statistical information were calculated. Figures were evaluated based on mean, median, standard deviations, confidence intervals, and paired *t*-tests. All reported *P* values are two-tailed. For all the statistical analysis used, a two-tailed *P* < .05 was considered significant.

## Surgical Technique: Part I

The surgical technique for cartilage biopsy harvesting that the patients underwent in this study previously has been described by Peterson et al.<sup>15</sup>

## Surgical Technique: Part II

The second surgery was performed under general anesthesia. Prophylactic antibiotics were given intravenously in

three doses over a 24-hour period during and after the surgery. A medial parapatellar arthrotomy was made without use of a tourniquet. The chondral lesion was excised as far as the normal surrounding cartilage but not as far as the subchondral bone plate.

The cartilage defect was covered with a periosteal flap obtained from the proximal medial tibia. The flap was sutured to the surrounding rim of the normal cartilage with interrupted 6-0 sutures. Fibrin glue was used to seal the patch. The cultured chondrocytes were injected beneath the periosteal flap. The joint capsule, retinaculum layer, and skin were sutured in separate layers. The knee was covered with a bandage. Passive movement of the knee without weight bearing was initiated 24 hours after surgery using a continuous passive motion machine. Weight bearing was gradually introduced and increased to the full extent, with isometric quadriceps training, during the first six weeks after surgery.

## **Postoperative Rehabilitation Program**

All patients who received an autologous chondrocyte implantation were prescribed a postoperative rehabilitation program to optimally achieve the goals of the procedure, to alleviate symptoms and return to a higher functional level of participation. The rehabilitation guidelines were based on the type and location of the defect. Five different programs were used and these were based on Genzyme Tissue Repair Postoperative Rehabilitation Guides. In general, the postoperative rehabilitation included nonweight bearing and use of a continuous passive motion machine for 6-8 hours/day for 4 weeks followed by progression to full weight bearing at 6 weeks. Patients were restricted from inline impact activities (eg, running) for 6-9 months, and cutting sports for at least 14-18 months.

The rate of progression through rehabilitation programs varied depending on the patient's defect size, location, and concomitant procedures, as well as on individual patient response to the surgery. It should be noted that each program served as a guide that was modified to meet the specific needs of each patient.

## **Results**

### **Clinical Evaluation**

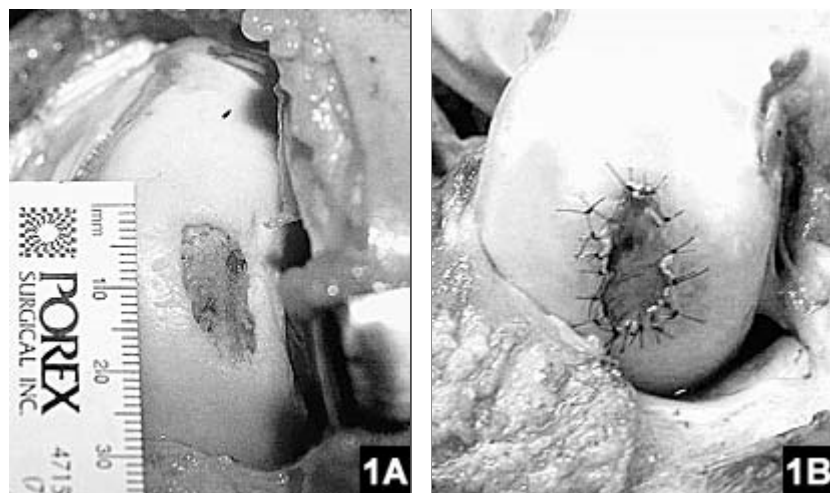
Twenty-four patients (16 men and 8 women) with a total of 26 articular cartilage defects were evaluated (11 isolated medial femoral condyle defects, 8 isolated lateral femoral condyle defects, 2 isolated trochlear defects, 1 isolated patellar defect, 1 with trochlear and medial femoral condyle defects, and 1 with medial and lateral femoral condyle defects). The average patient age was 39.1 years (range: 17-54 years) with a mean duration of symptoms prior to implantation of 71.3 months (range: 7-268 months). The average time to most recent follow-up visit in June 2001 was 26.5 months after implantation (range: 4-63 months). The study population had a total of 66 previous operations of the affected knee with an average of 2.8 procedures per patient. Fifteen (63%) patients injured their knee secondary to sports related activity, 7 (29%) patients due to work, and 2 (8%) patients because of a motor vehicle accident. Five (21%) patients had their surgery costs covered through workman's compensation (Table 3).

