Autologous Chondrocyte Implantation for Bipolar Chondral Lesions in the Patellofemoral Compartment

Clinical Outcomes at a Mean 9 Years' Follow-up

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Background: Treating bipolar chondral lesions in the patellofemoral (PF) compartment is a challenging problem. There are few reports available on the treatment of bipolar chondral lesions in the PF compartment.

Purpose: To evaluate the clinical outcomes and graft survivorship after autologous chondrocyte implantation (ACI) for the treatment of bipolar chondral lesions in the PF compartment.

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

Methods: The authors evaluated 58 patients who had ACI by a single surgeon for the treatment of symptomatic bipolar chondral lesions in the PF compartment between November 1995 and June 2014. All 58 patients (60 knees; mean age, 36.6 years) were included with a minimum 2-year follow-up. The mean ± SD sizes of the patellar and trochlear lesions were 5.6 ± 2.7 cm^2 and 4.2 ± 2.8 cm^2, respectively. Forty-two patients had osteotomy, as they had PF lateral maltracking, patellar instability, or tibiofemoral malalignment. Patients were evaluated with the modified Cincinnati Knee Rating Scale, Western Ontario and McMaster Universities Osteoarthritis Index, visual analog scale, the 36-Item Short Form Health Survey, and a patient satisfaction survey. Radiographs were evaluated with the Iwano classification.

Results: Overall, the survival rates were 83% and 79% at 5 and 10 years, respectively. Of the 49 (82%) knees with retained grafts, all functional scores significantly improved postoperatively with a very high satisfaction rate (88%) at a mean 8.8 ± 4.2 years after ACI (range, 2-16 years). At the most recent follow-up, 28 of 49 successful knees were radiographically assessed (mean, 4.9 years; range, 2-17 years), with no increase of the Iwano classification in 26 knees. Outcomes for 11 patients were considered failures at a mean 2.9 years. Forty-two knees (70%) required a mean 1.0 subsequent surgical procedure. The primary reasons for chondroplasty were hypertrophy of the ACI graft (17; periosteum in 14, collagen membrane in 3), delamination of the ACI graft (5; periosteum in 4, collagen membrane in 1), and new chondral lesions (3). The best survival rates were observed among patients who underwent ACI with concomitant tibial tubercle osteotomy (TTO) as the first procedure without previous failed TTO and/or marrow stimulation technique (91% at 5 and 10 years), while the worst survival rates were observed among patients who had previous marrow stimulation (43% at 5 and 10 years).

Conclusion: Results demonstrated that ACI with concomitant osteotomy, when it is necessary for the treatment of bipolar/kissing lesions in the PF compartments, gives significant improvement in pain and function, with good survival rates at 5 and 10 years (83% and 79%, respectively). The high patient satisfaction rate is encouraging, and a high survival rate can be expected when ACI with a concomitant TTO is performed at the initial surgery for this difficult condition.

Keywords: autologous chondrocyte implantation; bipolar/kissing; patella; trochlea; patellofemoral; articular; cartilage; repair

Treatment of chondral lesions in the patellofemoral (PF) compartment is one of the most difficult problems for orthopaedic surgeons. The regenerative ability of any repair technique is considered uncommon, owing to the high shear stress and the unique anatomic morphology of the PF compartment. Many factors—including tilt and subluxation because of malalignment, resulting in maltracking—may cause anterior knee pain and secondary articular cartilage breakdown, which may result in early osteoarthritis (OA) of the PF joint.[49,55] According to a previous study that reviewed 10,000 arthroscopies, the incidence of focal

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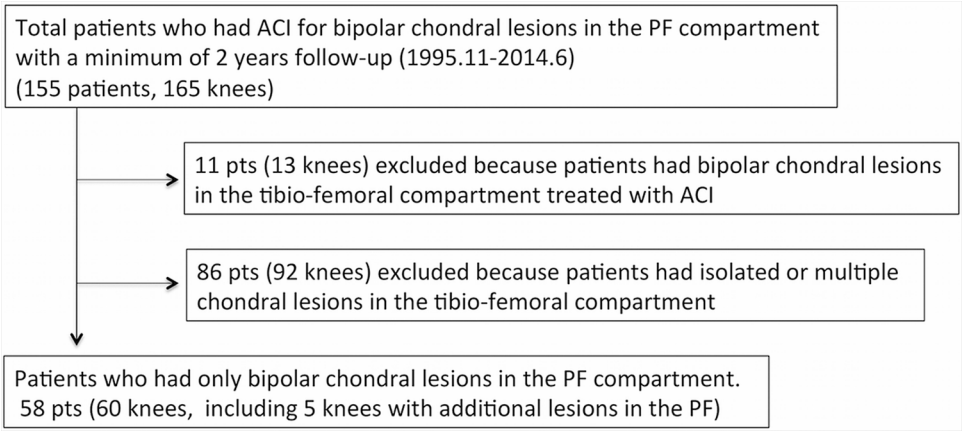

