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HIP

Arthroscopic matrix-associated, injectable autologous chondrocyte transplantation of the hip: significant improvement in patient-related outcome and good transplant quality in MRI assessment

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Abstract

Purpose Acetabular chondral lesions are common in patients with FAI. For large full-thickness cartilage defects, arthroscopic matrix-associated autologous chondrocyte transplantation (MACT) using an injectable in situ crosslinking product is an option. Aim of the study was to evaluate clinical and MRI results 12 months after MACT of acetabular cartilage defects in FAI patients.

Methods We report data on 21 patients with a focal cartilage defect of the hip [2.97 ± 1.44 cm^2 (mean ± SD)] caused by FAI treated with an arthroscopically conducted MACT combined with FAI surgery. The results were assessed with patient-reported outcome measures (iHOT33, EQ-5D) pre- as well as post-operatively and by MRI using MOCART scoring system 6 and 12 months post-operatively.

Results The iHOT33 score improved from 52.9 ± 21.14 (mean ± SD) pre-operative to 81.08 ± 22.04 (mean ± SD; $p = 0.0012$) 12 months post-operatively. The lower the pre-operative iHOT33 score and the larger the defect size, the greater the observed improvement compared to pre-operative scores at 12 months. Patients showed a significant improvement in EQ-5D-5L index value ($p = 0.0015$) and EQ-5D VAS ($p = 0.0006$). MRI analysis after 12 months revealed a complete integration of the transplant in 16 of 20 patients.

Conclusions Injectable MACT is a promising minimally invasive treatment option for full-thickness cartilage defects of the hip caused by FAI. A significant improvement in symptoms and function associated with an increase in quality of life was detected in patients treated with injectable MACT combined with FAI surgery. This is of considerable clinical relevance, since, in addition to the elimination of the mechanical cause, MACT allows the successful therapy of consequential cartilage damage.

Level of evidence Level 4, case series.

Keywords Hip arthroscopy · Matrix-associated autologous chondrocyte transplantation · MACT · Cartilage defect

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Introduction

Femoroacetabular impingement (FAI) is an important reason for the development of hip cartilage defects. Further causes for localized hip cartilage defects include other congenital and developmental hip deformities, traumatic lesions, chronic mechanical overload, and other pathologies [10, 11]. The aim of joint preserving surgery is to improve the patient's symptoms by correcting pathologic biomechanics and by addressing collateral damage including cartilage defects. The hope is that this also will reduce the risk of early onset hip osteoarthritis. Different cartilage treatment techniques for cartilage defects are available. Bone marrow-stimulating techniques with and without a biomaterial and autologous chondrocyte implantation have been proposed for the treatment of chondral lesions in the hip [13]. In a recent publication by a German Guideline initiative on biologic reconstruction of full-sized cartilage defects of the hip, the indications for the different procedures are summarized. Matrix-associated ACT (MACT), preferably a minimally invasive type of MACT (e.g., injectable chondrocyte implants), is recommended in isolated full-thickness cartilage defects of more than 1.5–2 cm^2 [7].

Less invasive surgical techniques are restricted due to anatomical conditions in the hip with limited joint space, whereas open surgery (i.e., surgical dislocation) is associated with relevant morbidity. If the conventional matrix-based techniques are applied, the fixation of the transplant is challenging. The injectable, in situ crosslinking MACT product was developed to overcome these limitations. It can be applied arthroscopically in the cartilage defect without an additional fixation. The initial results concerning feasibility of the method have been published [3]. Until now, the quality of the transplant in MRI after MACT of the hip has not been investigated in a study. Thus, the aim of the present study was to evaluate clinical and MRI data collected from FAI patients 6 and 12 months after MACT of the hip.

Materials and methods

This study was designed as a non-interventional prospective, multicenter case series. Patients were enrolled between 12/2014 and 11/2015. The study was approved according to the local institutional review board (#EK 48022014) and has been registered by ClinicalTrials.gov (NCT02179346).

Protocol design and patient cohort

The intermediate-term clinical and radiographic data of patients with a focal full-thickness cartilage defect of the hip caused by FAI, who were treated by an arthroscopically or arthroscopically assisted autologous chondrocyte transplantation in a two-step procedure, were assessed. Inclusion criteria were an age between 18 and 60 years (years), cartilage defects of the hip joint ICRS grade 3 or higher with intact surrounding cartilage and subchondral bone, and a defect size of ≥ 1.5 and ≤ 10 cm^2 [4]. Patients with more than two defects, opposing defects or radiographic signs of osteoarthritis higher than grade 1 according to Kellgren and Lawrence, were excluded.

