Acetabular Chondral Lesions Associated With Femoroacetabular Impingement Treated by Autologous Matrix-Induced Chondrogenesis or Microfracture: A Comparative Study at Eight-Year Follow-Up

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Purpose: The aim of this retrospective study was to investigate, at 8 years, the clinical follow-up and failure rate (revision rate/conversion to arthroplasty) of patients with hip chondral lesions associated with femoroacetabular impingement and to compare over time the treatment by microfracture (MFx) and autologous matrix-induced chondrogenesis (AMIC). **Methods:** Patients aged between 18 and 55 years, with acetabular grade III and IV chondral lesions (Outerbridge), measuring 2 to 8 cm^2 operated on at least 8 years before enrollment. Exclusion criteria were rheumatoid arthritis, dysplasia, or axial deviation of the femoral head. There were no arthritic lesions, Tonnis < 2, or joint space of at least 2 mm. MFx was performed with an awl, and the Chondro-Gide membrane used for the AMIC procedure was placed without glue. Outcomes used modified Harris hip score (mHHS) at 6 months and yearly for 8 years and patient acceptable symptomatic state. **Results:** Among 130 patients, 109 fulfilled inclusion criteria. Fifty were treated by MFx and 59 by AMIC. The mHHS significantly improved in both groups from 46 ± 6.0 to 78 ± 8.8 for mHHS at 6-12 months, even for lesions > 4 cm^2. From 2 to 8 years, mHHS in the AMIC group was better than in the MFx group ($P < .005$). This mHHS improvement in the AMIC group was maintained through the 8-year follow-up period, whereas it deteriorated after 1 year in the MFx group ($P < .005$). Eleven patients (22%) in the MFx group required total hip arthroplasty (THA); none in the AMIC group did. Patient acceptable symptomatic state analysis confirmed similar short-term improvement, but a significant ($P < .007$) degradation after 2-8 years in MFx patients. **Conclusions:** MFx and AMIC techniques led to marked clinical short-term improvement in patients with chondral defects resulting from femoroacetabular impingement in the first 2 years. However, AMIC gave significantly better results as measured by mHHS, which were maintained after 8 years, the results of MFx in the hip deteriorated over time with 22% of patients undergoing conversion to THA. No patient in the AMIC group was converted to THA; the results of AMIC appeared stable over time and independent of lesion size. **Level of Evidence:** III, retrospective patient group study.

Femoroacetabular impingement syndrome (FAI) is frequently associated with chondral damage[1,2] as a result of the abutment of the acetabular rim and the proximal femur.[3] It may be secondary to cam morphology (femoral site) or pincer morphology (acetabular site) and can lead to osteoarthritis (OA).[3] Both types of impingement cause damage to articular cartilage, which adversely affects the outcome of treatment for FAI.[4]

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The frequency of chondral lesions in patients treated with hip arthroscopy for FAI is high, up to 67.3%.[5,6] In the series of Byrd et al.,[7] 227 hips were treated with arthroscopy for FAI, mostly with cam or cam and pincer combined. Fifty-eight presented grade IV articular lesions (25% of associated cartilage lesions).

Several articular cartilage strategies have been used to restore large cartilage defects in the active patient, including autologous chondrocyte implantation, debridement, microfracture (MFx), osteochondral autografts, and fresh frozen allografts.[8] MFx is commonly used in the management of chondral lesions of both the knee and ankle. It may also be used in the hip, particularly since the introduction of hip arthroscopy.[9-13] It allows progenitor cells from bone marrow to permeate a chondral defect, clot, and promote repair. To improve stabilization of the clot, an enhanced technique, autologous matrix-induced chondrogenesis (AMIC), was developed.[14,15] This 1-step technique combines MFx with a bilayer collagen matrix that prevents progenitor cells from diffusing into the joint and protects the site from mechanical stress. Although the aim of all current surgical strategies to repair cartilage lesions is to bring symptomatic relief and to improve joint functionality by promoting a resurfacing of the articular layer with a fibrocartilaginous type of repair tissue,[16] there is no evidence of a method yielding a de novo cartilage tissue with time, but there is ample evidence showing an intermediate repair tissue, of mixed contribution, hyaline-like, and fibrous, depending on the methods used, on the models, with a lack of comprehensive human biopsies, Moreover, clinical results are not necessarily correlated with the structure of the repair tissue[17] confirmed by Knutsen et al.[18] Histologic support for “biomechanically superior” hyaline cartilage filling the defect even in autologous chondrocyte implantation procedures is lacking, as is evidence that the presence of this tissue ultimately delays the development of OA.[19,20]

Although AMIC is a clinically effective treatment for chondral lesions of the knee and ankle,[21-23] only a few authors have described its use in the hip.[13,24-26] The comparison of MFx and AMIC for the repair of hip chondral lesions showed that after an initial similar improvement of the functional scoring for both techniques, a significant decrease of performance was noted at 2 years and thereafter in the MFx group, whereas no deterioration was observed until 5 years in the AMIC-treated group.[26] In addition, 6 patients in the MFx group underwent total hip arthroplasty for recurrent pain and impaired function, whereas none of the AMIC-group patients needed revision. We hypothesized that AMIC is able to provide long-term stability of clinical results and prevents hip arthroplasty for at least 8 years in these young patients.

The aim of this retrospective study was to investigate, at 8 years, the clinical follow-up and failure rate (revision rate/conversion to arthroplasty) of patients with hip chondral lesions associated with FAI and to compare outcomes over time after treatment by MFx or AMIC.

Patients and Methods

FAI syndrome (FAIS) was diagnosed using standard anteroposterior, false-profile, and Dunn view radiographs and magnetic resonance imaging scans according to the commonly accepted criteria.[27,28] Patients were treated with either MFx or AMIC, and all operations were performed by the same senior surgeon. The retrospective investigation was approved by the institutional review board (PS 4.2.4-02).