Table 3

Patient Characteristics							
Patient No.	Age/Gender (y)	Duration of Symptoms (mo)*	Time to Last Follow-up (mo)†	Previous Operations	Etiology of Injury	Follow-up Bone Scan	Workers Compensation
1	36/M	217	14	3	Sport	No	No
2	34/F	7	27	2	MVA	No	No
3	38/F	53	44	2	Work	Yes	Yes
4	46/M	20	16	2	Sport	Yes	No
5	38/M	36	32	5	Work	No	No
6	43/M	161	24	6	Sport	Yes	No
7	47/F	167	18	2	Sport	No	No
8	39/M	268	44	5	Sport	Yes	No
9	37/M	27	20	3	Sport	Yes	No
10	54/M	40	16	2	Work	Yes	Yes
11	26/M	15	4	3	Work	No	Yes
12	44/F	267	48	3	Sport	No	No
13	43/F	167	63	2	Work	No	Yes
14	38/M	19	4	2	Sport	No	No
15	43/M	25	15	3	Sport	Yes	No
16	42/M	19	54	3	Work	Yes	No
17	42/M	51	42	2	Sport	Yes	No
18	34/F	37	47	4	Work	No	Yes
19	17/M	33	15	1	Sport	No	No
20	27/M	12	16	3	Sport	No	No
21	34/M	15	17	3	Sport	No	No
22	37/M	10	42	2	Sport	Yes	No
23	54/F	19	9	2	Sport	Yes	No
24	46/F	26	4	1	MVA	No	No
<b>Mean SEM</b>	<b>39.1</b>	<b>71.3±17.3</b>	<b>26.5±3.5</b>	<b>2.8±.3</b>			

Abbreviations: MVA= motor vehicle accident and SEM= standard error of mean.  
 \*Duration of symptoms from time of onset to implantation  
 †Follow-up time from time of implantation to June 2001.

In general, these were young patients with fairly large lesions who previously had undergone multiple attempts of surgical repair that had failed. The mean defect size was 4.8 cm<sup>2</sup> (range: 0.9-9.5 cm<sup>2</sup>) (Figure 1). Twelve (50%) patients underwent associated procedures at the time of biopsy or implantation. Five patients had complete meniscal allograft reconstruction, 2 had high tibial osteotomy, 3 had anterior cruciate ligament (ACL) reconstruction or revision, 1 had posterior cruciate ligament and complete meniscal allograft reconstruction, and 1 had tibial tubercle osteotomy in addition to autologous chondrocyte implantation. Seventeen (71%) patients had grade IV defects, 6 (25%) patients had grade III-IV defects, and 1 (4%) patient had a grade III defect (Table 4).



**Figure 1:** Isolated Grade 4 chondral defect of the medial femoral condyle about to undergo autologous chondrocyte implantation (A). Immediately after suturing of periosteal patch and implantation of chondrocytes (B).