Pre-operative diagnostics included a clinical examination, standardized supine anterior–posterior and cross-table radiographs, as well as magnetic resonance imaging with radial reconstructions [1, 19].

Patient relevant outcome was assessed by EQ-5D-5L consisting of a descriptive system (evaluating the health-related quality of life in five dimensions—mobility, self-care, usual activities, pain, and depression) converted into a single index value and the EQ-5D VAS, as well as iHOT33 (evaluation of pain and functional parameters of daily life and sports). The questionnaires were obtained from patients on the day before index arthroscopy (pre-operative) and at 6 and 12 months after MACT [6, 20].

Surgical technique

In all patients, a two-step-approach was applied.

First procedure

In supine position on a traction table with about 10 mm joint distraction, the defect area with localized cartilage defect was investigated utilizing two arthroscopic portals (anterolateral and anterior) and classified according to the International Cartilage Repair Society of the knee (ICRS) during index arthroscopy. The indication for MACT treatment was reconfirmed. At least two osteochondral cylinders were obtained from non-weight-bearing areas of the hip at the head–neck junction. They were sent together with 10 ml autologous blood to the manufacturer (TETEC® Tissue Engineering Technologies AG, Reutlingen, Germany).

Second procedure

MACT was performed either arthroscopically or through a mini-open (arthroscopically assisted) limited anterior approach about 4 weeks after the first procedure. In either technique, the defect was debrided to produce stable perpendicular margins according to the user manual for NOVOCART® Inject, immediately before the application. Then, the constant fluid irrigation was stopped, and all water was removed from the joint to keep the defect as dry as possible. The chondral defect was carefully filled with

NOVOCART® Inject using a double-chamber syringe consisting of a chamber with the autologous chondrocytes containing component and a second chamber with a cross linker [2, 22]. During the application, the cell-containing component and the cross linker are mixed resulting in a cross-linked hydrogel at the site of administration. Hydrogel formation is achieved after 30–60 s and the gel bonds immediately to the bottom of the defect. No further fixation has to be applied (Fig. 1).

Concomitant corrective surgeries

Contouring the head–neck offset and labral repair (if necessary) was performed during first surgery, either arthroscopically or via limited mini-anterior-open exposure in one center. The consecutive hydrogel application was also performed either arthroscopically or via limited mini-anterior-open exposure in one center.

Aftercare

All patients were reported to adhere to the standardized post-operative rehabilitation protocol.

All patients were only allowed partial weight-bearing (10–20 kp) for 6 weeks followed by a load increase of 10–20 kp per week until full load. A return to competition sport was allowed 9–12 months after operation. Patients with labral repair were, furthermore, restricted to a maximal flexion of 90° over 6 weeks. Continuous passive motion (CPM) therapy was conducted for 4 weeks with a minimum usage of 6 h daily. Furthermore, aftercare involved prophylaxis of heterotopic ossification with oral non-steroidal anti-inflammatory drugs (NSAIDs) medication (3×50 mg diclofenac daily for a period of 2 weeks), deep vein thrombosis (DVT) prophylaxis by means of subcutaneous administration of a low-molecular-weight heparin analogue up to full weight-bearing.

Cell isolation, cultivation, and production of NOVOCART® Inject

Patient's chondrocytes were isolated from the osteochondral cylinders and expanded for 24 ± 5 days as a primary culture in vitro. Cell cultivation and *NOVOCART® Inject* formulation were performed in a Good Manufacturing Practice (GMP) facility (TETEC AG, Reutlingen, Germany).

Magnetic resonance imaging

MRI examinations of the hip joints were performed on 1.5 or 3.0 T MR Scanner using a phased array receive coil or a flexible body coil. After localizer sequences, the following sequences were applied: a sagittal proton-density (PD) weighted turbo spin echo (TSE) sequence with frequency selective fat-suppression (FS), a coronal PD-TSE sequence with FS, a coronal high-resolution PD-TSE, and a three-dimensional T1 water excited gradient-echo sequence. Magnetic resonance Observation of Cartilage Repair Tissue grading scale (MOCART) scoring was obtained from all patients after 6 and 12 months [16, 26]. This score is assessing the degree of defect filling, integration to border zone and surface, structure as well as signal intensity of repair tissue. In addition, the subchondral lamina and bone as well as adhesions and effusion are graded.