Figure 1. Patients with patellofemoral (PF) lesions and the selection flowchart for this study. ACI, autologous chondrocyte implantation.

chondral and osteochondral lesions in the patella and trochlea was 11% and 6%, respectively.[18] In addition, a different study showed that the patella was one of the most frequent locations for chondral lesions observed during arthroscopic procedures.[7,57] When nonoperative treatment has failed, surgical treatment may be necessary. Surgical treatments include arthroscopic debridement with chondroplasty, microfracture,[25] osteochondral autologous transplantation, osteochondral allograft transplantation, autologous matrix-induced chondrogenesis,[9] and autologous chondrocyte implantation (ACI),[3,36,42] However, the optimal treatment for chondral lesions in the PF compartments remains unclear.[38,40,52] In addition, chondral lesions of the patella and trochlea, or bipolar/kissing lesions, increase the level of difficulty and bring into question the role of PF arthroplasty as patients get older. Many recent studies reported good clinical outcomes after ACI for the PF compartment; however, the majority of these studies investigated heterogeneous patient cohorts, including isolated patellar and trochlear lesions or both.[15,24,26] To date, few reports have considered the clinical outcomes of patients who had bipolar/kissing chondral lesions in the PF compartments treated with ACI and the potential preventative effect on developing OA. Thus, the purpose of this study was to evaluate clinical outcomes with the use of patient-reported functional scores after ACI for the treatment of bipolar chondral lesions of the PF compartment and to evaluate the development of OA.

METHODS

Patient Characteristics

This study was approved by our institutional review board. All patients signed an informed consent form. We performed a review of prospectively collected data from 155 patients (165 knees) who underwent ACI for bipolar articular cartilage lesions of the PF compartment from November 1995 to June 2014. During the study period, the use of collagen membranes and ACI for the patellar lesion and bipolar lesions were not approved by the US Food and Drug Administration for cartilage repair in the United States. A single surgeon (T.M.) performed all the surgery. Patients who had bipolar chondral lesions in the tibiofemoral compartment (11 patients, 13 knees) and patients who had additional full-thickness chondral lesions in the tibiofemoral compartment (86 patients, 92 knees) were excluded from this study. Thus, 58 patients (60 knees) with a minimum 2-year follow-up were included in this study (Figure 1). A subgroup of these patients was included in a previous study.[31] Four patients had 2 chondral lesions in the trochlea, and 1 patient had 2 chondral lesions in the patella. The mean ± SD size of patellar and trochlear lesions were 5.6 ± 2.7 cm^2 and 4.2 ± 2.8 cm^2, respectively (Table 1). According to the Fulkerson classification[48] (Appendix 1, available in the online version of this article), 82% of the patellar defects were type IVb.

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TABLE 1
Patient Characteristics (58 Patients, 60 Knees)

Variable	Mean ± SD (Range) or n (%)
Age at surgery, y	36.6 ± 9.2 (16-55)
Sex, male:female	25:33
Knee, right:left	31:29
Body mass index, kg/m^2	26 ± 3.9
Follow-up, y	8.8 ± 4.2 (2-16)
Duration of symptoms before ACI, y	4.9 ± 4.5 (1-23)
Received workers' compensation	8 (14)
Defect size, cm^2	
Patella	5.6 ± 2.7 (1-14)
Trochlea	4.2 ± 2.8 (0.8-13)
Total defect surface area per knee at index surgery, cm^2	10.2 ± 4.1 (2.7-19.7)
Type of patellar lesion[a]	60
Type I	2 (3.3)
Type II	4 (6.7)
Type III	4 (6.7)
Type II + III	1 (1.7)
Type IVb	49 (81.7)
Contained:uncontained	47:14
Location of trochlea lesion	62
Medial	8
Central	11
Lateral	16
Medial/central	6
Lateral/central	9
Medial/central/lateral	12
Contained:uncontained	44:18
Patella alta[b]	10 (16.6)
Trochlear dysplasia[c]	2 (3.3)

[a]According to Pidoriano et al.[48] Also see Appendix 1 (available online).
[b]According to Insall-Salvati index.[19]
[c]According to Dejour classification[8,50]; both are grade A.

Contained lesions were observed in 77% of the patellar lesions and 71% of the trochlear lesions. Fifty patients (86%) had undergone a mean ± SD of 1.9 ± 1.4 previous surgical procedures (range, 1-6) before the ACI, excluding diagnostic arthroscopy and ACI biopsy. Sixteen patients (28%) had tibial tubercle osteotomy (TTO; including TTO with high tibial osteotomy for 2 patients) at a mean of 6.2 ± 5.7 years (range, 0.7-21.8 years) before the ACI surgery, but they eventually required ACI owing to persistent pain and joint dysfunction (Appendix 2, available online).

