

Autologous Chondrocyte Implantation for Knee Cartilage Injuries: Moderate Functional Outcome and Performance in Patients With High-impact Activities

ANDREAS PANAGOPOULOS, MD, PHD; LOUW VAN NIEKERK, FRCS(ED), FRCS(ORTH);
IOANNIS TRIANTAFILLOPOULOS, MD, MSCI, PHD

abstract

Full article available online at ORTHOSuperSite.com. Search: 20111122-07

Few studies have assessed the results of autologous chondrocyte implantation in patients with high-impact activities. The purpose of this study was to evaluate the early functional outcome and activity level after 2-stage autologous chondrocyte implantation in professional soldiers and athletes. Nineteen patients with an average age of 32.2 years were treated with autologous chondrocyte implantation and followed up for a minimum of 2 years. All patients except 2 had received previous arthroscopic treatment with debridement and/or microfracture. The mean size of the postdebridement defect was 6.54 cm². Using Novocart technology (B. Braun-Tetec, Reutlingen, Germany), periosteal patch and matrix-assisted autologous chondrocyte implantation was sequentially performed with no randomization. The average subjective knee evaluation score and Lysholm score improved from 39.16 and 42.42, respectively, preoperatively to 62.4 and 69.4, respectively, at latest follow-up. Median Tegner activity score was 8.8 before injury, 3.8 preoperatively, and 6.15 at latest follow-up. Second-look arthroscopy was performed in 11 patients due to persistent pain, decreased range of movement, and mechanical symptoms. Six of 19 (31.5%) patients with professional or recreational athletic activities returned to preinjury levels of athletic performance.

This study shows that mid-term results with autologous chondrocyte implantation in high-performance patients are not as good as have been reported with other similar technologies. Motivational issues during prolonged rehabilitation, multiple surgical interventions before autologous chondrocyte implantation, patient age, and large defects can potentially influence the outcome and overall performance in this selected group of patients.

Dr Panagopoulos is from the Department of Sports Medicine, University Hospital of Patras, Patras, and Dr Triantafillopoulos is from the Department of Sports Medicine, Metropolitan Hospital, Athens, Greece; and Dr van Niekerk is from the Center for Sports Injury Surgery, Friarage and Duchess of Kent Military Hospitals, North Yorkshire, United Kingdom.

Drs Panagopoulos, van Niekerk, and Triantafillopoulos have no relevant financial relationships to disclose.

Correspondence should be addressed to: Andreas Panagopoulos, MD, PhD, Department of Sports Medicine, University Hospital of Patras, Papanikolaou Str, Rio, 26504 Patras, Greece (andpan21@gmail.com).

doi: 10.3928/01477447-20111122-07

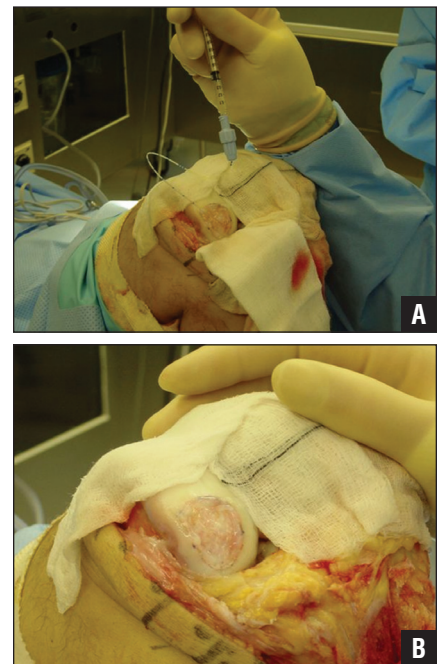


Figure: Intraoperative photographs of autologous chondrocyte implantation with periosteal flap coverage. Large defect on the lateral femoral condyle (A). Injection of the cultured cells and final sealing with fibrin glue (B).

Focal, full-thickness cartilage injuries have a significant health effect if left untreated, ranging from reduced participation in sports to severe limitations to activities of daily living. Although the natural history of focal articular cartilage injury in the knee is not completely understood, it is well known that articular cartilage has little inherent capacity for healing, which can be a precursor to osteoarthritis.¹

Mithoefer and Mandelbaum² categorized the procedures currently available to treat symptomatic articular cartilage defects of moderate or larger size into 3 groups: marrow stimulation techniques, such as microfracture chondroplasty³⁻⁶; osteochondral transplantation techniques, such as mosaicplasty⁷⁻⁹; and cell-based repair techniques, such as classic autologous or matrix-assisted chondrocyte implantation (MACI).^{3,10-12}

Autologous chondrocyte implantation is a well-established treatment option for symptomatic full-thickness articular cartilage lesions of the knee, especially in patients who have had an inadequate response to a prior cartilage repair procedure. Several studies have documented a success rate of autologous chondrocyte implantation of up to 90% at follow-ups of >10 years postoperatively.^{10,13-15} Harris et al¹⁶ systematically reviewed 82 autologous chondrocyte implantation studies, with 5276 patients regarding failures, reoperation rates, and overall complications; they found a mean failure rate of 5.8%, which was higher with first-generation techniques of autologous chondrocyte implantation.

However, whether autologous chondrocyte implantation provides adequate hyaline cartilage repair in large full-thickness articular cartilage lesions in the knee under high-impact loading or torsional forces routinely observed in high-performance patients has not been widely investigated.^{17,18} A recently reported systematic review by Harris et al¹⁹ regarding the treatment of chondral defects, specifically in the athlete's knee, showed better results

with autologous chondrocyte implantation and mosaicplasty, but the overall rate of return to preinjury level of sports was 66% for all types of intervention.

The purpose of this study was to evaluate the mid-term functional outcome and level of performance in a selected population of high-impact athletes and soldiers with large (>4 cm²) full-thickness cartilage defects of the knee who underwent classic autologous chondrocyte implantation with periosteal flap coverage (PACI) (n=11) or 3-dimensional MACI (n=8).