Statistical analysis

The SAS software version 9.4, SAS Institute Inc. Cary, NC, USA, was used for analyses. Score changes to pre-operative value were performed on quantified data using two-sided paired *t* tests. Multivariate mixed-effects linear regression model was applied to analyze parameters influencing the change in iHOT33. A two-sided level of 0.05 was used to detect significant effects. Statistical case number planning was not possible due to a lack of reliable assumptions about the expected target figure. Therefore, the number of cases was determined on the basis of practical aspects and in accordance with the number of cases in preliminary studies.

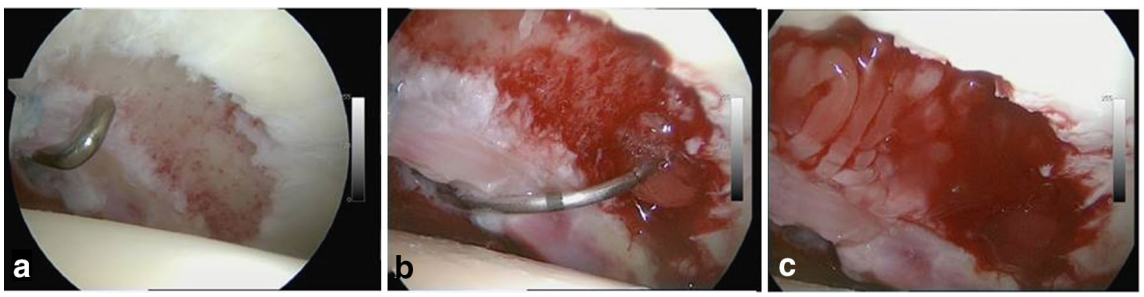

Fig. 1 **a** Cartilage preparation before application of Novocart Inject; **b** application of Novocart Inject into the cartilage defect; **c** intraoperative situation after chondrocyte transplantation

Results

Twenty-one patients (17 males and 4 females) aged between 20 and 53 y [mean ± standard deviation (SD); 32.3 ± 10.0] were included in the study. According to ICRS classification, 17 patients were diagnosed with a full-thickness chondral defect grade 3 b–d and 4 patients were diagnosed with a chondral defect grade 4a/b. The lesions had a defect size of 3.0 ± 1.4 cm^2 (mean ± SD) (Table 1). In all patients, an additional osteochondroplasty was performed for head–neck recontouring (in 14 patients arthroscopically and in 7 patients through mini-open limited anterior approach). The patients were hospitalized for 4.2 ± 2.9 days (mean ± SD) after the second surgery, which was also performed arthroscopically or mini-open, for MACT with NOVOCART®Inject.

There were two serious adverse events after MACT. One patient developed a bacterial arthritis after 6 days, which could be managed by appropriated antibiotic therapy without the need for removal of the MACT. The other patient had a persistent arthralgia after 8 months. Arthroscopy was performed for diagnostic purpose, whereby adhesiolysis of slight adhesions and trim of the acetabular rim were conducted. After first surgery for arthroscopic harvesting of the cartilage cylinders, there was one non-serious adverse event with a wound healing disturbance 17 days post-operatively. An incision was performed during MACT, and thereafter, the patient had a normal wound healing.

The iHOT33 score change was significantly after 6 [22.3 ± 26.6 (mean ± SD); $p = 0.0018$] and 12 months [28.4 ± 31.0 (mean ± SD); $p = 0.0012$] related to the pre-operative iHOT33 score (additional absolute values: Table 2).

The lower the pre-operative iHOT33 score and the larger the defect size, the greater the observed change to pre-operative results at 12 months (Fig. 2). We observed a positive correlation between iHOT33 improvement and lower pre-operative iHOT33 score ($p < 0.001$), larger defect size ($p = 0.0199$), increasing age ($p = 0.0028$), as well as lower ICRS grade ($p = 0.02$).

Patients who underwent MACT of the hip showed a significant overall improvement according to the EQ-5D-5L index value and EQ-5D VAS (additional absolute values Table 2). The EQ-5D-5L and EQ-5D VAS change related to the pre-operative score was significant after 6 [EQ-5D-5L: 0.1 ± 0.2 (mean ± SD); $p = 0.0023$; EQ-5D VAS: 15.0 ± 17.8 (mean ± SD); $p = 0.0013$] and 12 months [EQ-5D-5L: 0.2 ± 0.2 (mean ± SD); $p = 0.0015$; EQ-5D VAS: 17.5 ± 19.1 (mean ± SD); $p = 0.0006$] (Table 2).