Table 4

## Defect Characteristics

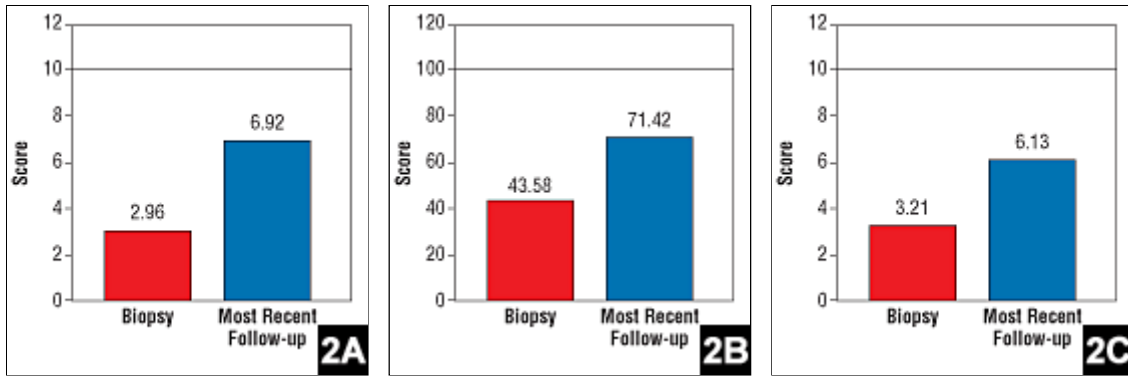
Patient No.	Location of Treated Defect	Size of Defect (cm <sup>2</sup> )	Grade of Defect (Preoperatively)*	Associated Operations†
1	Trochlea	8.8	IV	CMA
2	LFC	3	IV	CMA
3	MFC	1.9	IV	None
4	MFC	6.3	IV	HTO
5	Trochlea	4	IV	None
6	MFC	4	IV	ACL
7	LFC	9.5	IV	CMA
8	LFC	6	IV	CMA
9	LFC	5.3	III-IV	None
10	MFC	8	III-IV	None
11	LFC	2.5	IV	None
12	MFC	1.8	III-IV	CMA
13	LFC	7	III	None
14	MFC	5	III-IV	PCL, CMA
15	Trochlea	5	IV	None
	MFC	2.4	IV	
16	MFC	.9	IV	None
17	LFC	2.3	III-IV	None
18	Patella	2.1	IV	TTO
19	MFC	8.8	IV	None
20	LFC	3	IV	ACL
21	MFC	5.3	IV	HTO
22	MFC	6.8	IV	ACL
23	MFC	8.8	IV	None
	LFC	2	IV	
24	MFC	6.3	III-IV	None
Mean		4.9 ± .508		
SEM				

Abbreviations: ACL=anterior cruciate ligament reconstruction/revision, CMA=complete meniscal allograft, HTO=high tibial osteotomy, LFC=lateral femoral condyle, MFC=medial femoral condyle, PCL=posterior cruciate ligament reconstruction, SEM=standard error of mean, and TTO=tibial tubercle osteotomy.

\*Grade of defect based on Outerbridge<sup>17</sup> classification system.

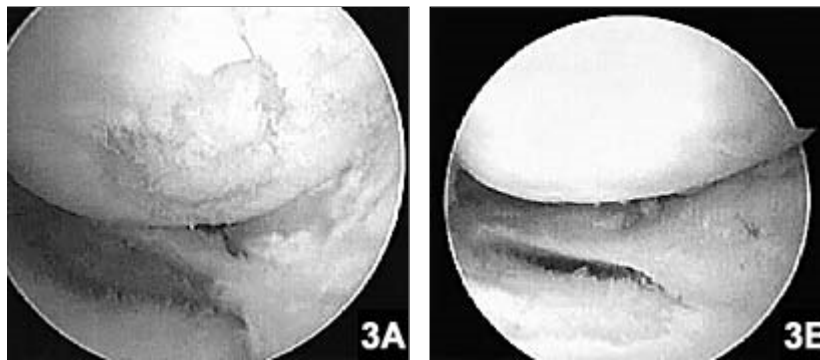
†Operations performed at biopsy and implantation.

The mean Lysholm score improved from 43.58 (range: 10-84) before surgery to 71.42 (range: 16-98) after surgery at the most recent follow-up visit; the mean modified Cincinnati knee score for overall clinician evaluation improved from 2.96 (range: 1-5) before surgery to 6.92 (range: 4-9) after surgery at the most recent follow-up visit; the mean modified Cincinnati knee score for overall patient evaluation improved from 3.21 (range: 1-6) before surgery to 6.13 (range: 2-9) after surgery at the most recent follow-up visit ( $P < .05$ ) (Figure 2).



**Figure 2:** Mean clinical points at most recent follow-up in June 2001 compared to baseline at time of biopsy. Modified Cincinnati Knee Score overall clinician evaluation (A), modified Cincinnati Knee Score overall patient evaluation (B), and Lysholm Score (C).