The inclusion criteria for the study were: age between 18 and 55 years; acetabular grade III and IV chondral lesions according to the Outerbridge classification measuring between 2 cm^2 and 8 cm^2, including concomitant chondral lesions of the femoral head; less than grade 2 degenerative changes radiologically according to the Tonnis scale; a joint space of at least 2 mm; and a theoretical follow-up of at least 8 years. Exclusion criteria were rheumatoid arthritis, dysplasia (center-edge angle of Wiberg $< 20°$), axial deviation of the femoral neck (anteversion angle $> 24°$, retroversion angle $> 18°$, coxa valga collum-diaphyseal angle $> 135°$, coxa vara collum-diaphyseal angle $< 120°$); coxa profunda; or protrusio acetabuli. Lesions > 4 cm^2 were considered “large” following the above-threshold value of 4 cm^2 established by Steadman et al.[29] and Crawford et al.,[30] which is considered suitable for MFx treatment in the knee as well as in the hip.

The collagen matrix reimbursement by the payer determined which treatment patients received. However, there was no other variation in the treatment strategy and postoperative care between both treatment groups.

Patients with cam-FAI (alpha angle $> 55°$) pincer-FAI (positive cross over sign), or combined were included in this study. For cam-type impingement, arthroscopic femoral head-neck resection arthroplasty was performed to eliminate the bony prominence that impinges the labrum and acetabular rim and restore the anatomic offset between the femoral head and neck (Figure 1). For pincer-type impingement, arthroscopic acetabular rim trimming was used to reduce the bony overhang and to reshape the acetabulum into its normal contour. Detached labrum was reattached to the acetabular rim with suture anchors. Mixed cam-pincer impingements have been surgically addressed for both pathologies.[24,31,32]

After grading the cartilage damage and debriding the lesion with a motorized shaver, the calcified layer was removed from the subchondral bone until sharp and vertical margins were obtained. A solid awl was used to penetrate the subchondral bone with multiple holes,

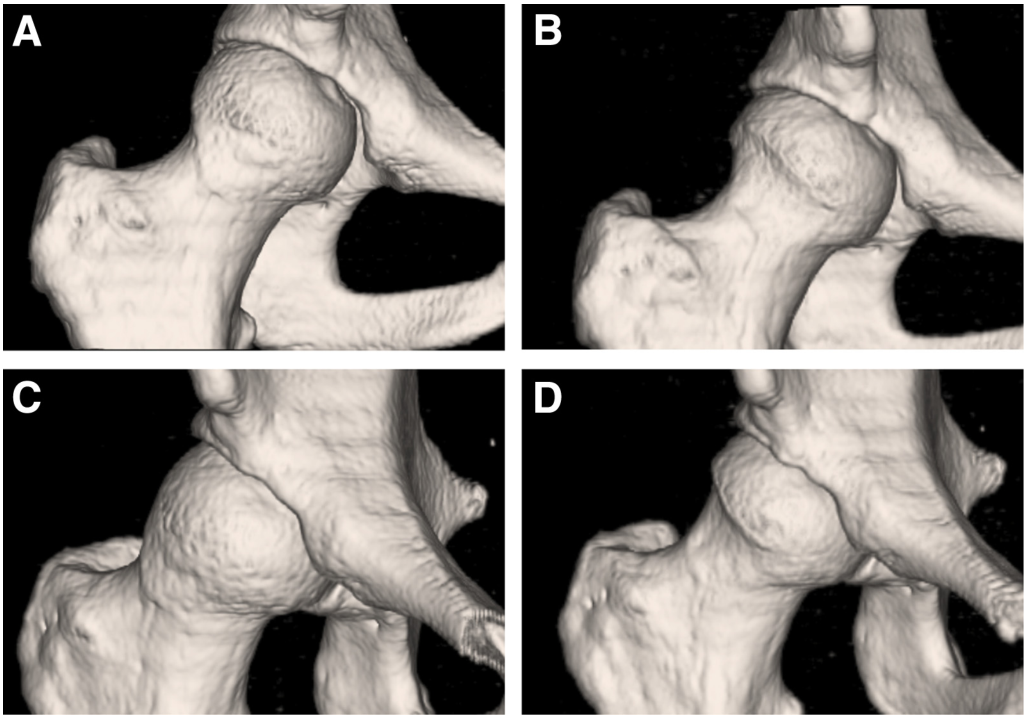

Fig 1. Preoperative and postoperative 3D CT scan of a cam-type femoroacetabular impingement. (A) A preoperative low-dose 3D CT scan of the right hip in a 21-year-old female demonstrates a cam-type deformity on the anterior are of the femoral head junction. (B) The postoperative 3D CT scan demonstrates the resection of the cam-type deformity. (C) Preoperative false profile view. (D) Postoperative false profile view. (3D, 3-dimensional; CT, computed tomography.)

3 mm deep, as perpendicular as possible, about 3-4 mm apart, starting at the periphery and moving to the center of the lesion. The arthroscopic fluid was then removed and subchondral penetration verified by the MFx-associated bleeding (Figure 2).

The AMIC procedure was also performed in a single surgical step as previously described,[13] combining MFx with a resorbable collagen I/III matrix 0.5 mm thick in a dry state (Chondro-Gide, Geistlich Pharma AG, Wolhusen, Switzerland). After MFx, the collagen matrix was cut to fit the lesion, which was measured with an arthroscopic probe. The matrix was slightly undersized because it swells by about 10% when wet. The intra-articular side was marked with a skin marker to facilitate placement because the matrix has a double layer consisting of an intra-articular smooth surface and a porous surface designed to face the bone. After removing the fluid from the joint, the matrix was inserted using an arthroscopic cannula and placed over the lesion. Traction was released and a series of articular movements were performed. Traction was then reapplied and the stability of the matrix verified (Figure 2). In 13 cases (22%), the membrane was unstable and a new membrane had to be reapplied. In no case was fibrin glue or any other fixation used to stabilize the membrane. The postoperative management used in this study has been described (Table 1).[13]Continuous passive motion was applied twice per day for 4 days postoperatively, starting 0°-60°, with an increase of 10° per day. After 7 weeks, strengthening of the lower limb and pelvis (abdominals and lumbar included) was prescribed.