MR images were evaluated using the MOCART score 6 and 12 months after MACT [18] (Fig. 3). Since a T1-weighted 3D GRE sequence was not available in most of the cases, the variable "signal intensity with gradient-echo T1-weighted" was not included in the analysis; therefore, the maximum MOCART Score was 85 instead of 100. At follow-up, one patient could not be evaluated due to metal wear artefacts, which overlayed the transplant tissue area. In the remaining patients, it was possible to perform an assessment of cartilage quality according to the MOCART score and its subcategories: 12 months post-operatively, the defect filling was complete in 11 of 20 patients and no hypertrophy could be observed in any patient. Sixteen of twenty patients showed a complete integration at the border zone without visible delamination or demarcation between transplant and adjacent cartilage. The surface of the transplant was intact in 14 patients (no fibrillation of repair tissue) and the subchondral bone was also intact in 11 of 20 patients. In 8 patients, an isointense signal between repair tissue and

Table 1 Demographic data and baseline characteristics of study population

Sex	Age (years)	BMI (kg/m^2)	Cartilage defect			
			Defect size (cm^2)	Defect number	ICRS	Defect location (h)
Female (4/21)	32.3 ± 10.0	25.5 ± 3.6	3.0 ± 1.4	1 (19/21)	3 (17/21)	Acetabular 9–12 (15/21) Acetabular 12–3 (14/21)
Male (17/21)				2 (2/21)	4 (4/21)	Acetabular 3–6 (1/21) Femoral anterior cranial (2/21)

Table 2 Outcome evaluation of iHOT 33, EQ-5D-5L and EQ-5D VAS pre-operative, 6 and 12 month follow-up [mean ± standard deviation (SD)]

	Pre-operative		6 Month follow-up		12 Month follow-up	
	Mean	SD	Mean	SD	Mean	SD
iHOT 33	52.9	21.1	75.7	19.7	81.1	22.0
EQ-5D-5L	0.8	0.2	0.9	0.1	0.9	0.1
EQ-5D-5L VAS	67.0	20.1	82.8	13.9	85.3	11.6

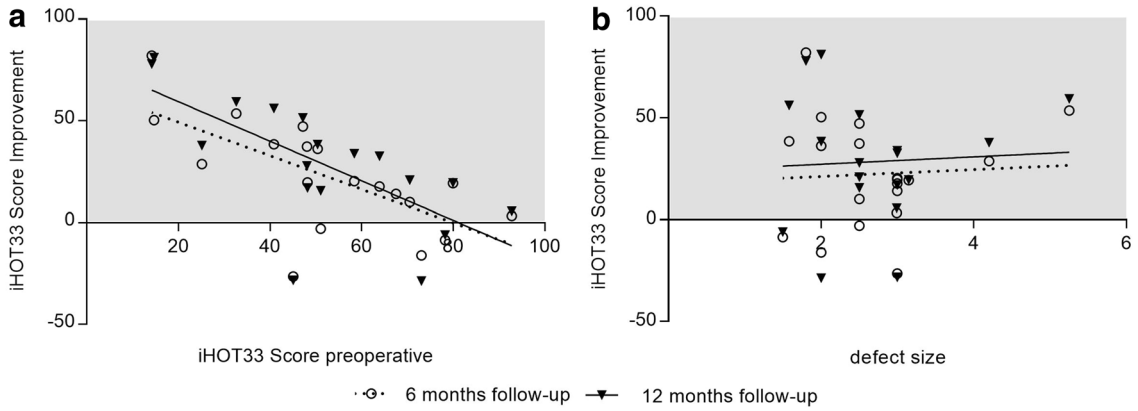

Fig. 2 **a** Change in iHOT33 score in relation to baseline iHOT33 at 6 and 12 month follow-up; **b** change in iHOT33 score in relation to defect size after 6 and 12 months. The grey area indicates an improvement in iHOT33