The 92 previous procedures were performed among 50 patients (86%). Some patients had >1 procedure.

Surgical Technique

ACI was performed as previously described in detail.[22,29,34] Briefly, after an arthroscopic cartilage biopsy was performed during the initial surgery, chondrocytes were cultured, cryopreserved, and then thawed and recultured for definitive implantation after insurance approval. Secondary surgery was then performed for implantation with arthrotomy. For surgery performed before May 2007, the periosteum was harvested from the proximal tibia or distal femur (18 knees). After May 2007, a type I/III bilayer collagen membrane derived from porcine peritoneum and skin (Bio-Gide; Geistlich Pharma) was used (42 knees) instead of autologous periosteum. The periosteum or collagen membrane was placed on the cartilage defect and secured with multiple 6-0 Vicryl sutures (Ethicon). In some uncontained defects, small wires were used to drill holes in adjacent bone, and sutures were passed through these holes to anchor the membrane. The suture line was waterproofed with fibrin glue (Tisseel; Baxter Biosurgery), and autologous cultured chondrocytes were injected underneath the membrane (Figure 2).

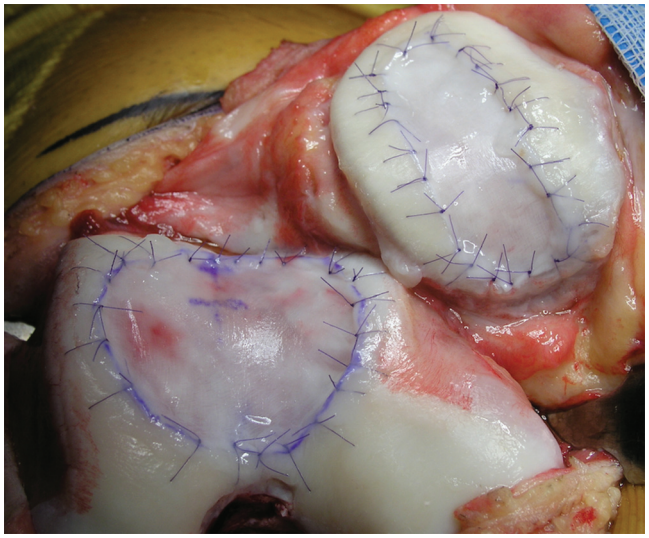

Figure 2. Intraoperative photo demonstrating that cartilage defects in both patella and trochlea are covered with type I/III collagen membrane and sutured. Autologous cultured chondrocytes are injected underneath the membrane and the membrane is sealed with fibrin glue.

Articular comorbidities were addressed at the time of surgery. PF lateral maltracking or patellar instability was addressed with anteromedialization TTO to centralize patellar tracking[12,31] and proximal soft tissue balancing (lateral release, vastus medialis obliquus advancement) as necessary to centralize the extensor mechanism. Tibiofemoral malalignment >2° to 3° was corrected via osteotomy of the tibia or femur, with correction of the mechanical axis to neutral or 0°. Concomitant procedures at the time of the ACI are shown in Table 2. Two patients underwent surgery via the "sandwich technique,"[35,47,56] which involves the use of an autologous bone graft for the subchondral bone defect and ACI for the overlying cartilage defect. Patelloplasty, which included removal of osteophytes to allow for better fitting of the patella on the trochlea, was performed for 6 patients who had excessive osteophytes. Trochleoplasty was performed for 2 patients who had patellar instability owing to hypoplastic trochlea with the surgical technique previously described.[30,46]

The 133 concomitant procedures were performed among 52 patients. Some patients had >1 procedure.

☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10 POOR FAIR GOOD VERY GOOD EXCELLENT		
Poor	(1-2)	I have significant limitations that affect activities of daily living.
Fair	(3-4)	I have moderate limitations that affect activities of daily living. No sports possible.
Good	(5-6)	I have some limitations with sports but I can participate; I compensate.
Very Good	(7-8)	I have only a few limitations with sports.
Excellent	(9-10)	I am able to do whatever I wish (any sport) with no problem.

Figure 3. Modified Cincinnati Knee Rating Scale: overall condition.

TABLE 2
Concomitant Procedures at the Time of the Autologous Chondrocyte Implantation[a]

Procedure	Patients, n
Lateral release	46
Osteotomy	42
TTO alone	35
Combined TTO and HTO	5
Combined TTO and DFO	1
HTO alone	1
VMO advancement	35
Patelloplasty	6
Trochleoplasty	2
Sandwich technique alone	2
No concomitant procedure	6

[a]DFO, distal femoral osteotomy; HTO, high tibial osteotomy; TTO, tibial tubercle osteotomy; VMO, vastus medialis obliquus.