All patients (except 3) were assessed preoperatively, 6 months, and 1, 2, 3, 4, 5, 6, 7, and 8 years or more postoperatively using the mHHS (maximum value, 91)[33,34] by direct clinical examination. The patient acceptable symptomatic state described for the mHHS by Chahal et al.[35] and the threshold value for the mHSS of 74 proposed for the assessment of hip arthroscopy and treatment of FAI was also used to assess the clinical relevance of the scores and their individual change through the duration of follow-up. Levy et al.'s[36] description of a minimal clinically important difference (MICD) of 8 at 8 years versus preoperative values for the mHHS was also considered. Plain anteroposterior x-rays were routinely performed preoperatively, at 6 months, and almost yearly. A Tonnis grade of 2 was considered an indication for THA. Magnetic resonance imaging scans were not performed regularly during the follow-up. Complications and the requirement for further surgery were also recorded.

Statistical Analysis

Missing mHHS values were interpolated using cubic spline interpolation as a mathematical method commonly used to construct new points within the

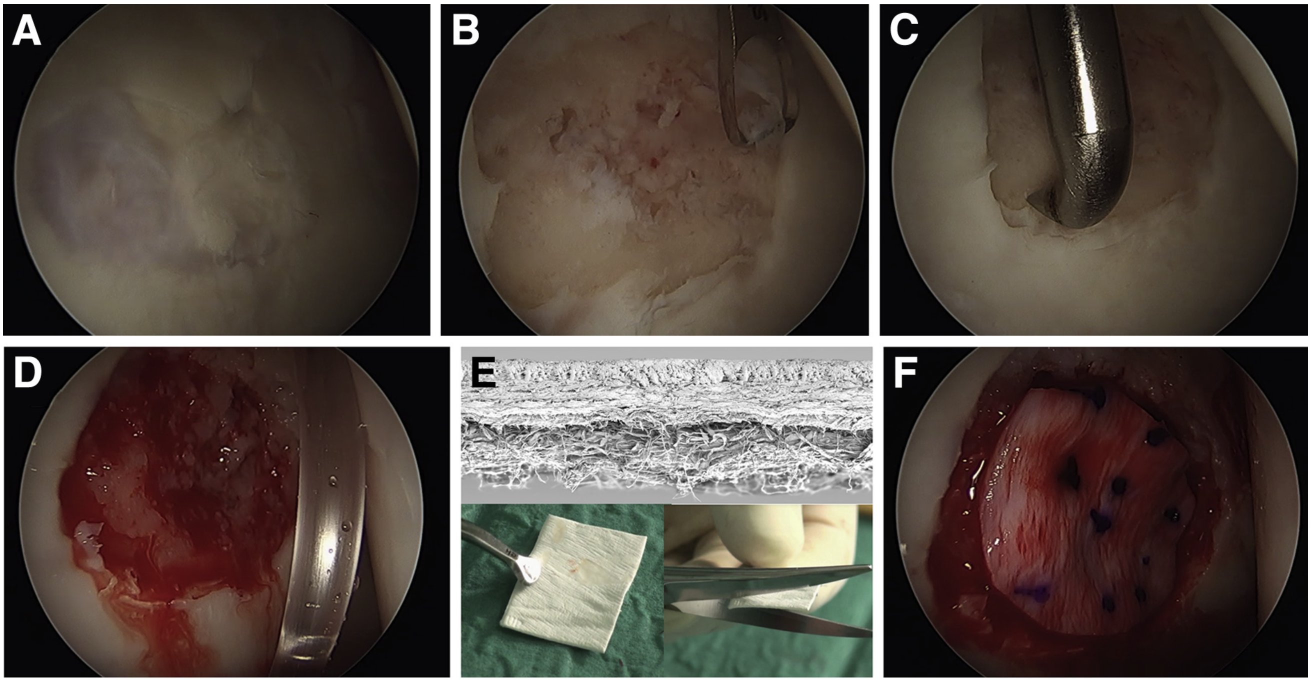

Fig 2. Autologous matrix-induced chondrogenesis for the treatment of a chondral defect in the hip. (A) Mixed third/fourth-degree chondral lesion on the anterior and superior area of the acetabulum in a 25-year-old male. (B) Debridement and chondrectomy of the frail fibrous tissue are performed to expose the subchondral bone. (C) A solid awl is used to penetrate the subchondral bone with multiple holes, 3 mm deep, as perpendicular as possible, about 3-4 mm apart, starting at the periphery and moving to the center of the lesion. (D) Arthroscopic fluid is then removed and subchondral penetration verified by the microfracture-associated bleeding. (E) The Chondro-Gide matrix is cut to fit the lesion, which was measured with an arthroscopic probe. The matrix is slightly undersized because it swells when wet. The intra-articular side is marked with a skin marker to facilitate placement because the matrix has a double layer consisting of an intra-articular smooth surface and a porous surface designed to face the bone. (F) After removing the fluid from the joint, the matrix is inserted using an arthroscopic cannula and placed over the lesion. Traction is released and a series of articular movements were performed. Traction is then reapplied and the stability of the matrix verified.

boundaries of a set of known points. These new points are function values of an interpolation function (referred to as *spline*), which themselves consist of multiple cubic piecewise polynomials.[37] This interpolation was used for 3 patients during the course of the follow-up and for 10 patients for whom scorings were reported at 9 or 10 years instead at 8 years. All were in the AMIC group.