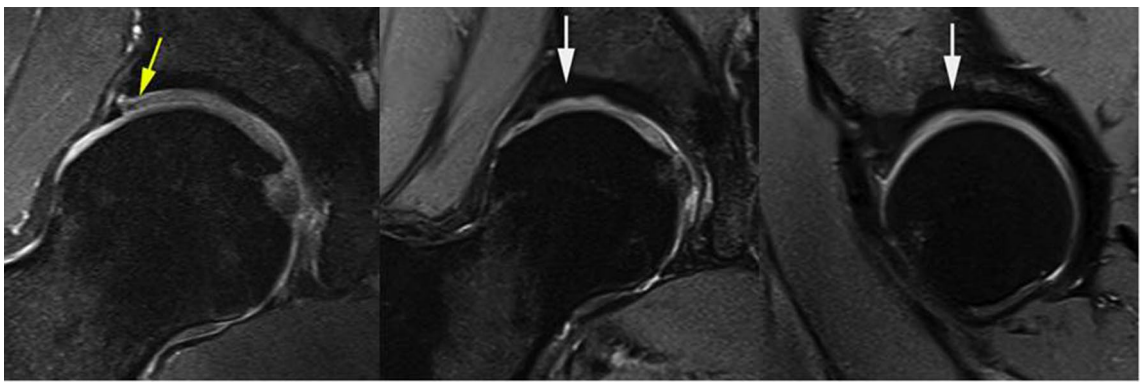

Fig. 3 Proton-density weighted MR images pre-operative (**a**) with cartilage delamination and labrum crack formation as well as post-operative in the coronal (**b**) and sagittal (**c**) planes show a good post-operative outcome with cartilage repair tissue (white arrows) in the acetabular region with a complete filling of the defect, complete integration, and a smooth surface. The signal intensity is slightly different to normal adjacent cartilage

adjacent cartilage on TSE sequence could be observed. The overall MOCART score was 57 ± 14.6 (mean $\pm$ SD) at 6 months and 60.5 ± 16.5 (mean $\pm$ SD) at 12 months follow-up ($p = 0.21$). Regarding the change in MOCART score from 6 to 12 month follow-up, 10 patients showed a significant increase ($p < 0.0001$), and in 5 patients, the score remained unchanged, and in 5 patients, a decrease ($p = 0.06$) of the score could be observed.

Discussion

The most important finding of the present study was a significant improvement in symptoms and functions and an improvement in quality of life associated with complete defect filling in MRI in the majority of patients after injectable MACT in combination with FAI surgery.

Aim of the present study was the evaluation of patient-reported outcome measures after NOVOCART® Inject application and in addition the assessment of transplant quality by MRI investigation. 6 and 12 months after correction of FAI and MACT, the iHOT33, the EQ-5D-5L index value, und EQ-5D VAS improved significantly. A complete defect filling was detected by MRI in the majority of patients. MACT with Novocart Inject and correction of the underlying Cam-type pathogenesis seems regarding pain relief, improvement of hip function, and MRI- based morphological changes to be an effective treatment for full-thickness cartilage defects at the hip.

Type of cartilage defect (increasing size and degree of damage), older age, and pre-operative lower iHOT33 score value were associated with an improvement of patient-related outcome. The literature regarding these facts is controversial. Using injectable spheroids, Fickert et al. confirmed a significant influence of the defect size on the

modified Harris Hip Score (mHHS), whereas the defect size has no significant impact on the functional outcome in the Nonarthritic Hip Score (NAHS) or the physical subscore of the Short Form 36 [8]. Schroeder et al. showed that the defect size did not influence the mHHS or the iHOT33 [23]. In both studies, the defect size was larger than in our investigation (average defect size of 3.5 cm^2 [8] and 5.05 cm^2 [23] respectively). In a further study with a mean defect size of 2.21 cm^2, no relevant influence of the cartilage defect size on the functional outcome in the iHOT33, EQ-5D, and NAHS at 12 and 24 months could be detected [25]. In summary, the influence of the defect size is discussed controversially, not all studies correlate the defect size with post-operative outcome, and due to different outcome scores, a final conclusion is challenging.

Regarding the patient age, Jannelli and Fontana concluded in their review that the best results for MACT or AMIC in the hip have been obtained in patients younger than 50 years [12]. Schroeder et al. constituted no relevant influence of the age on the pre-operative or on the post-operative results in the mHHS and iHOT33 in their study with a mean age of 33 years [23]. In other studies, the association between patient age and clinical outcome have not been assessed [8, 14, 15].

Our observation of a correlation between pre- and post-operative iHOT33 scores has not been reported before. Although the mean values of our study cohort before the operation and at follow-up are similar to the results of Schroeder et al. (iHOT33 pre-operatively 44 points, at 6 months post-operatively 61 points, and at 12 months post-operatively 79 points) [23] as well as Fickert et al. (pre-operatively 50 points and 12 months post-operatively 76 points) [8], they have not evaluated any association. Fontana et al. reported an association between low pre-operative HHS values and unsatisfactory results after arthroscopic autologous chondrocyte transplantation with a bioresorbable two-component gel–polymer scaffold [9].