MATERIAL AND METHODS

This study was approved by the Institutional Review Board and the local ethical committee. Each patient signed a consent form before participating in the study. Between 2006 and 2008, nineteen patients with 22 full-thickness articular cartilage lesions in 19 knees were treated with autologous chondrocyte implantation by the senior author (L.V.N.). Fifteen men and 4 women had an average age of 32.2 years (range, 18-43 years) at implantation. Prior surgical treatment had failed in all but 2 patients, for whom magnetic resonance imaging (MRI) showed evidence of a large osteochondritis dissecans lesion, which was confirmed during first-stage autologous chondrocyte implantation. Seventeen patients (89.5%) had undergone at least 1 surgical procedure before autologous chondrocyte implantation, including 5 failed microfracture techniques in 4 patients and 1 failed osteochondritis dissecans fixation.

Patient demographics, symptom duration, clinical presentation, previous operations, and radiological and arthroscopic findings were carefully recorded according to the instructions of the International Cartilage Repair Society (ICRS) Cartilage Injury Evaluation Package (Table 1). Autologous chondrocyte implantation (PACI or MACI) was sequentially performed with no randomization of the patients. The MACI technique was introduced after the start of the study. Our decision to use this new product was mainly

based on its availability, but also to avoid common periosteal patch-related complications, such as hypertrophy, ossification, and partial delamination.²⁰⁻²²

Autologous chondrocyte implantation (PACI or MACI) was performed by standardized techniques for chondrocyte harvesting, culturing, and surgical implantation, as previously described.^{23,24} The first stage of the procedure was identical in both groups. Two or 3 osteochondral plugs were harvested from a nonweight-bearing area of the knee and sent for standardized commercial isolation and culturing of the chondrocytes (Novocart and Novocart 3D; B. Braun-Tetec, Reutlingen, Germany). Elective reimplantation was performed 3 weeks after cartilage harvesting, when a sufficient number of cells for the defect had been obtained (up to 500,000 cells per cm² for the suspension and >850,000 cells per cm² for the 3-D patch). At implantation, in a tourniquet-controlled bloodless field, the cartilage defect was thoroughly debrided to an intact margin under careful avoidance of osseous bleeding from the bed of the defect.

In the PACI group, an appropriately sized periosteal flap was harvested, generally from the adjacent femoral condyle or tibia, and sutured flush to the surrounding rim of the articular cartilage using interrupted 6-0 absorbable sutures (Monosyl; Aesculap, Reutlingen, Germany) with the cambium layer facing into the defect. The periosteal patch was sealed watertight with fibrin glue (Tisseel; Baxter, Vienna, Austria) except for 1 corner, where the implanted chondrocytes (Novocart) were injected through an epidural catheter into the defect (Figure 1). After cell injection, the remaining corner was secured with sutures and sealed with fibrin glue. In the 9 most recent patients, the defect in the cartilage was filled with the impregnated patch (Novocart 3D) and sutured level with the surrounding rim using intermittent sutures; in 2 patients, additional fixation was achieved with 4-6 darts (Chondral Dart; Arthrex, Naples, Florida). In the Novocart

Table 1
Clinical Data

Patient No./ Sex/Age, y	Side	Trade	Symptom Duration, mo	Previous Arthro	Location	Postdebridement Defect, cm (cm ²)	Bone Graft Depth, cm	Other Injuries	Treatment Mode	Follow- up, mo	No. of Reop
1/M/38	R	S	11	2	MFC	6.0×2.5 (15)	–	–	PACI	38	1
2/M/30	R	PA	43	1 ^a	LFC, TRC	2.5×2.5 (6.25), 2.5×2.0 (5.0)	–	–	PACI	39	1
3/M/30	L	S	30	1	TRC	2.5×3.0 (7.5)	–	–	PACI	36	1
4/M/41	L	S	72	3	MFC	3.0×1.8 (5.4)	2.2	–	PACI	36	1
5/M/34	L	S	40	1 ^a	LFC	4.0×2.5 (10.0)	–	PCLD, PMM	PACI	40	1
6/M/34	R	S	3	1 ^a	TRC	3.0×2.0 (6.0)	–	PLM	PACI	42	1
7/F/32	R	S	240	1	LFC	2.5×1.8 (4.5)	–	ACLR	PACI	36	–
8/M/31	R	PA	36	1	LFC	2.0×3.0 (6.00)	–	PLM	PACI	36	1
9/M/35	R	S	48	2	TRC, LFC	2.1×2.0 (4.2), 1.8×1.8 (3.24)	–	ACLR, PLM	PACI	37	–
10/F/43	L	A	34	2	MFC	2.5×1.8 (4.5)	–	–	PACI	38	–
11/F/34	R	PA	30	2 ^a	TRC, LFC	2.5×1.8 (4.5), 2.8×1.7 (4.76)	–	PLM, PMM	PACI	36	3
12/M/28	L	S	26	1	LFC	2.0×3.0 (6.0)	–	MMR	MACI	36	–
13/M/22	L	S	30	1 ^b	MFC	2.5×3.0 (7.5)	2.5	–	MACI	40	1
14/M/37	L	S	50	1 ^a	MFC	2.5×2.5 (6.25)	–	–	MACI	39	1
15/F/28	R	A	18	–	MFC ^c	3.0×3.0 (9.0)	–	–	MACI	37	–
16/M/34	R	PA	12	1	LFC	3.0×2.0 (6.0)	–	–	MACI	38	–
17/M/18	R	PA	10	–	LFC ^c	2.8×3.0 (8.4)	2	–	MACI	36	–
18/M/28	R	S	11	1	LFC ^c	3.0×2.8 (8.40)	1.6	–	MACI	37	1
19/M/35	R	S	12	1	MFC	2.0×2.8 (5.6)	–	–	MACI	36	–

Abbreviations: A, athlete; ACLR, anterior cruciate ligament reconstruction; Arthro, arthroscopies; LFC, lateral femoral condyle; MACI, matrix-assisted autologous chondrocyte implantation; MFC, medial femoral condyle; MMR, medial meniscus repair; PA, professional athlete; PACI, periosteal patched autologous chondrocyte implantation; PCLD, posterior cruciate ligament deficiency; PLM, partial lateral meniscectomy; PMM, partial medial meniscectomy; Reop, reoperations; S, soldier; TRC, trochlear.