TABLE 3
Classification of Subgroup[a]

Group: Procedures	Patients, n
A: ACI alone	5
B: ACI with TTO	34
C	
Failed TTO with subsequent ACI	12
Failed TTO with subsequent ACI + TTO	2
D	
Failed MST with subsequent ACI + TTO	5
Failed MST + TTO with subsequent ACI	2

[a]ACI, autologous chondrocyte implantation; MST, marrow stimulation technique; TTO, tibial tuberosity osteotomy.

Postoperative Course

Postoperatively, patients were instructed to use a continuous passive motion machine for 6 to 8 hours every day at 0° to 40° for 3 weeks, in which PF contact forces were lessened, including gravity-assist flexion from 0° to 90° every hour with the leg dangling over the edge of the bed or chair to avoid stiffness. Patellar mobilizations in full extension—proximal-distal and medial-lateral—were implemented the day of surgery to diminish the risk of Hoffa fat pad fibrosis. At 3 to 6 weeks, full motion was encouraged with continuous passive motion and a stationary bike with no resistance. Patients remained 50% weightbearing for 4 to 6 weeks, with gradual progression to full weightbearing by 8 weeks and with treadmill walking and elliptical trainer at 4 to 5 months. Patients were allowed to return to most activities of daily living after 3 to 4 months. Inline sporting activities without cutting movements after 6 to 9 months, such as outdoor cycling, roller blading, and swimming with kicking, were allowed as long as the knee was without pain or effusions after activity. After 18 months, inline jogging was permitted if there was no swelling or pain evident. Pivoting activities were permitted from 18 to 24 months. The postoperative recovery protocol was individually adjusted according to defect location, size, concurrent procedures, degree of graft maturation, and previous activity level.[32]

Failure Definition

Graft failure was defined as persistent or recurrent clinical symptoms in conjunction with magnetic resonance imaging and/or arthroscopic evidence of graft delamination or surgical removal of >25% of the graft area, revision cartilage repair, or conversion to prosthetic arthroplasty. In addition, subsequent surgical procedures (SSPs) that were required postoperatively were recorded.

Survival Analysis and Clinical Outcomes Assessment

Survival rate was evaluated with the Kaplan-Meier method, with failure of the graft as the endpoint measure. Patients were evaluated with a range of functional scores, including the modified Cincinnati Knee Rating Scale,[4,28] Western Ontario and McMaster Universities Osteoarthritis Index,[1] visual analog scale, and the 36-Item Short Form Health Survey.[2] The original Cincinnati Knee Rating Scale was based on a continuous scale of 0 to 100,[39] whereas the modified Cincinnati Knee Rating Scale uses a categorical scale of 1 to 10, with a 2-point change being considered clinically meaningful (Figure 3).[4,28] Patients also answered questions regarding self-rated knee function and satisfaction with the procedure. Scores were collected preoperatively and at the latest postoperative follow-up during consultations or via a mailed

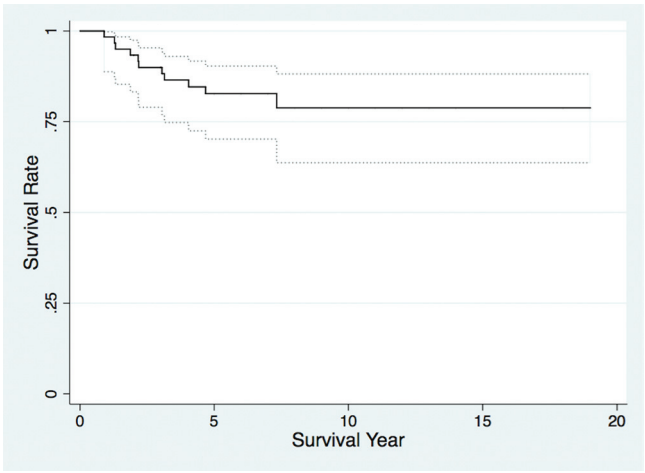

Figure 4. Kaplan-Meier survival curve with 95% CI: overall survival rate. Endpoint was defined as failure of the graft.

questionnaire. Subanalysis for the survival rates and functional scores was performed per age at the time of ACI (<40 vs ≥40 years), sex, body mass index (<30 vs ≥30), cartilage defect size (<10 vs ≥10 cm^2), status of the patellar lesions (contained vs uncontained), type of membrane (periosteum vs collagen membrane), and presence of concomitant TTO.

Radiographic Assessment

Standing long axial alignment radiographs and anteroposterior, posteroanterior (Rosenberg), and lateral radiographs of the tibiofemoral compartment were obtained, as well as weightbearing skyline views of the PF compartment. Skyline views of the PF compartment were graded according to the Iwano classification[20] to evaluate the progression of OA in the PF compartment before and after the index surgery: stage 0, normal; stage 1, mild—the joint space was at least 3 mm; stage 2, moderate—the joint space was <3 mm with no bony contact; stage 3, severe—partial bony contact less than one-quarter of the joint surface was present; and stage 4, very severe—in which the joint bony surfaces entirely touched each other. The Kellgren-Lawrence classification[21] was used with anteroposterior knee radiographs to evaluate the tibiofemoral compartment. Radiographs were scored by 1 author who was a completely trained orthopaedic surgeon (T.O.).