The quality of repair tissue assessed by MRI was evaluated as one of the first in our study. Using the MOCART Score, the MRI images were evaluated 6 and 12 months post-operatively. The feasibility of MOCART scoring according to MACT on the hip joint has already been described [16]. In the 12 month follow-up, the defect filling was complete in 11 of 20 patients, which is comparable to the described defect-filling rate of 60% reported by Trattnig et al. after MACT in the knee [26]. Complete integration at the border zone without visible delamination or demarcation between transplant and adjacent cartilage in the majority of our patients as well as intact cartilage surface at 12 months post-operatively are promising findings. Due to the short-term follow-up observation as well as a lack of reports from other hip cartilage transplant studies with MRI assessment, our observations must be interpreted with caution. In combination with the observed good clinical results, however, we are optimistic about the morphologic quality and stability of the repair tissue. This is of clinical relevance, since, in addition to the elimination of the mechanical cause, MACT allows the successful therapy of consequential cartilage damage.

In the limited hip joint space, the fixation of conventional MACT products is challenging. The injectable, in situ polymerizable (MACT) product NOVOCART® Inject was developed to overcome this limitation. One of the advantages of the in situ crosslinking albumin/hyaluronan hydrogel is the easy handling in narrow joint space without necessary additional transplant fixation. The feasibility of injectable autologous chondrocyte transplantation for full-thickness cartilage defects could be demonstrated in the initial studies for human autologous spheroids [8, 14, 15, 23] and recently for NOVOCART Inject® as well [24]. Thier et al. even compared the clinical outcome after application of both MACT products in a single-center cohort study of 29 patients and could not detect significant differences [25]. As a possible advantage of NOVOCART® Inject, they mention, however, the remarkable bonding capacity of the in situ polymerizable hydrogel. They did not perform structural evaluation of the repair tissue at follow-up.

Regarding different treatment strategies, the DGOU group "Clinical Tissue Regeneration" and the Hip Committee of the AGA have recently published current treatment recommendations [7]. Additional pathologies, such as CAM and Pincer deformities, should be concomitantly treated thoroughly and advanced osteoarthritis of the hip is a contraindication for any kind of hip-preserving surgery. If cartilage damage is restricted to only a part of the acetabular surface, however, an attempt should be made to repair the defect. According to the published recommendations, full-thickness cartilage defects with a size of more than 1.5–2 cm^2 size should be treated with MACT. Furthermore, according to the recommendations of the DGOU group "Clinical Tissue Regeneration" and the Hip Committee of the AGA, bone marrow-stimulating techniques in combination with a biomaterial covering like Autologous Matrix-Induced Chondrogenesis (AMIC®) should be preferred to standard microfracture, if the patient favored a one-step procedure or there are other reasons against MACT [7]. Jannelli and Fontana, however, recommend AMIC as primary repair alternative even in patients with a defect size larger than 2 cm^2 due to the advantage of a one-step procedure and lower costs [12]. Currently, the database regarding the appropriate treatment of large full-thickness cartilage defects is limited and the evidence for every recommendation is weak. All authors agree, however, that minimal invasive surgical techniques are preferable over open surgery [7–9, 12, 14, 15, 23–25].

We observed two serious adverse events (bacterial arthritis and persistent arthralgia) as well as one non-serious adverse event (superficial wound healing disturbance) during

follow-up, which may be caused by two surgical procedures within a limited time period and, thus, potentially increased the risk of infection. All of them are common post-operative complications in arthroscopic as well as open hip surgery. Therefore, these events were not rated as specific for NOVOCART® Inject treatment. Nevertheless, they were allocated to the MACT (bacterial arthritis and persistent arthralgia) or osteochondral biopsy (superficial wound healing disturbance) in the context of the study. In the systematic review of Nakano et al. including 36,761 arthroscopies of the hip, the overall complication rate was 3.3% and they described a rate of 0.2% infections [21]. Malviya et al. reported a 30-day readmission rate caused by wound-related problems of 0.22% in England after hip arthroscopy [17]. Degen et al. analyzed 8267 procedures of primary hip arthroscopy in 7836 patients from 1998 to 2012. Revision surgery occurred in 1087 cases (13.2%) at a mean of 1.7 ± 1.6 (mean ± SD) years following hip arthroscopy [5].