Qualitative variables were described by absolute and relative frequencies (in percentages) of their categories. The homogeneity of the treatment groups with respect to binary and multiclass variables was tested using Fisher's exact test. Homogeneity with respect to continuous variables was tested using exact Wilcoxon's rank-sum tests. The clinical endpoint (mHHS) was analyzed descriptively using means with standard

Table 1. Postoperative Management for Femoral Acetabular Impingement-Induced Chondral Lesions

	1-4 d	5 d-4 wk	>4 wk-6 mo	6 mo-1 y	>1 y
Load bearing	None	None	Partial load bearing up to 7 wk; afterwards, full	Full	Full
Mobilization	Continuous passive motion twice per day starting at 0°-60° of hip flexion, with an increase of 10° per day	Regain step-wise full range of movement	No restriction	No restriction	No restriction
Physiotherapy and sport	No sporting activities Isotonic and isometric quadriceps exercises	No sporting activities Active and passive physiotherapy	Light sporting activities (e.g., swimming, cycling)	Jogging	Full return to sports

deviation and confidence intervals for each time point by treatment, gender, and size of the defect (large/small). Differences between selected time points were also analyzed in this manner. To compare mHHS per time point and differences compared with preoperative measurements between the 2 groups, and also by gender or size of the defect, 2-sided *t* tests and exact permutation tests were performed, using the Shift algorithm.[38] Whether the 2 treatments showed a different course over time in mHHS was checked by the test for interaction using nonparametric repeated measures analysis of variance (ANOVA). Using a 3-way adaptation of these methods, the effect of gender and of the size of the defect on the result was tested, according to the method of treatment and time. This 3-way ANOVA was complemented by 2-way ANOVA stratified by gender or by the size of the defect.

The main null hypothesis was “absence of treatment effect measured by mHHS over time.” A P value $< .05$ was considered statistically significant. Survival with an endpoint of total hip arthroplasty (THA) was assessed using Kaplan-Meier life tables comparing the 2 forms of treatment in an exploratory manner by the log-rank test.

Analyses were performed using R, version 3.3.2 (The R Foundation for Statistical Computing, Vienna, Austria), along with packages survival (Kaplan-Meier estimates), coin (exact Wilcoxon’s tests), and nparLD (rank-based repeated measure ANOVA).

Results

To address the 8 year follow-up, the inclusion period extended from 2004 until 2009. In this period, 130 patients with FAI underwent arthroscopic treatment of an acetabular chondral lesion. A total of 109 patients fulfilled the inclusion criteria and formed the study group. There was no arthritic lesion, with a Tonnis classification < 2, and a joint space of at least 2 mm. Between November 2004 and June 2009 and 50 were treated arthroscopically with MFx, 59 were treated arthroscopically using AMIC (Figure 3). All patients (100%) in the MFx group and 58 among 59 in the AMIC group were available for review at 8 or 9-10 years postoperatively, except if THA had to be performed before the eighth year of follow-up.

The preoperative patient stratification is shown in Table 2. The MFx group was less homogeneous in gender than the AMIC group ($P = .003$). The FAI-cam procedure was performed in 40 (80%) and 33 (66%) of MFx and AMIC patients, respectively. There were no significant differences between mean age and mean size of the defects in the 2 groups.

The respective percentage of defects > 4 cm^2 and preoperative mHHS were similar in both treatment groups. In all cases, the chondral defects were located on the anterosuperior area of the acetabulum. Femoral chondral lesions, if present, were treated by MFx alone.

The preoperative mHHS was significantly lower in the AMIC group at 44.5 ± 6.2 (range 34-60, $P = .006$) than in the MFx group at 47.6 ± 5.3 (range 36-60). Large defects measuring ≥ 4 cm^2 were seen in <50% of patients in both groups.

The mean mHHS improved significantly ($P < .001$) in both groups 6 months postoperatively (77.04 ± 9.8 for MFx [range 58-98] and 78.8 ± 7.8 for AMIC [range 68-96]; Figure 4 shows the confidence intervals). The mean improvement of mHHS at 6 months was 30-34 points versus preoperative values (Figure 5). At this time, there were no better results in the AMIC group versus the MFx group. Differences in outcomes between the 2 groups became apparent 2 years postoperatively, and this trend continued throughout the follow-up. A significant decrease in the MFx scoring had occurred already after 2 years as compared with the 1-year values. The scores in the AMIC group were significantly better than in the MFX group at all time points from 2 to 8 years ($P < .005$). The respective values of mHHS at 8 years were of 76.4 ± 9.2 (range 58-94) and 81.5 ± 6.8 (range 69-96) for MFx- and AMIC-treated patients. Moreover, the improvement in mHHS seen in the AMIC group was maintained throughout the 8-year assessment period.

Patients with THA conversion, all in the MFx group, and therefore low scores were progressively out of the group values during the follow-up and at 8 years, improving subsequently the mean scoring for this group of patients. According to the patient acceptable symptomatic state criteria defined for FAI treatment, the threshold value of 74 was established for the mHHS; all patients except 5 in each treatment group (plus 2 THA in the MFx group) achieved the value of 74 at 1 year. Thereafter, at 2 years, 10 patients (plus 2 who underwent THA) were below this value in the MFx group, whereas only 3 were below it in the AMIC group. Finally, at 8 years, 16 patients (plus 11 THA) were below the threshold value of 74 in the MFx group, whereas only 7 were ranked below in the AMIC group. After 8 years, all patients in the AMIC group had an MICD of at least 8 for the mHHS versus preoperative values. In the MFx group, among patients not submitted to THA, all except 2 had an MICD of more than 8, 2 had an MICD of 8, after 8 years versus preoperative values.

Patients with small lesions (< 4 cm^2, n = 31 and 36 for MFx and AMIC, respectively) had similar outcomes until 3 years. Each follow-up period between 3 and 8 years postoperatively revealed significantly better results in the AMIC group ($P < .01$) except at 8 years (Figure 6). For patients with larger lesions (n = 19 and 23 for MFx and AMIC, respectively), the differences were more pronounced and reached statistical significance at 2 years ($P < .005$). The differences remained significant for all subsequent time points (Figure 7).