^aFailed microfracture technique.

^bFailed osteochondritis dissecans fixation.

^cOsteochondritis dissecans lesion.

3D patch, the autologous chondrocytes are embedded in a 3-D collagen–chondroitin sulfate scaffold. Two periosteal patches were applied in all 3 patients with bifocal defects and in 2 patients with large defects. Four patients required autologous bone grafting (from the ipsilateral iliac crest) to rebuild the subchondral bone. The depth of the defect exceeded 10 mm in these patients: in 1 patient in the PACI group, the osseous defect was filled with cancellous graft to the level of the subchondral

plate, and the cultured chondrocytes were implanted between 2 periosteal flaps according to the sandwich technique.^{23,24} In the other 3 patients in the MACI group, we used chondral darts to secure the corticocancellous bone graft, placed a periosteal patch over it, and filled the defect with a Novocart 3D patch; the latter was secured with sutures (Figure 2).

Concomitant procedures were performed in 7 (36.8%) patients: reconstruction of the anterior cruciate ligament was

performed in 2 patients (1 prior to autologous chondrocyte implantation), medial meniscus repair in 1, and partial (medial or lateral) meniscectomy in 5. A posterior cruciate ligament rupture was identified in 1 patient without further intervention.

Postoperatively, continuous passive motion was initiated within 12 hours and administered for 2 weeks. Patients remained nonweight bearing for 6 to 8 weeks, with gradual progression to full weight bearing by 10 to 12 weeks. Most

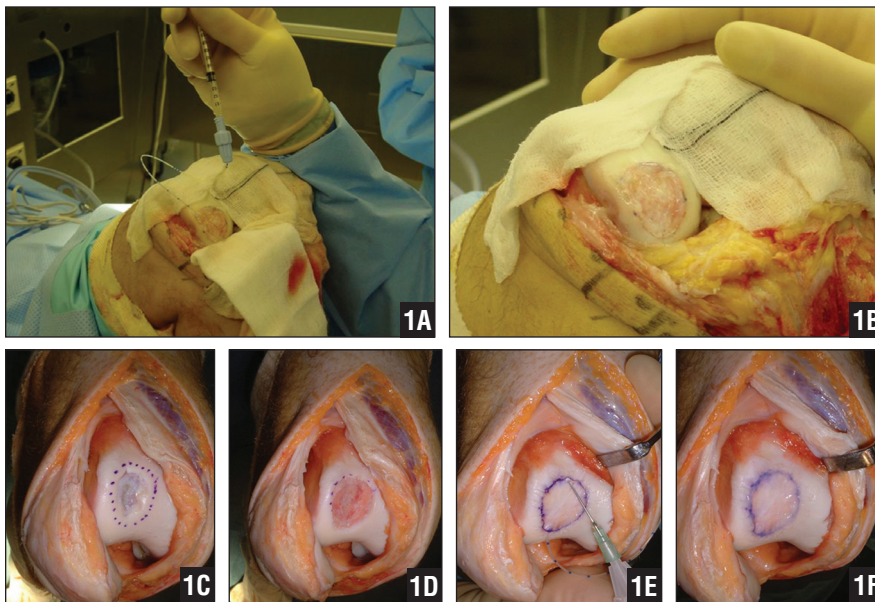


Figure 1: Intraoperative photographs of autologous chondrocyte implantation with periosteal flap coverage. Large defect on the lateral femoral condyle (A). Injection of the cultured cells and final sealing with fibrin glue (B). Large defect in the trochlear (C). Preparation of the defect (D) and injection of the cultured cells under the periosteal patch (E). Final sealing with fibrin glue (F).

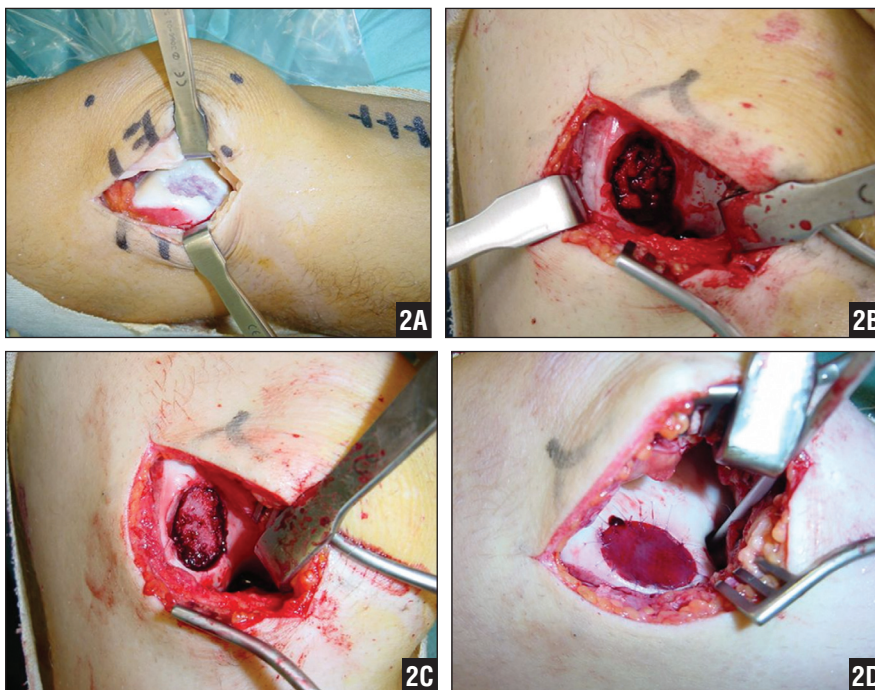


Figure 2: Intraoperative photos of matrix-assisted autologous chondrocyte implantation. Large defect on the lateral femoral condyle (A). The depth of the defect was 2 cm, and bone grafting was applied (B). Periosteal patch over the graft (C). Novocart 3D (B. Braun-Tetec, Reutlingen, Germany) patch secured with sutures (D).

patients were allowed to return to regular daily activities by 3 months and low-impact pursuits by 6 months, with progression to

running at 8 months. Demanding high-impact and pivoting sports were avoided for 10 to 12 months.