Subgroup Analysis

For subgroup analysis, we stratified patients into 4 groups: ACI alone (group A, n = 5), ACI with concomitant TTO (group B, n = 34), history of failed TTO with subsequent ACI with or without TTO (group C, n = 14), and history of failed marrow stimulation technique (group D, n = 7) (Table 3). Functional scores and survival rates were compared among these 4 groups.

TABLE 4
Pre- and Postoperative Clinical Scores in Patients With Retained Grafts (49 Knees)[a]

Knee Scoring System	Preoperative (n = 49)	Latest Follow-up (n = 49)
Modified Cincinnati	3 ± 1.2	6.4 ± 1.7
VAS	5.4 ± 1.4	2.7 ± 1.8
WOMAC		
Total	43.1 ± 15.9	24.6 ± 13.7
Pain	9.4 ± 3.8	5.5 ± 3.4
Stiffness	3.7 ± 1.9	2.4 ± 1.5
Function	30.0 ± 11.0	16.8 ± 9.4
SF-36		
PCS	38.5 ± 9.1	45.5 ± 10.2
MCS	42.5 ± 11.3	49.9 ± 6.5

[a]Data reported as mean ± SD. For each pre- vs postoperative score, $P < .001$. MCS, mental component score; PCS, physical component score; SF-36, 36-Item Short Form Health Survey; VAS, visual analog scale; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

Statistical Analysis

All statistical analyses were performed with Stata (v 13; Statacorp LP). Kaplan-Meier curves were used for survival analyses. The Wilcoxon signed-rank test was used to compare differences in functional scores (obtained from the modified Cincinnati, visual analog scale, Western Ontario and McMaster Universities Osteoarthritis Index, and 36-Item Short Form Health Survey) between the 2 time points (preoperatively and at each follow-up). Mann-Whitney *U* tests were used to compare the improvement in scores between different groups. The level of significance was set a priori at $P < .05$.

RESULTS

Survivorship Analysis

Overall survivorship was 83% (95% CI, 70%-90%) and 79% (95% CI, 64%-88%) at 5 and 10 years after the index surgery, respectively (Figure 4). No significant difference was found in the survival rates per age, sex, body mass index, total surface area of cartilage defect (<10 vs ≥10 cm^2), status of the patellar lesions (contained vs uncontained), type of membrane (periosteum vs collagen membrane), and presence of concomitant TTO. Better survival rates were observed among patients with collagen membrane and with the total surface area <10 cm^2 but did not reach statistical difference: at 10 years, 80% vs 67% ($P = .1120$) and 85% vs 75% ($P = .1596$), respectively.

Functional Scores and Patient Satisfaction

All patient-reported outcomes for those with retained grafts showed a significant improvement at the latest postoperative follow-up (mean ± SD, 8.8 ± 4.2 years; range, 3-16 years) as compared with preoperative scores (Table 4).

TABLE 5
Subgroup Characteristics[a]

Variable	Group A (n = 5)	Group B (n = 34)	Group C (n = 14)	Group D (n = 7)
Age at the time of ACI, y	38.4 ± 12.4 (19-52)	35.5 ± 9.6 (16-55)	34.1 ± 7.2 (22-47)	41.1 ± 8.3 (31-54)
Sex, male:female, n	5:0	11:23	4:10	5:2
Body mass index, kg/m^2	28.0 ± 2.7 (24.4-31.5)	25.8 ± 4.2 (18.6-39)	26.3 ± 4.3 (19.7-32.3)	26.2 ± 2.7 (22.4-31.2)
Total defect surface area, cm^2	7.2 ± 3.5 (4.2-13)	9.9 ± 4.4 (2.7-19.7)	10 ± 4.0 (4-18)	12.7 ± 2.3 (10-16.5)
Patella, cm^2	3.3 ± 1.6 (1.2-5)	5.6 ± 2.4 (0.5-11.3)	6.0 ± 3.5 (1-14)	7.0 ± 1.6 (4.8-9.2)
Trochlea, cm^2	4.2 ± 2.6 (1.5-8)	4.4 ± 3.2 (0.8-13.7)	4.0 ± 2.3 (1-9)	5.7 ± 2.3 (2.3-9.6)
Previous surgical procedures, excluding biopsy	1.4 ± 1.7 (0-4)	1.4 ± 1.1 (0-4)	3.1 ± 1.6 (1-6)	2.1 ± 0.9 (1-3)
Cover membrane, periosteum:collagen, n	4:1	9:25	2:12	3:4
Type, I:II:III:IV, n	0:1:2:2	2:1:2:28[b]	0:1:0:13	0:1:0:6

[a]Data are reported as mean ± SD (range), unless otherwise indicated. ACI, autologous chondrocyte implantation.
[b]Type II + III, n = 1.