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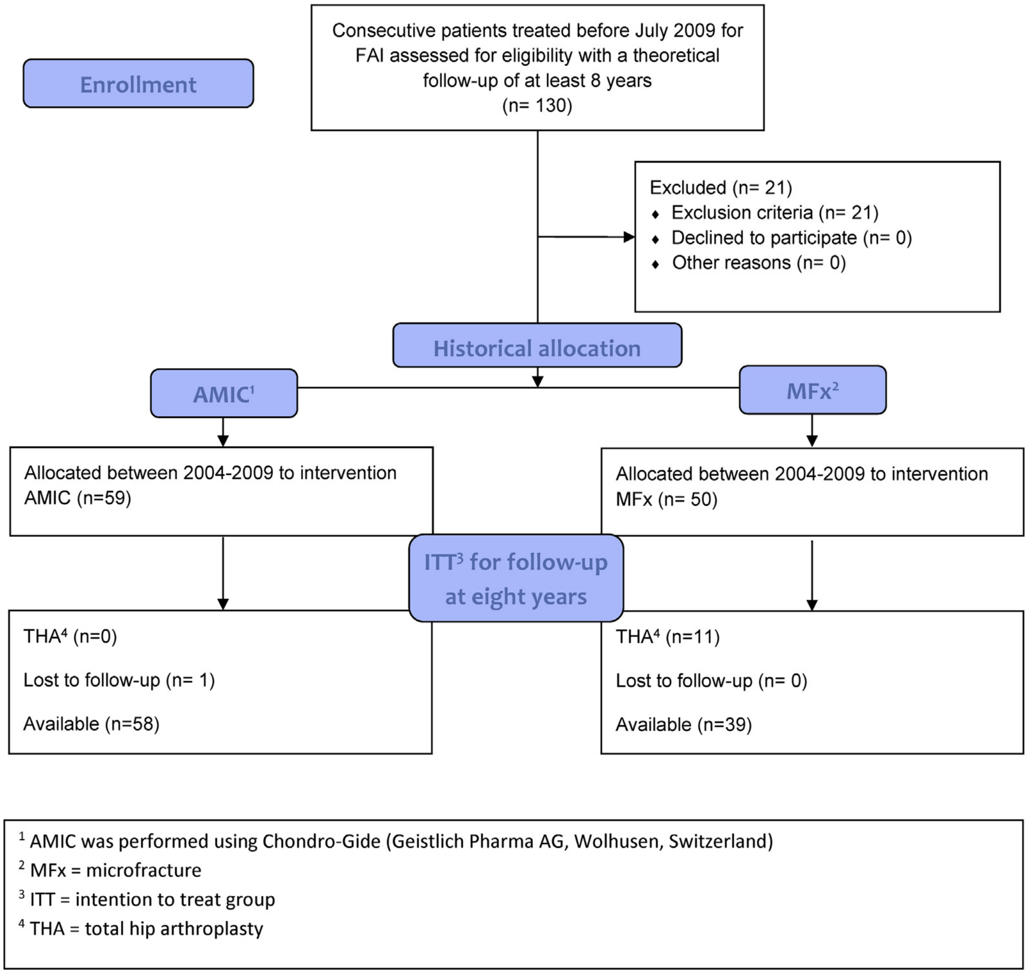

Fig 3. CONSORT flow diagram showing the progress of all 130 patients assessed for the study. The theoretical follow-up of 8 years means that the patients were operated on at least 8 years previous. (AMIC, autologous matrix-induced chondrogenesis (performed using Chondro-Gide, Geistlich Pharma AG, Wolhusen, Switzerland); FAI, femoroacetabular impingement; MFx, microfracture; THA, total hip arthroplasty; ITT, intention to treat.)

A total of 11 patients (2%) in the MFx group required THA after 6-12 months (n = 2), 2 (n = 1), 3 (n = 1), 4 (n = 2), 5 (n = 2), 6 (n = 1), and 7 years (n = 2). None in the AMIC group required THA (Table 3 and Figure 8). Conversion to THA related to a degradation of the Tonnis grade (2 or more). Revision hip arthroscopies were also performed in, respectively, 2 and 3 patients in the MFX group and AMIC group for partial cam or pincer resections (n = 4) and in 1 case for a medial snapping hip. They were not considered failures of the chondroplasty procedure. An incidental second look was, however, performed 13 months after AMIC procedure in 1 patient. Here, satisfactory tissue quality with a fibrocartilage-like aspect was seen. No other complications have been reported.

Table 2. Preoperative Characteristics of the Study Groups

	MFx	AMIC	*P*-value
Number	50	59	
Gender, M/F	37/13	27/32	.003
FAI-cam, n	40	33	.006
FAI-pincer, n	4	13	.038
FAI-combined, n	6	13	.164
Preoperative mean age, yr	38.3 (19-55)	39.3 (18-55)	.677
Preoperative mean defect size, cm^2	3.6 (2-8)	3.5 (2-8)	.807
Preoperative mean mHHS	47.6 (36-60)	44.5 (34-60)	.006
Large defects ≥4 cm^2, n (%)	19 (*38.0*)	23 (*40.0*)	1.000

AMIC, autologous matrix-induced chondrogenesis; F, female; FAI, femoroacetabular impingement; M, male; MFx, microfracture; mHHS, modified Harris Hip Score.

Plain x-rays performed pre- and postoperatively allowed evaluation of the FAI correction's stability and the extent of OA progression. The Tonnis grade data collected are reported in Table 4 for both groups. They show a relative stability of the Tonnis grade with time in the AMIC group, with only 3 patients reaching a Tonnis grade of 2 at 7-8 years, whereas Tonnis grade of 3 was observed in 20 patients from the MFx group at 8 years (in addition to the 9 patients who already went to

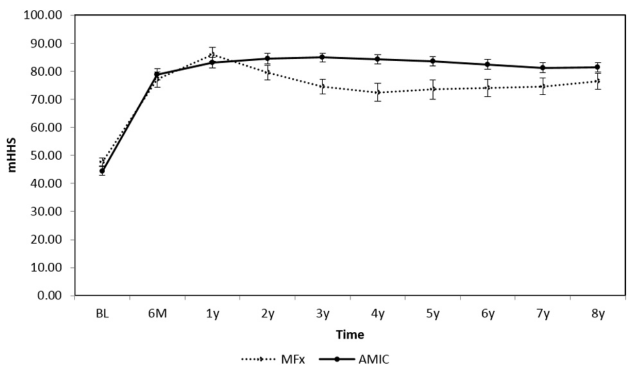

Fig 4. Graph showing mean (95% confidence interval) of the modified Harris hip scores (mHHS) preoperatively and up to 8 years after MFx and AMIC. AMIC patients show significantly better results at 2 years ($P < .01$), as well as at each subsequent follow-up ($P < .005$). (AMIC, autologous matrix-induced chondrogenesis; MFx, microfracture.)