Patients were clinically evaluated at baseline and prospectively at 3, 6, 12, and at least 36 months after the implantation using the ICRS-International Knee Documentation Committee (IKDC) evaluation forms, the Lysholm score, and the Tegner activity level scale. Clinical examination and administration of the questionnaires was performed by an independent clinical fellow (I.T.) not involved in the overall patient management.

Statistical analysis was performed using the SPSS software package (version 11.0; SPSS Inc, Chicago, Illinois). Comparison between variables was performed with the Student *t* test and paired *t* test. Differences between variable proportions were evaluated by χ^2 analysis. Relationships between variables were determined by linear regression and correlation analysis; $P < .05$ was considered statistically significant.

RESULTS

Nineteen patients with 22 full-thickness articular cartilage lesions in 19 knees underwent 2-stage autologous chondrocyte implantation. Mean interval between injury and surgery was 39.8 months (range, 3-240 months). Three patients (15.7%) had bifocal defects. The right knee was involved in 12 (63.1%) patients. At presentation, the most dominant symptom was activity-related pain in all patients (100%), followed by swelling in 16 (84%), catching in 7 (36.8%), locking in 4 (21%), and giving way in 3 (15.7%).

Isolated lesions were located on the medial femoral condyle in 7 patients (36.8%), on the lateral femoral condyle in 7 (36.8%), and on the trochlear in 2 (10.5%). The bifocal lesions in the other 3 patients were located on the lateral femoral condyle and trochlear. Mean size of the postdebridement defect was 6.54 cm² (range, 4.5-15 cm²) (Table 1). No cases of skin, vascular, or soft tissue complications were noted. Although 1 patient developed a superficial wound infection, it was treated successfully with oral antibiotics. Another

patient showed evidence of medial portal neuroma, which was managed with 2 corticosteroid injections.

A second-look arthroscopy was performed in 11 of 19 (57.8%) patients after an average postoperative period of 12.3 months due to persistent pain, decreased range of motion, and mechanical symptoms. Evidence of graft hypertrophy was noted in 3 patients in the PACI group and in 2 in the MACI group. In the MACI patients, a periosteal patch and bone grafting had been used underneath the 3-D patch. Generally, the autologous chondrocyte implantation site showed adequate graft integration (Figure 3), except for 1 case with complete delamination of the central area (2.0×2.0 cm²) of the graft that was debrided and treated with microfracture. Hypertrophic overgrowth of the periosteal patch has been described as being up to 36% of cases^{21,22} and usually occurs at 7 to 9 months postoperatively. The overall need for further surgery ranges from 5.8% to 37%.^{10,16,20} Five of our second-look arthroscopies were not directly related to the site of autologous chondrocyte implantation; arthrolysis was the main indication for improving the range of motion in 3 of them.

The overall functional and clinical outcome is shown in Table 2, at a mean follow-up period of 37.5 months (range, 36–42 months). The mean Tegner activity scale was 8.73 before injury, 3.63 preoperatively, and 6.15 at latest follow-up.

Paired *t* test was used to compare the IKDC scores (Figure 4) obtained preoperatively and those obtained at latest follow-up. There was a significant difference ($P < .001$) between the mean scores, with the scores at 36 months being significantly higher after autologous chondrocyte implantation. Comparison of the mean Lysholm scores (Figure 5) preoperatively and at 36-month follow-up also showed a significant improvement ($P < .001$).

We also examined the correlation between defect size and duration of symptoms individually with the change in IKDC scores and Lysholm scores (preopera-

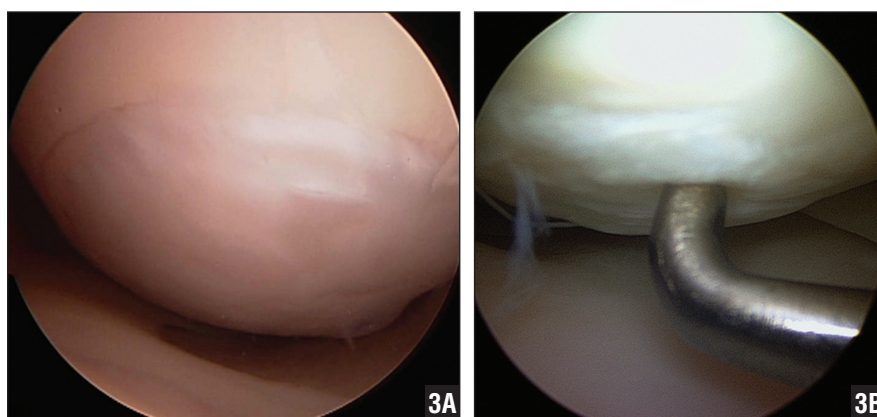


Figure 3: Postoperative arthroscopic images showing excellent integration of the graft 24 months postoperatively after matrix-assisted autologous chondrocyte implantation for a large defect on the lateral femoral condyle (A) and unstable periosteal edges of the graft and central smoothing 22 months after autologous chondrocyte implantation with periosteal flap coverage for a defect in the medial femoral condyle (B).

Table 2

Overall Functional and Clinical Outcome

Patient No.	IKDC Score		Functional Status			Tegner Scale			Lysholm Score	
	Preop	FU	PRI	Preop	FU	PRI	Preop	FU	Preop	FU
1	43.6	63.2	I	II	III	9	3	6	53	58
2	60.9	86.2	I	III	II	10	3	8	45	74
3	44.8	49.4	II	III	III	7	4	5	33	61
4	34.4	40.2	I	II	III	9	4	6	44	67
5	31.0	54.0	I	II	III	10	5	5	32	51
6	42.5	93.1	I	III	I	10	4	8	47	90
7	24.1	40.2	I	II	III	9	3	6	39	48
8	32.1	66.6	II	II	III	9	3	7	38	74
9	43.6	75.8	I	III	II	10	4	7	39	78
10	49.4	79.3	I	III	II	9	3	7	49	88
11	26.4	35.5	I	III	IV	9	3	4	32	40
12	32.1	58.6	I	III	II	8	3	6	40	69
13	49.4	58.6	I	IV	III	8	5	7	44	65
14	35.6	39.0	I	III	II	9	4	6	37	62
15	33.3	73.5	I	III	II	7	3	5	42	84
16	33.4	57.4	I	III	III	8	4	7	37	65
17	65.5	82.7	I	III	II	9	4	6	63	90
18	33.3	59.7	I	III	II	7	4	5	38	79
19	28.7	73.5	I	III	II	9	3	6	54	76

Abbreviations: FU, follow-up; IKDC, International Knee Documentation Committee; Preop, preoperatively; PRI, preinjury.

tively vs 36-month follow-up). Although the trend was toward negative correlation, which means the greater the defect size of

defect or symptom duration, the lower the final IKDC and Lysholm scores, the results did not achieve statistical significance.