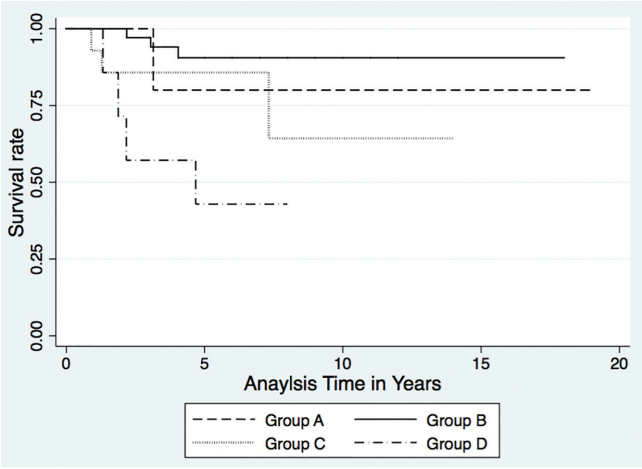

Figure 5. Kaplan-Meier survival curve per subgroup. Endpoint was defined as failure of the graft. Group A, ACI alone (n = 5); group B, ACI with TTO (n = 34); group C, failed TTO with subsequent ACI ± TTO (n = 14); group D, failed MST ± TTO with subsequent ACI ± TTO (n = 7). ACI, autologous chondrocyte implantation; MST, marrow stimulation technique; TTO, tibial tubercle osteotomy.

Of 49 knees with retained graft, 88% were satisfied with ACI procedures; 96% reported that their knees were better than before surgery; and 86% rated the results of surgery as good/excellent (Appendix 3, available online).

Radiographic Outcomes

Of 49 successful knees, 28 were available for postoperative radiographic evaluation at a mean 4.9 ± 3.2 years (minimum, 2 years; range, 2-17 years). Based on the Iwano classification for the PF compartments, preoperative OA grade was 1 for 20 knees, 2 for 7 knees, and 3 for 1 knee, while postoperative OA grade was 1 for 18 knees, 2 for 9 knees, and 3 for 1 knee. The Iwano classification showed no increase among 26 knees, while the remaining 2 knees had a 1-point increase. Based on the Kellgren-Lawrence grade for the tibiofemoral compartments, preoperative OA grade was 0 for 7 knees, 1 for 17 knees, and 2 for 4 knees, while postoperative OA grade was 1 for 12 knees, 2 for 15 knees, and 3 for 1 knee. The K-L grade showed no increase for 10 knees, while the remaining 17 knees and 1 knee had 1- and 2-point increases, respectively.

Subgroup Analysis

Patient and defect characteristics among the 4 subgroups are shown in Table 5. The best survival rates were observed in group B (91% at 5 and 10 years) (Figure 5), and 93% of patients with retained grafts in group B reported good and excellent results. Compared with group B, group A ($P = .4898$) and group C ($P = .1929$) demonstrated no significant differences. However, significantly worse survival rates were observed in group D, which had previous marrow stimulation, as compared with group B ($P < .001$) (Table 6). There was no significant difference in the postoperative clinical scores of patients with retained grafts among the groups as compared with group B.

Subsequent Surgical Procedures

A total of 42 knees (70%) required a mean 1.0 ± 0.9 SSPs (total, n = 61; range, 1-4). Among these, 54 SSPs (89%) were performed arthroscopically, including chondroplasty (22), lysis (28), lysis with minimal chondroplasty (3), and abrasion chondroplasty (1). The primary reasons for chondroplasty were hypertrophy of the ACI graft (17; periosteum in 14, collagen membrane in 3), delamination of the ACI graft (5; periosteum in 4, collagen membrane in 1), and new chondral lesions (3). The other 7 SSPs were open surgery, including removal of painful hardware (6) and vastus medialis obliquus advancement (1). Of the 42 knees requiring SSPs, 8 proceeded to become failure cases (periosteum in 5, collagen membrane in 3).

TABLE 6
Survival Rates at 5 and 10 Years Among the Subgroups[a]

	Group A (n = 5)	Group B (n = 34)	Group C (n = 14)	Group D (n = 7)
5 y	80 (20-97)	91 (73-97)	86 (54-96)	43 (10-73)
10 y	80 (20-97)	91 (73-97)	64 (18-89)	43 (10-73)[b]
Difference vs group B, *P* value	.4898	Baseline	.1929	<.001

[a]Data are reported as % (95% CI), unless otherwise indicated. Group A, ACI alone; group B, ACI with TTO; group C, failed TTO with subsequent ACI ± TTO; group D, failed MST ± TTO with subsequent ACI ± TTO. ACI, autologous chondrocyte implantation; MST, marrow stimulation technique; TTO, tibial tubercle osteotomy.
[b]At 8 years.