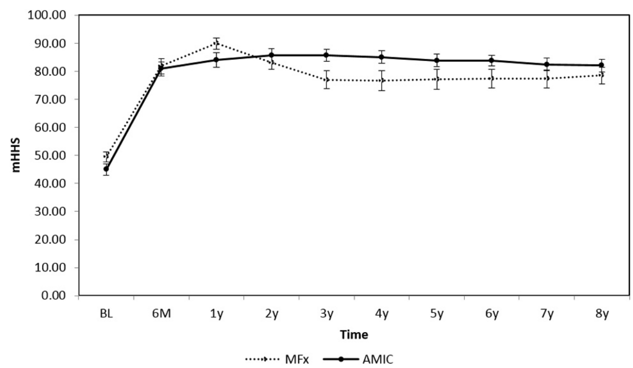

Fig 6. Graph showing mean (95% confidence interval) of the pre- and postoperative mHHS of patients with < 4 cm^2 defect size for both MFx (n = 31) and AMIC (n = 36) treatment groups. AMIC patients had significantly better results at 1 and 3 to 7 years postoperatively ($P < .01$). (AMIC, autologous matrix-induced chondrogenesis; MFx, microfracture; mHHS, modified Harris hip scores.)

THA).The patients who underwent THA had risk factors for the development of degenerative changes, including cam lesions associated with increased depth of chondral injury,[39] a defect size $\geq$ 4 cm^2 (in 10 among 11), an associated femoral defect (in 8 among 11), a low mean preoperative mHHS (44.5, range 40-50), and a mean mHHS of 58.2 (range 48-68) at the latest review before THA. At that time, the mean mHHS improvement versus preoperative values was only 14. In the AMIC group, a large defect had no effect on the mHHS because a mean mHHS improvement of 36.9 $\pm$ 8.0 was observed after 8 years.

Discussion

The results reported confirmed a significant and stable improvement of the functional hip scoring, after AMIC procedures performed on acetabular chondral lesions resulting from FAI, whereas the results of MFx alone, degrade with time after an initial improvement during the first year. Concomitantly, the conversion rate to THA was 22% for MFX-treated patients during the 8-year follow-up, whereas no THA conversion occurred in the AMIC-treated patients.

Several authors have investigated short-term outcomes of FAI repair. The results of an arthroscopic treatment for FAI were analyzed by Philippon et al.[40] for a mean follow-up of 2.3 years. The mean mHHS improved from 58 to 84 (mean difference 24), and 10 patients underwent THA at a mean of 16 months after arthroscopy. In this series, 47 patients were treated by MFx for moderate to severe cartilage lesions. Philippon also examined the articular cartilage defect fill and reported 95%-100% coverage at 20 months for 8 of 9 patients. The authors found a correlation between the need for revision, THA, and the age of the patient.

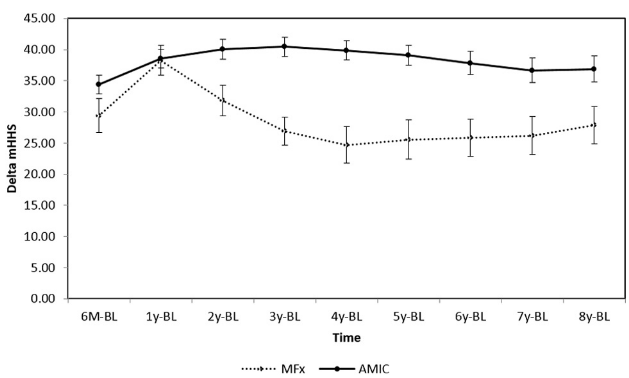

Fig 5. Graph showing mean (95% confidence interval) of the differences in the post- versus preoperative mHHS for both groups. AMIC patients show significantly better results at 2 years and later ($P < .005$). (AMIC, autologous matrix-induced chondrogenesis; mHHS, modified Harris hip scores.)

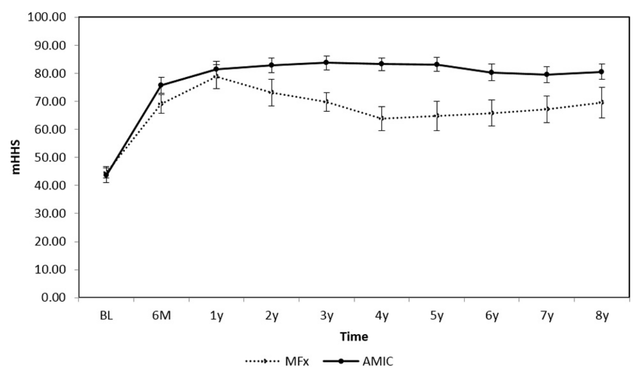

Fig 7. Graph showing mean (95% confidence interval) of the preoperative and postoperative mHHS scores of patients with $\geq$ 4 cm^2 defect size for both MFx (n = 19) and AMIC (n = 23) treatment groups. AMIC patients had significantly better results at 6 months and 2 years ($P < .01$) and all subsequent time intervals ($P < .005$). (AMIC, autologous matrix-induced chondrogenesis; MFx, microfracture; mHHS, modified Harris hip scores.)

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Table 3. Characteristics of Patients Who Underwent THA

Patient ID	FAI	Gender	Age, yr	Defect Size, cm^2	Femoral Head Defect	Time to THA, yr	Preoperative mHHS	mHHS Maximum	mHHS Last Before THA Conversion
60	Cam	F	48	4.0	Y	0.5-1	46	60	60
73	Combined	F	49	6.0	Y	4	40	84	68
89	Cam	M	31	4.0	Y	3	40	70	64
77	Cam	F	54	6.0	Y	3	48	70	48
99	Cam	F	51	4.0	Y	4	50	78	48
100	Cam	F	51	4.0	Y	0.5-1	48	58	58
62	Pincer	F	52	3.0	N	5	44	98	62
86	Cam	M	50	6.0	Y	6	40	78	60
97	Cam	M	51	4.0	N	7	46	92	62
101b	Cam	M	39	4.0	N	7	48	88	60
104	Cam	M	44	8.0	Y	5	40	80	50

Cam, cam FAI (cam FAI is caused by a nonspherical portion of the femoral head abutting against the acetabular rim in flexion); combined, cam and pincer FAI; F, female; FAI, femoroacetabular impingement; M, male; mHHS, Modified Harris hip score; pincer, pincer FAI (pincer FAI is the result of linear contact between the acetabular rim and the femoral head-neck junction); THA, total hip arthroplasty.