A subgroup was extracted from the data collection to compare their preoperative results with the results from the most recent follow-up visit. The subgroup consisted of patients with an isolated femoral condyle defects with a mean follow-up of 29.2 months treated with autologous chondrocyte implantation (n=9). In this subgroup, the mean Lysholm score improved from 37.33 (range: 10-84) before surgery to 69.78 (range: 20-89) after surgery at the most recent follow-up visit; the mean modified Cincinnati knee score for overall clinician evaluation improved from 3.11 (range: 1-5) before surgery to 6.22 (range: 4-8) after surgery at the most recent follow-up visit; overall patient evaluation improved from 2.78 (range: 1-4) before surgery to 5.56 (range: 4-8) after surgery at the most recent follow-up visit ( $P<.05$ ) (Table 5) (Figure 3).



**Figure 3:** Chondral Defect before (A) and after (B) autologous chondrocyte implantation in combination with meniscus transplantation.

Table 5		
Clinical Results of Isolated Femoral Condyle Defects With Autologous Chondrocyte Implantation*		
Variables	Biopsy	Most Recent Follow-Up
Modified Cincinnati Knee Score		
Overall Clinician Evaluation	3.11	6.22
Overall Patient Evaluation	2.78	5.56
Lysholm Score	37.33	69.78

\*Number of patients = 9 and mean age = 38.3 years.

When patients were asked whether they would have the same knee surgery again, 19 (79%) patients responded definitely yes, 3 (13%) patients responded probably yes, 1 (4%) patient was completely uncertain, 0 patients responded probably not, and 1 (4%) patient responded definitely not (Table 6). Fourteen (58%) patients rated the results of their knee surgery as excellent, 6 (25%) good, 3 (13%) fair, and 1 (4%) poor (Table 6).

Table 6

### Satisfaction Questionnaire Regarding Patient Perception of Surgical Outcome at Most Recent Follow-up in June 2001

**Question 1:** *If you could go back in time and make decisions again, would you choose to have an autologous chondrocyte implantation procedure?*

Response	No. Surveyed	% Response
Definitely yes	19	79
Probably yes	3	13
Completely uncertain	1	4
Probably not	0	0
Definitely not	1	4
<i>Total</i>	24	100

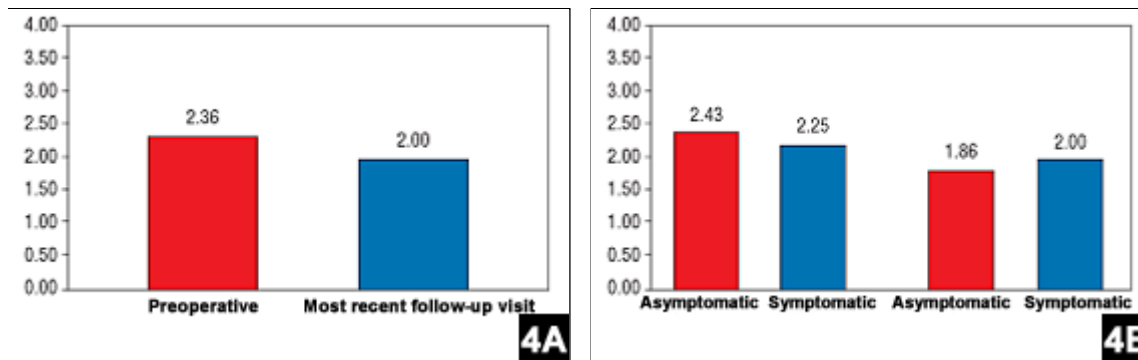
**Question 2:** *How would you rate the results of your autologous chondrocyte implantation?*

Response	No. Surveyed	% Response
Excellent	14	58
Good	6	25
Fair	3	13
Poor	1	4
<i>Total</i>	24	100