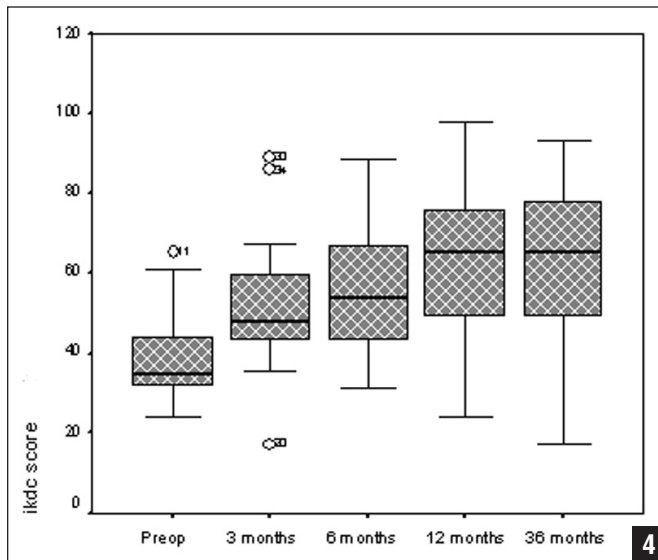


Figure 4: Comparison of preoperative (Preop) and postoperative International Knee Documentation Committee (IKDC) scores.

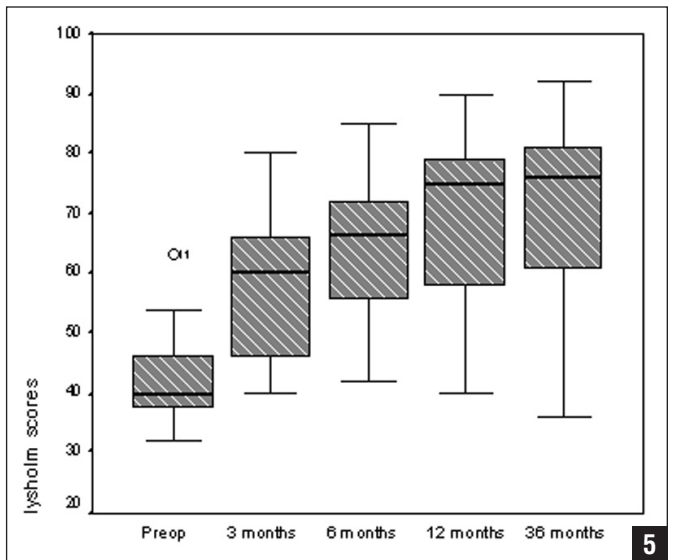


Figure 5: Comparison of preoperative (Preop) and postoperative Lysholm scores.

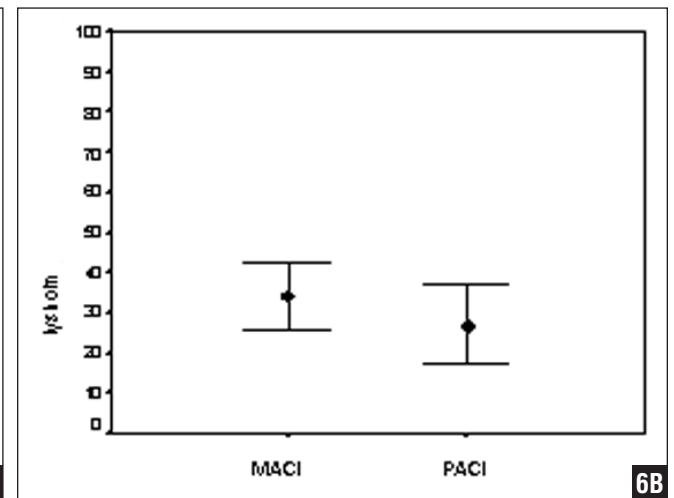
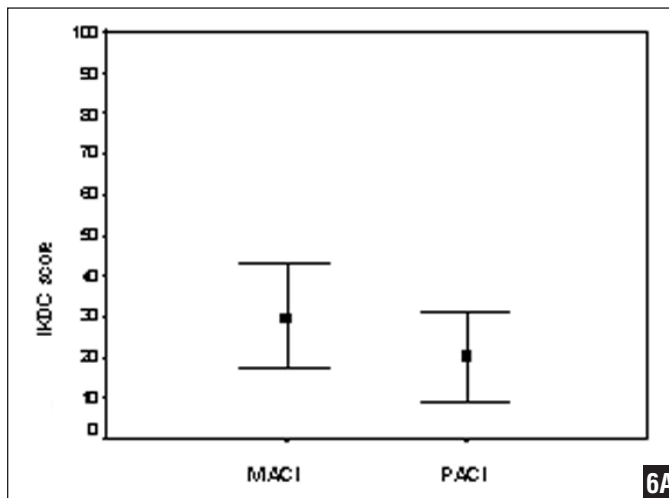


Figure 6: Comparison of pre- and postoperative International Knee Documentation Committee (IKDC) (A) and Lysholm (B) scores for both groups. Abbreviations: MACI, matrix-assisted autologous chondrocyte implantation; PACI, autologous chondrocyte implantation with periosteal flap coverage.

An independent samples *t* test was used to compare the MACI ($n=8$) and the PACI groups ($n=11$) for differences in IKDC and Lysholm scores (Figure 6). Although a trend toward better subjective results was noted in the MACI group, no statistically significant difference existed between the 2 groups with regard to the final scores. In contrast, the Tegner scale was slightly higher in the PACI group but without significant statistical difference (Figure 7).