Patients requiring THA were significantly older (58 versus 39 years), had significantly lower preoperative mHHS (47 versus 60), and MFx performed on both femoral and acetabulum were more likely to require THA. The rate of conversion to THA after MFX was similar in this study as in our patient group (21%). Similarly, 96% defect filling were reported by Karthikeyan et al.,[11] who confirmed that arthroscopic MFx can be considered as an effective treatment for acetabular chondral lesions.

Byrd et al.[38] showed, in an FAI patient population of 207 hips, that 58 required a chondral repair-associated procedure for grade IV articular lesions. MFx resulted in an average improvement of 20 points on the mHHS over a 2-year period. One patient in this series (1.5%) with extensive grade IV articular loss was converted to THA at 8 months post-therapy for recalcitrant pain.

Lodhia et al.[41] compared, in a match-control study with average 3-years' follow-up, patients with labral tears and chondral damage treated with MFx and a group that did not have chondral damage. At 2 years, the conversion rate to THA was 6%-8% in the MFx group. The chondral defect area was small (1.5 cm^2) and showed an improvement of 15 points at 3 years versus preoperative values; however, 2-3 years postoperatively, a progressive deterioration was observed.

As reported recently by MacDonald et al.[42] in a systematic review on the indications for MFx as an adjunct to hip arthroscopy for the treatment of chondral defects associated with FAI, the technique is effective. In this review of 12 studies, the mean chondral defect size was 3.0 cm^2 (range 0.2-12 cm^2). Independent of hip score used, there was statistically significant improvement in all studies except in a single case report. But only short- to mid-term outcomes were available (mean follow-up of 29 months reported).

Finally, in a recent survey of arthroscopic management of hip chondral defects based on 12 clinical studies, Marquez-Lara et al.[43] showed that arthroscopic debridement, MFx, and ACT are associated with equivalent improvement in clinical outcomes in patients with high-grade chondral defects in the hip in short- and mid-term follow-up. In this survey, the rate of total hip arthroplasty ranged from 0.5% to 8.9% within $<$ 2 years after the procedure. Reviewing their case series of 70 patients, Trask et al.[44] reported a THA conversion rate of 17% within the first 2 years. Finally, the latest review by Horner et al.[45] based on 17 studies on hip arthroscopy outcomes showed that the rate of conversion to THA is higher in patients $>$ 40 years of age and increases with each decade of life, based on a mean follow-up of 43.9 months. In our experience, the cam-only type of impingement could also be considered as a risk factor for larger acetabular chondral defects because of the larger volume and extension of this deformity compared with the pincer deformity.

MFx is still the treatment of choice for small chondral defects of the acetabulum and femoral head ($\leq$ 2 cm^2).

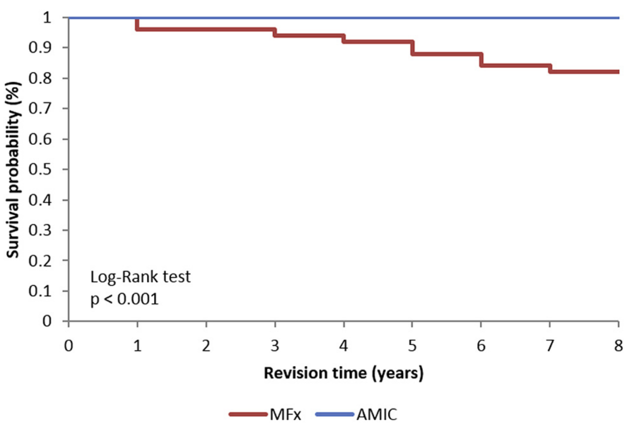

Fig 8. Kaplan-Meier survival curve with THA as the endpoint. The Kaplan-Meier survival curves were compared in an exploratory manner by the log-rank test. (AMIC, autologous matrix-induced chondrogenesis; MFx, microfracture.)

Table 4. Evolution of the Tonnis Grade and Conversion Rate to THA in the MFx and AMIC Groups Versus Time

	Tonnis 0	Tonnis 1	Tonnis 2	Tonnis 3	THA	Number of Patients Available
MFx (n = 50)						
Preoperative	11	39	0	0		50
1 yr	8	38	2	0	2	48
2 yr	5	41	2	0	0	48
3 yr	0	44	3	0	1	47
4 yr	0	40	6	0	1	46
5 yr	0	33	10	1	2	44
6 yr	0	29	12	1	2	42
7 yr	0	24	15	2	1	41
8 yr	0	18	20	1	2	39
AMIC (n = 59)						
Preoperative	17	42	0	0	0	59
1 yr	16	43	0	0	0	59
2 yr	16	43	0	0	0	59
3 yr	13	46	0	0	0	59
4 yr	12	47	0	0	0	59
5 yr	12	46	1	0	0	59
6 yr	10	46	2	0	0	58
7 yr	8	47	3	0	0	58
8 yr	8	47	3	0	0	58

AMIC, autologous matrix-induced chondrogenesis; MFx, microfracture; THA, total hip arthroplasty.

Satisfactory clinical results after MFx for lesions in the hip,[10,11,46] including those in athletes,[46] have been reported; however, the follow-up did not exceed 2 years.[46,47] In the knee, MFx has been shown to be effective in the management of lesions measuring < 2 cm^2 in the knee, but deterioration in the knee function in 47% to 80% of patients after a mean of 2 years has been reported in an evidence-based systematic analysis assessing a total of 3,122 patients.[48] Clinical data relating to the size of the lesion, the choice of treatment, and the evaluation of cartilage repair procedures beyond 2 years postoperatively are of great importance to determine the appropriate treatment for chondral defects of the hip.