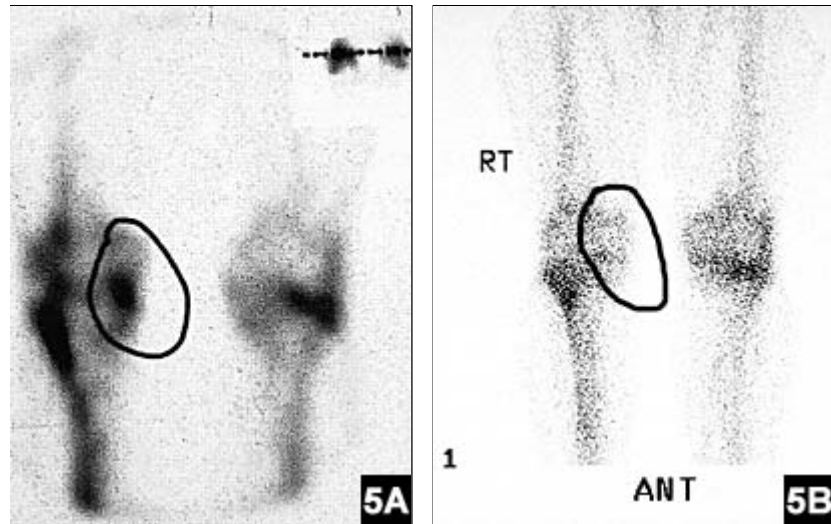
### Bone Scan Assessment

Eleven patients (9 males and 2 females) with a mean follow-up of 29.6-months were evaluated. Mean subchondral bone score for the limited radionuclide bone scan with single photon emission CT preoperatively was 2.36 (CI+.543) and the mean subchondral bone score at most recent follow-up visit in June 2001 was 2.00 (CI+.520) (Figure 4A). The total subchondral bone score was 26 preoperatively and 22 at most recent follow-up visit in June 2001; 6 patients improved, 3 patients stayed the same, and 2 patients deteriorated. Although there was a trend toward improvement, when a paired *t* test was performed, the sample data from these two groups were not statistically different.

A separate comparison also was done between the subgroup of patients who reported being asymptomatic following the procedure (n=7) with those patients who still reported having symptoms (n=4). The asymptomatic group had a mean score of 2.43 (CI+.728) preoperatively and 1.86 (CI+.989) at most recent follow-up visit in June 2001. The symptomatic group had a mean score of 2.25 (CI+1.523) preoperatively and 2.00 (CI+1.299) at most recent follow-up visit in June 2001. Although there was a trend toward improvement, when a paired *t* test was performed, the sample data from these two groups were not statistically different (Figures 4B and 5).



**Figure 4:** Mean subchondral bone score for the limited radionuclide bone scan with single photon emission CT at most recent follow-up visit in June 2001 compared to preoperative bone scan (A). Mean subchondral bone score of the asymptomatic group and the symptomatic group for the limited radionuclide bone scan with single photon emission CT at most recent follow-up visit in June 2001 compared to implantation (B).



**Figure 5:** Bone scan before (A) and 2 years after (B) autologous chondrocyte implantation for a defect of the medial femoral condyle. Note improvement in medial compartment homeostasis.

### Adverse Events

Seven adverse events in 7 (29%) patients were recorded following autologous chondrocyte implantation. Three patients presented with periosteal hypertrophy that was resolved with arthroscopic shaving. Three patients had intra-articular adhesions that was resolved with arthroscopic lysis of the adhesions. One patient had signs of early cellulites that was successfully treated with antibiotics. There were no deep infections or failures of the graft to incorporate.

### Discussion

The true natural history of chondral defects in the knee has not yet been defined and the clinical course may be unpredictable. Nonetheless, it is recognized that articular cartilage lesions often are associated with progressive patient symptoms such as pain, decreased joint motion, and finally joint dysfunction followed by degenerative changes typical to osteoarthritis.

Thus far, there are no perfect ways to treat articular cartilage injury. The traditional methods of treating these defects through bone marrow stimulation to provide access to the bone-blood supply have demonstrated mixed early results with fair to poor long-term results and hyaline-like repair tissue is seldom achieved.<sup>1-7</sup> However, the use of autologous chondrocyte implantation to treat isolated as well as complex chondral defects of the knee including those that have failed previous alternative treatments has shown encouraging clinical outcomes.<sup>15,16,20</sup>

Peterson et al<sup>15</sup> conducted a clinical outcome study of 94 patients with a 2- to 9-year follow-up after autologous chondrocyte implantation of the knee. The study reported that patients treated with autologous chondrocyte implantation for their isolated femoral condyle defects improved significantly clinically; the mean Lysholm score was 43.5 before surgery and 84.7 after surgery. For the more complicated cases, such as patients treated with cell therapy and concomitant reconstructive procedures (ACL reconstruction), results showed a mean Lysholm score of 55.2 before surgery and 79.0 after surgery.