The following limitations existed in the study design: The number of patients investigated in our protocol ($n = 21$) was rather small and a control group without cartilage repair was not included. Due to the missing control group, a comparison to other operative treatments was not possible. The cohort size, however, was comparable to other feasibility studies which described results for groups of 6–30 patients [8, 9, 14, 23]. In addition, we only included patients with cartilage damage due to FAI and can, therefore, not transfer our results to patients with other disorders. Although the majority of localized cartilage defects in the hip joint with limited size are probably due to FAI, this may display a potential selection bias. The investigation had a rather short follow-up time of 12 months. The value of cartilage repair techniques has to be assessed in the long term and we, therefore, plan an ongoing follow-up. Finally, in all our patients, we performed concomitant corrective surgeries either arthroscopically during first surgery or via limited mini-anterior-open exposure during the second surgery. We were, therefore, not able to distinguish between the effects of these additional corrections and the MACT results. In addition, it was not possible to compare arthroscopic and mini-open application of the chondrocytes, as the patient numbers in both groups were too small. Regardless if arthroscopic or mini-open procedures were preferred, experienced surgeons should perform the complex surgical technique.

Conclusion

Injectable MACT is a promising minimally invasive treatment option for full-thickness cartilage defects of the hip caused by FAI. A significant improvement in symptoms and function associated with an increase in quality of life was detected in patients treated with injectable MACT combined with FAI surgery. A complete defect filling was detected by MRI in the majority of patients. However, further randomized-controlled trials with a larger number of patients, comparison to other treatment options, and a long-term follow-up are needed.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The study was approved according to the local institutional review board (#EK 48022014) and has been registered by ClinicalTrials.gov (NCT02179346).

References

1. Anderson LA, Peters CL, Park BB, Stoddard GJ, Erickson JA, Crim JR (2009) Acetabular cartilage delamination in femoroacetabular impingement. Risk factors and magnetic resonance imaging diagnosis. J Bone Jt Surg Am 91:305–313
2. Benz K, Freudigmann C, Müller J, Wurst H, Albrecht D, Badke A, Gaissmaier C, Mollenhauer J (2010) a polyethylene glycol-crosslinked serum albumin/hyaluronan hydrogel for the cultivation of chondrogenic cell types. Adv Eng Mater 12:B539–B551
3. Bretschneider H, Stiehler M, Hartmann A, Boger E, Osswald C, Mollenhauer J, Gaissmaier C, Günther K-P (2016) Characterization of primary chondrocytes harvested from hips with femoroacetabular impingement. Osteoarthr Cartil 24:1622–1628
4. Brittberg M, Winalski CS (2003) Evaluation of cartilage injuries and repair. J Bone Jt Surg Am 85-A (Suppl 2):58–69
5. Degen RM, Pan TJ, Chang B, Mehta N, Chamberlin PD, Ranawat AS, Nawabi DH, Kelly BT, Lyman S (2017) Risk of failure of primary hip arthroscopy-a population-based study. J Hip Preserv Surg 4:214–223
6. EuroQol Group (1990) EuroQol–a new facility for the measurement of health-related quality of life. Health Policy Amst Neth 16:199–208
7. Fickert S, Aurich M, Albrecht D, Angele P, Büchler L, Dienst M, Erggelet C, Fritz J, Gebhart C, Gollwitzer H, Kindler M, Lampert C, Madry H, Möckel G, Niemeyer P, Schröder J, Sobau C, Spahn G, Zinser W, Landgraeber S (2017) Biologische Rekonstruktion lokalisiert vollschichtiger Knorpelschäden des Hüftgelenks: Empfehlungen der Arbeitsgemeinschaft "Klinische Geweberegeneration" der DGOU und des Hüftkomitees der AGA. Z Für Orthop Unfallchirurgie 155:670–682
8. Fickert S, Schattenberg T, Niks M, Weiss C, Thier S (2014) Feasibility of arthroscopic 3-dimensional, purely autologous chondrocyte transplantation for chondral defects of the hip: a case series. Arch Orthop Trauma Surg 134:971–978
9. Fontana A, Bistolfi A, Crova M, Rosso F, Massazza G (2012) Arthroscopic treatment of hip chondral defects: autologous chondrocyte transplantation versus simple debridement—a pilot study. Arthroscopy 28:322–329
10. Ganz R, Leunig M, Leunig-Ganz K, Harris WH (2008) The etiology of osteoarthritis of the hip: an integrated mechanical concept. Clin Orthop Relat Res 466:264–272