The study compares the clinical outcomes associated with MFx and AMIC for the treatment of FAI-induced acetabular chondral defects having 8 years of follow-up. Our data show that when compromised cartilage is associated with FAI, treatment that targets both pathological processes gives a significant improvement of the functional scoring over time. Specifically, we found improvement in the clinical scores with both MFx and AMIC following treatment of chondral lesions >4 cm^2. The >30-point increase in mHHS seen up to 1 year postoperatively in patients treated with MFx was not maintained after 1 year. Patients who were treated with AMIC showed a similar improvement in mHHS 1 year postoperatively, an effect maintained over the next 7 years. Notably, a similar pattern was found in the treatment of smaller lesions. Very few long-term data about the outcome of large chondral lesions of the hip are reported in literature, and none of these clearly reveal the possible differences between smaller and larger lesions.[2,10,30] However, it can be speculated from the experience in the knee field, that smaller lesions, as well as age, may be a predictor of functional improvement over the long-term.[49] Our findings that AMIC outperformed MFx over time in the hip support this concept.

Our data showed a mean improvement of the mHHS of 37 ± 8 points at 8 years versus preoperative values in the AMIC treated group, whereas it was only of 28 ± 9.4 in the MFx group. These values for the AMIC group compare favorably with data from the review of Sim et al.,[50] who reported after MFx a mean improvement of 25-30 points in the mHSS at 2 years.[47,51-56]

Our respective revision rates of 2.6% and 3.9% at 2 and 3 years, and cumulative 22% THA conversion at 8 years, with concomitant treatment for FAI and chondral lesions, also compare favorably with those of Ilizalitturi et al.[46] They reported a deterioration of 16% after a mean of 2.4 years in a consecutive series of 19 patients with the diagnosis of cam FAI treated with arthroscopic proximal femur reshaping. Phillipon et al.[47] reported a deterioration of 9% after a mean of 2.3 years in 112 patients treated with hip arthroscopy. More recently, Larson et al.,[55] in a series of 44 patients, reported a conversion rate to THA of 8%-9% after a mean of 3.5 years, whereas in our study the cumulated revision rate after 8 years was 22%, notably only in the MFx group.

AMIC, which includes MFx, appears to give satisfactory results. It exploits the regenerative potential of mesenchymal progenitor cells deriving from subchondral bone and the collagen type I/III matrix protects the blood clot and supplies the regenerating site with a proper microenvironment, which supports the adhesion, growth, and differentiation of cells. This effect is supported by evidence of collagen matrices promoting the chondrogenic differentiation of mesenchymal stem cells[57] and maintaining chondrocyte phenotype,[58] in particular when the matrix is composed of collagen types I and III.[59]

Some of the limitations of MFx can be overcome by AMIC, especially in the treatment of acetabular defects ranging from 2 to 8 cm^2. In a small study of 6 patients using an open approach, AMIC was already shown to be effective in the management of chondral lesions <2 cm^2 at a mean follow-up of 1-2.5 years.[25]

Our findings in the hip are similar to those reported after the treatment of cartilage defects of knee and talus with AMIC.[21,23,60,61] Gille et al.[21] showed that 27 patients (32 knees) with a large grade IV chondral defect (4.2 cm^2) had significant improvements at 12 and 24 months after AMIC. Similar results were found in a larger multicenter observational study including 57 patients with grade III or IV chondral lesions evaluated 2 years postoperatively.[23] In a randomized multicenter study in the knee that included large lesions, AMIC was compared with MFx and a significant score degradation in the MFx group after 2 years was reported, whereas in the AMIC arm of the study, all functional parameters remained stable for at least 5 years.[62] Satisfactory outcomes were also reported for osteochondral lesions of the talus in 23 cases of AMIC-aided repair.[63] Similar results were observed 3 years postoperatively in 20 patients treated by AMIC assessed by the Foot Function Index and American Orthopedic Foot and Score.[64,65] Until now, long-term comparative outcome data for the treatment of chondral defects of the hip using MFx and AMIC were not available. Our data demonstrate sustainable positive outcomes, reflected by high mHHS over an 8-year period for patients who underwent AMIC compared with those who underwent MFx. AMIC may therefore represent a valuable therapeutic alternative for the treatment of chondral lesions, particularly for those measuring > 2 cm^2 because no patient treated in this way subsequently required THA.

Limitations

The study has limitations. First, it was a retrospective observational study and patients were not randomized. The treatment allocation was based on the reimbursement of the membrane through social care. Otherwise, all other steps of the treatment including follow-up visits and rehabilitation procedures were identical for both patient groups. Second, clinical outcome was only assessed using the mHHS. Although this test has high validity and reliability,[33] it is most suitable for the assessment of functionality in elderly arthritic patients and may not be sensitive enough to assess subtle changes in function in young, otherwise healthy patients.

A review by Sim et al.[50] established that the mHHS is still the more commonly reported. Additionally, the broad use of the mHHS in 81.5% of included studies for the objective assessment of surgical success was recently reported in a systematic review of Khan et al.[66] In addition, 1 cannot exclude some potential for gender bias (with significantly more women in the AMIC group) but also a higher number of patients with isolated pincer FAI in the AMIC group with a potentially lower progression rate to end-stage arthritis than cam or mixed FAI. Because of the small size of the groups and multiple covariables, it was not possible to identify factors that were predictive of failure.

Finally, for ethical reasons, no biopsy of the newly regenerated tissue was performed, so no histologic data on the new tissue are available.

Conclusions

MFx and AMIC techniques led to marked clinical short-term improvement in patients with chondral defects resulting from FAI in the first 2 years. However, AMIC gave significantly better results as measured by mHHS, which were maintained after 8 years, but the results of MFx in the hip deteriorated over time, with 22% of patients undergoing conversion to THA. No patient in the AMIC group was converted to THA; the results of AMIC appeared stable over time and independent of lesion size.

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