DISCUSSION

The purpose of this study was to investigate the mid-term functional outcome of and the patient's ability to return to competition in high-performance activities after 2-stage autologous chondrocyte implantation of the knee joint. The principle finding was a moderate mid-term outcome and a significant reduction of athletic performance regardless of the mode of autologous chondrocyte implantation.

A possible reason for this outcome could be explained by the former National Institute of Clinical Excellence recommendations regarding ideal candidates for autologous chondrocyte implantation: the majority of our referrals were patients with poor preoperative functional scores, prolonged rehabilitation period after final implantation, large cartilage defects, and multiple operations before autologous chondrocyte implantation, such as debridement, drilling, or microfracture.

Moreover, all patients were involved in highly athletic or military activities, which had been restricted by their long-term disability.

Of the numerous cartilage restoration techniques available today, no method has yet been able to consistently reproduce normal hyaline cartilage, and the best treatment in the long term is still unknown.^{25,26} Furthermore, a recent analysis of the quality of cartilage repair studies by Jakobsen et al²⁷ showed a modified Coleman Methodology Score of 43.5 out of 100, indicating poor methodological quality regarding designing, performing, and reporting autologous chondrocyte implantation clinical studies.

Classic PACI has been proposed as the cornerstone technique for the restoration of full-thickness articular cartilage lesions in the knee and has shown excellent long-term durability and improved knee function up to 11 years postoperatively.^{2,12,16,28,29} The long-term efficacy of MACI has not yet been investigated, but it appears that this technique can give favorable functional results compared with classic PACI. In addition, a shorter operative time, smaller incision, and lower incidence of graft-related reoperations can be expected.^{16,30-34}

Other available techniques for the repair of articular cartilage defects include microfracture and mosaic osteochondral autologous transplantation. Steadman et al⁴ reported that 80% of patients rated themselves as improved 7 years after microfracture. The patients in the study were retrospectively selected from a larger group and had relatively small chondral defects, with a mean size of 2.8 cm². The largest single series to date of mosaic osteochondral autologous transplantation is that of Hangody and Fules,⁸ who reported the results of operations on 597 femoral condyles, 76 tibial plateaus, and 118 patellofemoral joints at up to 10 years postoperatively. Good or excellent results were reported in 92%, 87%, and 79% of patients, respectively.

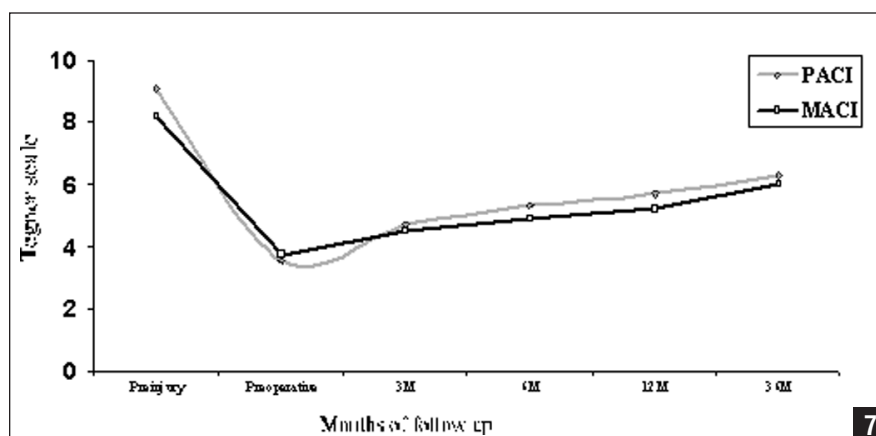


Figure 7: Change in Tegner activity scale pre- and postoperatively. Abbreviations: MACI, matrix-assisted autologous chondrocyte implantation; PACI, autologous chondrocyte implantation with periosteal flap coverage.

Regarding the outcomes of these alternative cartilage techniques in high-demand patients, Blevins et al³⁵ and Steadman et al⁵ demonstrated that 77% and 76% of their high-level athletes returned to athletic activity at a mean of 9.3 months and 10 months, respectively, after microfracture. Average lesion size in those studies was 2.23 cm² and 3.80 cm², respectively. Cernik et al³⁶ reported that 21% of National Basketball Association (NBA) players treated with microfracture did not return to competition in an NBA game, and those who returned to competition demonstrated diminished performance and playing minutes per game. However, Kish et al³⁷ reported that 61% of 52 athletes treated with mosaic osteochondral autologous transplantation returned to full athletic activity after a mean preoperative symptomatic interval of 8 months.

Randomized clinical trials have failed to identify the superiority of each method of cartilage repair. Bentley et al⁷ reported in a large series of 100 patients that autologous chondrocyte implantation resulted in slightly better Cincinnati and ICRS scores than did mosaic osteochondral autologous transplantation, whereas Horas et al⁹ concluded that no compelling evidence existed in favor of mosaic osteochondral autologous transplantation vs autologous

chondrocyte implantation, although they reported higher Lysholm scores in the mosaic osteochondral autologous transplantation group 24 months postoperatively. Knutsen et al³ reported no significant clinical and histological difference between autologous chondrocyte implantation and microfracture in 80 randomized patients, other than slightly better SF-36 scores in the microfracture group. Finally, Gudas et al³⁸ conducted a prospective randomized study of mosaic osteochondral autologous transplantation vs microfracture in 60 young athletes with no prior intervention in the knee; they found that 52% of the microfracture group was able to return to competitive sports compared with 93% of the mosaic osteochondral autologous transplantation group.

The effectiveness of autologous chondrocyte implantation in the high-demand population has only been investigated recently. Mithöfer et al¹⁷ reported 72% good to excellent overall results after autologous chondrocyte implantation in 45 professional (27%) and recreational (73%) soccer players. Players who successfully returned to soccer (83% of competitive-level players and 16% of recreational players) were significantly younger and had a shorter preoperative duration of symptoms.