TABLE 7
Outcome Assessments in Failure Cases[a]

Case	Age, y; Sex	Bipolar Size, cm^2 (Patella: Trochlea)	Patellar Lesion Type	Concurrent Surgery	Preoperative Iwano Grade	Revision Surgery
1	19; M	5:8	IV	None	1	1: Re-ACI to trochlea at 3.1 y. 2: Revision re-ACI to patella and trochlea at 12 y
2	38; F	6.9:9.6	II	None	2	1: Re-ACI to patella at 1.3 y. 2: TKA at 13.7 y
3	54; M	9.2:5.5	IV	Trochleoplasty	1	A/S chondroplasty to trochlea and patella at 1.9 y
4	44; F	8:2.3	IV	TTO	1	TKA at 4.7 y
5	22; F	7.5:2.5	IV	Lateral release	1	Re-ACI to patella at 7.3 y
6	19; F	3.8:1	IV	TTO, VMO, lateral release	1	Re-ACI to patella at 4 y
7	33; F	8:6	IV	TTO, VMO, lateral release	1	Failed at 3.1 y; no revision surgery needed
8	36; M	6:4.5	IV	Patelloplasty	2	PF prosthetic arthroplasty at 1.3 y
9	32; M	7:5	IV	VMO, lateral release	2	Re-ACI to trochlea at 2.2 y
10	32; M	7:6.3	IV	TTO, VMO, lateral release, patelloplasty	2	Re-ACI to patella and trochlea at 2.2 y
11	30; F	5:3.75	II	VMO, lateral release	2	TKA at 10 mo

[a]A/S, arthroscopic; F, female; M, male; PF, patellofemoral; re-ACI, revision autologous chondrocyte implantation; TKA, total knee arthroplasty; TTO, tibial tubercle osteotomy; VMO, vastus medialis obliquus.

Treatment Failures

During the study period, 11 patients (19%) failed at a mean 2.9 ± 1.9 years (range, 0.9-7.3 years; ACI-periosteum in 6 patients, ACI–collagen membrane in 5 patients). Seven patients with previous marrow stimulation had a higher failure rate (57%) as compared with the overall failure rate. In detail, 6 patients underwent revision ACI; 2 had prosthetic arthroplasty and 1 had chondroplasty; and 1 needed no further treatment. Among 6 patients who underwent revision ACI, 1 underwent a third ACI, and 1 eventually had to convert to prosthetic PF arthroplasty (Table 7).

DISCUSSION

In this retrospective review of a prospectively collected data set, we analyzed data from 58 patients (60 knees) who underwent ACI for symptomatic bipolar articular cartilage lesions in the PF compartments of the knee. Our results showed an 83% survival rate at 5 years and 79% survival rate at 10 years and significant improvement in all clinical outcomes. Importantly, a very high patient satisfaction rate was observed at a mean 8.8 years. As far as we are aware, this study is the first to describe the clinical outcomes after ACI among patients who had bipolar lesions of the PF compartment in a large cohort with the longest follow-up.

Several previous studies reported the clinical outcomes after ACI for PF lesions despite the heterogeneous nature of the patient cohorts, including isolated patellar or trochlear lesions, or both, with inconsistent results. Several studies reported no difference between unipolar and bipolar lesions,[10,15] while another study reported unfavorable results with bipolar lesions.[54] Our results are comparable with the results for unipolar lesions in the PF compartment.[14,15,26] Addressing factors responsible for chondral damage and managing them at the time of reconstruction, such as maltracking, is supported by others and was always performed at the time of reconstruction in the present study.[11,13,14,51]

Among the 4 subgroups in our study, no significant difference was found in the survival rates of group A (ACI alone) and group C (failed TTO with subsequent ACI ±

TTO) as compared with group B (ACI with concomitant TTO), which is in line with previous studies that showed no significant difference between ACI alone and ACI + concomitant surgery for the treatment of cartilage lesions in the PF compartment.[10,44,53] The need of TTO for those with normal patellar tilt and normal PF tracking remains unclear, as previous studies showed better outcomes in ACI with TTO than ACI alone.[17,51] However, our results showed that group A (ACI alone) provided significant improvement and good survival rates with no significant difference in survival rates and postoperative clinical scores as compared with group B (ACI with TTO), which indicates that concomitant TTO should be performed as necessary. In contrast, a significantly worse survival rate was observed in group D (failed marrow stimulation technique ± TTO with subsequent ACI ± TTO) as compared with group B (ACI with TTO). This observation is in line with previous studies that showed the negative affect of a history of marrow stimulation on the outcomes after ACI.[33,45] Micro- and macroalteration of subchondral bone architecture after marrow stimulation, including formation of intralesional osteophytes[37] and subchondral cysts,[6,43] was reported, which might explain the poor outcomes after ACI. Thus, for those who have a history of marrow stimulation, our recommendation is the ACI sandwich technique[35] or osteochondral auto-/allograft transplantation to restore the osteochondral unit. The ACI sandwich technique includes addressing the subchondral injury by removing the diseased subchondral bone and autologous bone grafting, followed by ACI after separating cultured chondrocytes from bone grafting with collagen membrane.