Peterson et al<sup>16</sup> recently published a follow-up report to an earlier study published in 2000,<sup>15</sup> which included 61 patients who received autologous chondrocyte implantation secondary to symptomatic moderate-to-large full-thickness chondral defects of the knee. Mean follow-up was 7.4 years (range: 5-11 years). Fifty of the 61 patients had good to excellent clinical results at 2 years after implantation and 51 of 61 had good or excellent clinical results at 5 to 11 years after implantation. The modified Cincinnati knee score for patients with femoral condyle defects improved from 1.2 preoperatively to 9.2 at follow-up; osteochondritis dissecans lesions improved from 1.7 to 9.0 at follow-up; patellar lesions improved from 1.6 to 6.6 at follow-up; and femoral condyle lesions with ACL reconstructions improved from 2.3 to 7.6 at follow-up.

Eleven patients also were examined by second-look arthroscopy where histologic characteristics and biomechanical findings of the repair tissue were evaluated. Eight of 12 biopsy samples taken from these patients showed homogenous appearance and hyaline characteristics.

When the Cartilage Repair Registry data (conducted by Genzyme Biosurgery who tracks treatment outcomes in patients undergoing implantation with Carticel in the United States) was examined for March 2000. The results indicated improvement with autologous chondrocyte implantation at 48-month follow-up compared to baseline. The mean Cincinnati knee score for overall clinician evaluation was 3.03 at baseline and 6.26 at 48-months after surgery; mean score for overall patient evaluation was 3.0 at baseline and 6.03 at 48-months after surgery.<sup>19</sup>

In our current study, autologous chondrocyte implantation was evaluated using both clinical and radiological criteria. Short-term clinical results were good and consistent with previous studies. The outcome results of the overall patient evaluation for the modified Cincinnati knee score showed that 79% improved, 8% stayed the same, and 13% declined. The overall clinician evaluation showed 100% improvement. The outcome results for the Lysholm score was that 75% improved, 8% stayed the same, and 17% declined. The patient perception questionnaire of surgical outcome indicated that 83% of the patients rated the results of their knee surgery as good to excellent, and 92% would possibly or definitely have the autologous chondrocyte implantation procedure repeated.

Higher clinical mean scores may have been achieved if the scoring systems used were less sports oriented. Many patients, especially those with multiple previous surgeries or those in the earlier stages of their recovery, chose to limit their activity level beyond the recommendations of the rehabilitation protocol to avoid risk of re-injury despite reporting feeling good.

To the authors' knowledge there are no reports available for comparison that use limited radionuclide bone scan with single photon emission CT to assess subchondral bone adjacent to treated articular cartilage defects. With regard to the 11 patients who underwent limited radionuclide bone scan with single photon emission CT, this study's small sample size precluded determination of statistically significant changes in patient severity. However, a trend was demonstrated suggesting improvement in subchondral bone scores especially in the patients with the best clinical outcome scores.

Radionuclide bone scanning is a sensitive imaging modality that may require a prolonged period of time (longer than our existing follow-up period) to demonstrate normal pattern of uptake in the affected knee following autologous chondrocyte implantation procedure. However, the use of radionuclide scanning may not be fully realized until larger patient samples and longer follow-up time periods are achieved.

The results of this study suggests that autologous chondrocyte implantation of the knee can be successful in improving pain and function in patients with articular cartilage defects and may improve subchondral bone homeostasis based on bone scan evaluation. A larger patient population and longer follow-up are necessary to confirm statistical significance and determine the long-term efficacy of this procedure.

## What is already known on this topic

- Autologous chondrocyte implantation is an effective method for resurfacing full thickness articular cartilage defects of the knee.
- Restoration of joint homeostasis is felt to be an important determinant of a successful cartilage resurfacing procedure.

## What this article adds

- Autologous chondrocyte implantation is an effective method for resurfacing articular cartilage defects of the knee based on both clinical evaluation and improvement in joint homeostasis.
- This technique is effective even in complex injuries with simultaneous ligament reconstruction and osteotomy procedures.

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