Furthermore, Mithöfer et al¹⁸ reported 96% good or excellent results at a mean

47-month follow-up after autologous chondrocyte implantation in 20 adolescent athletes; 96% of them returned to high-impact sports and 60% to an athletic level equal to or higher than that before knee injury. All adolescents with preoperative symptoms ≤ 12 months returned to preinjury-level athletics, compared with 33% with preoperative intervals > 12 months.

Harris et al¹⁹ performed a systematic review to determine which surgical techniques had improved outcomes and enabled athletes to return to their preinjury level of sports and which patient and defect factors significantly affect outcomes after cartilage repair or restoration. Defect size of < 2 cm², preoperative duration of symptoms < 18 months, no prior surgical treatment, younger patient age, and higher preinjury and postsurgical level of sports all correlated with improved outcomes after cartilage repair, especially autologous chondrocyte implantation. The rate of return to sports was generally lower after microfracture vs autologous chondrocyte implantation or MOAT, and if a patient was able to return to sports, performance was diminished.

In our study, the overall improvement in functional scores was statistically significant in comparison with preoperative scores. Seventy-nine percent of patients stated that, if needed, they would undergo surgery again, but only 6 of 19 (31%) of patients returned to prior levels of athletic performance. Twelve patients were professional soldiers, 5 were professional athletes (1 soccer player, 3 rugby players, and 1 karate teacher), and 2 were recreational athletes (1 cricket player and 1 marathon runner). Two of 7 athletes returned to sports at the same preinjury skill level at a mean of 13 months postoperatively. Ten of the 12 soldiers were medically downgraded regarding their employment status via the United Kingdom's army fitness performance test (PULHHEEMS). At a mean 18.4 months postoperatively, 1 soldier was upgraded to P2 level (fit for full service), 8 were classi-

fied as P3 (able for light duties only), 2 P0 (still under medical care), and 1 P8 (medically discharged). Of the 9 of 12 soldiers who routinely participated in contact sports prior to injury, only 4 returned to a similar recreational level at a mean 15.5 months postoperatively.

CONCLUSION

This study, despite its limitations (a small number of patients and the use of 2 different autologous chondrocyte implantation techniques), shows that in high-demand patients who have a longstanding disability, large defects, and failed previous cartilage techniques, the results of autologous chondrocyte implantation may not be as good as those reported or expected. Recent studies have shown that the ideal candidate for autologous chondrocyte implantation is a young and fit patient with high preoperative functional scores and no previous operations who is < 12 months symptomatic and has an isolated and moderate-sized cartilage defect.^{7,12,24-26,39} The quality of cartilage restoration studies is poor, and heterogeneity exists regarding the techniques followed, the included populations, and the reported outcomes. There is an urgent need for more high-quality studies and for uniformity of their reported outcomes to enrich the existing evidence and enable patients and clinicians to make informed decisions. The results of randomized and well-designed prospective studies may give more specific answers in the future. Until then, autologous chondrocyte implantation must prove its superiority, especially in the high-demand population. 

REFERENCES

1. Buckwalter JA. Articular cartilage injuries. *Clin Orthop Relat Res*. 2002; (402):21-37.
2. Mithoefer K, Mandelbaum BR. Current treatment methods for articular cartilage injury. *European Musculoskeletal Review*. 2009; 4:108-112.
3. Knutsen G, Engebretsen L, Ludvigsen TC, et al. Autologous chondrocyte implantation

compared with microfracture in the knee. A randomized trial. *J Bone Joint Surg Am*. 2004; 86(3):455-464.

4. Steadman JR, Briggs KK, Rodrigo JJ, Kocher MS, Gill TJ, Rodkey WG. Outcomes of microfracture for traumatic chondral defects of the knee: average 11-year follow-up. *Arthroscopy*. 2003; 19(5):477-484.
5. Steadman JR, Miller BS, Karas SG, Schlegel TF, Briggs KK, Hawkins RJ. The microfracture technique in the treatment of full-thickness chondral lesions of the knee in National League Football players. *J Knee Surg*. 2003; 16(2):83-86.
6. Solheim E, Øyen J, Hegna J, Austgulen OK, Harlem T, Strand T. Microfracture treatment of single or multiple articular cartilage defects of the knee: a 5-year median follow-up of 110 patients [published online ahead of print October 29, 2009]. *Knee Surg Sports Traumatol Arthrosc*. 2010; 18(4):504-508.
7. Bentley G, Biant LC, Carrington RW, et al. A prospective, randomized comparison of autologous chondrocyte implantation versus mosaicplasty for osteochondral defects in the knee. *J Bone Joint Surg Br*. 2003; 85(2):223-230.
8. Hangody L, Füles P. Autologous osteochondral mosaicplasty for the treatment of full-thickness defects of weight-bearing joints: ten years of experimental and clinical experience. *J Bone Joint Surg Am*. 2003; 85(suppl 2):25-32.
9. Horas U, Pelinkovic D, Herr G, Aigner T, Schnettler R. Autologous chondrocyte implantation and osteochondral cylinder transplantation in cartilage repair of the knee joint. A prospective, comparative trial. *J Bone Joint Surg Am*. 2003; 85(2):185-192.
10. Brittberg M, Peterson L, Sjögren-Jansson E, Tallheden T, Lindahl A. Articular cartilage engineering with autologous chondrocyte transplantation. A review of recent developments. *J Bone Joint Surg Am*. 2003; 85(suppl 3):109-115.
11. Bartlett W, Skinner JA, Gooding CR, et al. Autologous chondrocyte implantation versus matrix-induced autologous chondrocyte implantation for osteochondral defects of the knee: a prospective randomised study. *J Bone Joint Surg Br*. 2005; 87(5):640-645.
12. Vasiliadis SH, Wasiak J, Salanti G. Autologous chondrocyte implantation for the treatment of cartilage lesions of the knee: a systematic review of randomized studies [published online ahead of print February 2, 2010]. *Knee Surg Sports Traumatol Arthrosc*. 2010; 18(12):1645-1655.
13. Peterson L, Minas T, Brittberg M, Lindahl A. Treatment of osteochondritis dissecans of the knee with autologous chondrocyte transplantation: results at two to ten years. *J Bone Joint Surg Am*. 2003; 85(suppl 2):17-24.
14. Peterson L, Brittberg M, Kiviranta I, Akerlund EL, Lindahl A. Autologous chondrocyte transplantation. Biomechanics and long-term durability. *Am J Sports Med*. 2002; 30(1):2-12.