There is no strong evidence for the use of cartilage repair when combined with unloading osteotomy. However, a previous study showed that clinical outcomes after TTO alone are poor when patellar lesions are type III and IV.[48] In our study, 90% of patients with type III or IV and all patients with retained grafts showed significant postoperative improvement, thereby indicating that ACI plays an important role for these lesions in particular, which may not be manageable with TTO alone, and thus supporting the recommendation that ACI with concomitant TTO be done as the first procedure when it is necessary. Unloading osteotomy with debridement for cartilage lesions could be a suitable control group. A well-designed randomized study will be needed in future research.

Treatment options for bipolar chondral lesions in the PF compartments are limited. Microfracture and osteochondral autograft transplantation are not supported in the literature to treat large chondral lesions as presented in our study. Although Dhollander et al[9] reported good clinical outcomes after autologous matrix-induced chondrogenesis over a short-term follow-up (mean, 2 years) for the treatment of isolated patellar or trochlear cartilage defects, no case presented bipolar defects, and a longer follow-up will be necessary. Meric et al[27] reported clinical outcomes after osteochondral allografts among patients who had bipolar chondral lesions, including 29% in the PF compartment. They showed a survival rate of 64% at 5 years and significant improvement among patients with retained grafts at a mean 7 years. However, there are no reports on the PF treated separately from tibiofemoral bipolar lesions. This should be taken into consideration, as recent studies reported that osteochondral allograft transplantations have inferior results in the PF compartment when compared with the tibiofemoral compartment of the knee.[5,16]

There was no demonstration of OA progression among our patients during the study period at a mean 4.9 years based on the Iwano classification. However, controversy still exists whether cell therapy can prevent the progression of OA or not.[23,41] Thus, more accurate imaging, such as magnetic resonance imaging, will need to be used to confirm this finding over a longer period.

The patients treated here with bipolar PF disease ranged in age from 16 to 55 years. Treating young patients with ACI becomes an easy decision for patients and surgeons alike as nonoperative treatment results in persistent disabling symptoms and early progression to OA. When there is loss of the PF joint space on skyline radiographs, the window for joint preservation has been lost, and a prosthesis is the only remaining treatment option. As patients approach their 40s and 50s, however, PF arthroplasty (PFA) as a transition operation before total knee arthroplasty becomes a more appealing option for patients. PFA is also more acceptable to orthopaedic surgeons because of an easier recovery and the good survivorship. Bipolar ACI ± TTO and PFA are both discussed as options for patients trying to match their desires and expectations: some patients decide on PFA, and others wish to preserve the knee joint and thus choose ACI, knowing they have not "burnt any bridges." Patients who have had prior treatments—such as microfracture, which jeopardizes the success rate of subsequent ACI—are told this.[33,45] However, many still wish to proceed with ACI. In this way, informed consent for the patient can be made by the joint discussion between patient and surgeon, matching outcomes to expectations. The stratification of the outcomes from this study, however, demonstrates that bipolar ACI ± TTO as the primary treatment offers the best survivorship. Preoperative counseling may therefore change to recommend this based on the outcomes from this study.

The strength of this study included a single-surgeon series with the same indications, postoperative course, and high follow-up rate (100%) over a long-term period. However, several limitations should be noted. First, this study was a case series with no control group. However, to have a control (nontreatment) group is difficult because of the pain and joint dysfunction with which patients presented upon seeking treatment. Second, as our study included many patients who had TTO with ACI, it was not possible to separate out the effects of the TTO from the ACI, but these were mostly Fulkerson type IV defects, which do poorly with TTO alone. Third, the subgroup analysis was challenging owing to the heterogeneity of the groups. However, they do represent the surgeon's philosophy of correcting all background factors during the biological reconstruction, as well as the desire for patients with prior microfracture (group D), who are younger, to save their knees from a PFA. Aside from group B, the other subgroups were small, which may limit the generalizability of the results and the power of comparisons involving these groups. Larger study samples and follow-up, as well as other studies to validate the subgroup analysis, are

necessary. Finally, we were unable to obtain follow-up films on all our patients and to determine if there was truly a protective effect of ACI on the progression to OA among these patients.

In conclusion, our results demonstrate that ACI for the treatment of bipolar/kissing lesions in the PF compartment provides significant improvement in pain and function with excellent survival at 5 and 10 years (83% and 79%, respectively) when maltracking is also corrected. The best results are for those patients who have ACI and TTO performed as the index operation, with a 5- and 10-year survivorship of 91%. Although a relatively high rate of SSPs (70%) was observed, patient satisfaction was high.

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