15. Zaslav K, Cole B, Brewster R, et al. A prospective study of autologous chondrocyte implantation in patients with failed prior treatment for articular cartilage defect of the knee: results of the Study of the Treatment of Articular Repair (STAR) clinical trial [published online ahead of print October 16, 2008]. *Am J Sports Med.* 2009; 37(1):42-55.
16. Harris JD, Siston RA, Brophy RH, Lattermann C, Carey JL, Flanigan DC. Failures, re-operations, and complications after autologous chondrocyte implantation—a systematic review [published online ahead of print February 17, 2011]. *Osteoarthritis Cartilage.* 2011; 19(7):779-791.
17. Mithöfer K, Peterson L, Mandelbaum BR, Minas T. Articular cartilage repair in soccer players with autologous chondrocyte transplantation: functional outcome and return to competition [published online ahead of print August 10, 2005]. *Am J Sports Med.* 2005; 33(11):1639-1646.
18. Mithöfer K, Minas T, Peterson L, Yeon H, Micheli LJ. Functional outcome of knee articular cartilage repair in adolescent athletes [published online ahead of print July 6, 2005]. *Am J Sports Med.* 2005; 33(8):1147-1153.
19. Harris JD, Brophy RH, Siston RA, Flanigan DC. Treatment of chondral defects in the athlete's knee. *Arthroscopy.* 2010; 26(6):841-852.
20. Henderson I, Tuy B, Oakes B. Reoperation after autologous chondrocyte implantation. Indications and findings. *J Bone Joint Surg Br.* 2004; 86(2):205-211.
21. Henderson I, Gui J, Lavigne P. Autologous chondrocyte implantation: natural history of post-implantation periosteal hypertrophy and effects of repair-site debridement on outcome. *Arthroscopy.* 2006; 22(12):1318-1324.e1.
22. Kreuz PC, Steinwachs M, Erggelet C, et al. Classification of graft hypertrophy after autologous chondrocyte implantation of full-thickness chondral defects in the knee [published online ahead of print July 13, 2007]. *Osteoarthritis Cartilage.* 2007; 15(12):1339-1347.
23. Peterson L. Chondrocyte transplantation. In: Jackson DW, ed. *Master Techniques in Orthopaedic Surgery: Reconstructive Knee Surgery.* Philadelphia, PA: Lippincott Williams & Wilkins; 2003:353-373.
24. Brittberg M. Autologous chondrocyte implantation—technique and long-term follow-up. *Injury.* 2008; 39(suppl 1):S40-S49.
25. Smith GD, Knutsen G, Richardson JB. A clinical review of cartilage repair techniques. *J Bone Joint Surg Br.* 2005; 87(4):445-449.
26. Benthien JP, Schwaninger M, Behrens P. We do not have evidence based methods for the treatment of cartilage defects in the knee [published online ahead of print November 18, 2010]. *Knee Surg Sports Traumatol Arthrosc.* 2011; 19(4):543-552.
27. Jakobsen RB, Engebretsen L, Slauterbeck JR. An analysis of the quality of cartilage repair studies. *J Bone Joint Surg Am.* 2005; 87(10):2232-2239.
28. Jobanputra P, Parry D, Fry-Smith A, Burls A. Effectiveness of autologous chondrocyte transplantation for hyaline cartilage defects in knees: a rapid and systematic review. *Health Technol Assess.* 2001; 5(11):1-57.
29. Minas T. The role of cartilage repair techniques, including chondrocyte transplantation, in focal chondral knee damage. *Instr Course Lect.* 1999; 48:629-643.
30. Getgood A, Bhullar TPS, Rushton N. Current concepts in articular cartilage repair. *Orthopaedics and Trauma.* 2009; 23(3):189-200.
31. Fabian S. Clinical experience with MACI. In: Bentley G, ed. *Current Developments in Autologous Chondrocyte Transplantation: Round Table Series 77.* London, England: Royal Society of Medicine Press; 2003:35-40.
32. Haddo O, Mahroof S, Higgs D, et al. The use of chondrocyte membrane in autologous chondrocyte implantation. *Knee.* 2004; 11(1):51-55.
33. Bartlett W, Gooding CR, Carrington RW, Skinner JA, Briggs TW, Bentley G. Autologous chondrocyte implantation at the knee using a bilayer collagen membrane with bone graft. A preliminary report. *J Bone Joint Surg Br.* 2005; 87(3):330-332.
34. Behrens P, Bitter T, Kurz B, Russlies M. Matrix-associated autologous chondrocyte transplantation/implantation (MACT/MACI)—5-year follow-up [published online ahead of print April 24, 2006]. *Knee.* 2006; 13(3):194-202.
35. Blevins FT, Steadman JR, Rodrigo JJ, Siliman J. Treatment of articular cartilage defects in athletes: an analysis of functional outcome and lesion appearance. *Orthopedics.* 1998; 21(7):761-767.
36. Cerny DL, Lewullis GE, Joves BC, Palmer MP, Tom JA. Outcomes of microfracture in professional basketball players [published online ahead of print March 19, 2009]. *Knee Surg Sports Traumatol Arthrosc.* 2009; 17(9):1135-1139.
37. Kish G, Módis L, Hangody L. Osteochondral mosaicplasty for the treatment of focal chondral and osteochondral lesions of the knee and talus in the athlete. Rationale, indications, techniques, and results. *Clin Sports Med.* 1999; 18(1):45-66.
38. Gudas R, Kalesinskas RJ, Kimtys V, et al. A prospective randomized clinical study of mosaic osteochondral autologous transplantation versus microfracture for the treatment of osteochondral defects in the knee joint in young athletes. *Arthroscopy.* 2005; 21(9):1066-1075.
39. Krishnan SP, Skinner JA, Bartlett W, et al. Who is the ideal candidate for autologous chondrocyte implantation? *J Bone Joint Surg Br.* 2006; 88(1):61-64.