11. Ganz R, Parvizi J, Beck M, Leunig M, Nötzli H, Siebenrock KA (2003) Femoroacetabular impingement: a cause for osteoarthritis of the hip. Clin Orthop Relat Res 417:112–120
12. Jannelli E, Fontana A (2017) Arthroscopic treatment of chondral defects in the hip: AMIC, MACI, microfragmented adipose tissue transplantation (MATT) and other options. SICOT-J 3:43
13. Jordan MA, Van Thiel GS, Chahal J, Nho SJ (2012) Operative treatment of chondral defects in the hip joint: a systematic review. Curr Rev Musculoskelet Med 5:244–253
14. Körsmeier K, Claßen T, Kamminga M, Rekowski J, Jäger M, Landgraeber S (2016) Arthroscopic three-dimensional autologous chondrocyte transplantation using spheroids for the treatment of full-thickness cartilage defects of the hip joint. Knee Surg Sports Traumatol Arthrosc 24:2032–2037
15. Krueger DR, Karczewski D, Ballhausen M, Geßlein M, Schütz M, Perka C, Schroeder JH (2017) Is a minimal invasive autologous chondrocyte implantation (ACI) in the hip possible? A feasibility and safety study of arthroscopic treatment of full thickness acetabular cartilage defects with an injectable ACI. Sci Pages Orthop Surg 1(1):1–6
16. Lazik A, Körsmeier K, Claßen T, Jäger M, Kamminga M, Kraff O, Lauenstein TC, Theysohn JM, Landgraeber S (2015) 3 T high-resolution and delayed gadolinium enhanced MR imaging of cartilage (dGEMRIC) after autologous chondrocyte transplantation in the hip. J Magn Reson Imaging JMRI 42:624–633
17. Malviya A, Raza A, Jameson S, James P, Reed MR, Partington PF (2015) Complications and survival analyses of hip arthroscopies performed in the national health service in England: a review of 6,395 cases. Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc 31:836–842
18. Marlovits S, Singer P, Zeller P, Mandl I, Haller J, Trattnig S (2006) Magnetic resonance observation of cartilage repair tissue (MOCART) for the evaluation of autologous chondrocyte transplantation: determination of interobserver variability and correlation to clinical outcome after 2 years. Eur J Radiol 57:16–23
19. Meyer DC, Beck M, Ellis T, Ganz R, Leunig M (2006) Comparison of six radiographic projections to assess femoral head/neck asphericity. Clin Orthop Relat Res 445:181–185
20. Mohtadi NGH, Griffin DR, Pedersen ME, Chan D, Safran MR, Parsons N, Sekiya JK, Kelly BT, Werle JR, Leunig M, McCarthy JC, Martin HD, Byrd JWT, Philippon MJ, Martin RL, Guanche CA, Clohisy JC, Sampson TG, Kocher MS, Larson CM, Multicenter Arthroscopy of the Hip Outcomes Research Network (2012) The Development and validation of a self-administered quality-of-life outcome measure for young, active patients with symptomatic hip disease: the International Hip Outcome Tool (iHOT-33). Arthroscopy 28:595–605 (**quiz 606–610.e1**)
21. Nakano N, Lisenda L, Jones TL, Loveday DT, Khanduja V (2017) Complications following arthroscopic surgery of the hip: a systematic review of 36 761 cases. Bone Jt J 99-B:1577–1583
22. Scholz B, Kinzelmann C, Benz K, Mollenhauer J, Wurst H, Schlosshauer B (2010) Suppression of adverse angiogenesis in an albumin-based hydrogel for articular cartilage and intervertebral disc regeneration. Eur Cell Mater 20:24–36 (**discussion 36–37**)
23. Schroeder JH, Hufeland M, Schütz M, Haas NP, Perka C, Krueger DR (2016) Injectable autologous chondrocyte transplantation for full thickness acetabular cartilage defects: early clinical results. Arch Orthop Trauma Surg 136:1445–1451
24. Thier S, Baumann F, Weiss C, Fickert S (2018) Feasibility of arthroscopic autologous chondrocyte implantation in the hip using an injectable hydrogel. Hip Int 28(4):442–449. https://doi.org/10.5301/hipint.5000580
25. Thier S, Weiss C, Fickert S (2017) Arthroscopic autologous chondrocyte implantation in the hip for the treatment of full-thickness cartilage defects - A case series of 29 patients and review of the literature. SICOT-J 3:72
26. Trattnig S, Ba-Ssalamah A, Pinker K, Plank C, Vecsei V, Marlovits S (2005) Matrix-based autologous chondrocyte implantation for cartilage repair: noninvasive monitoring by high-resolution magnetic resonance imaging. Magn Reson Imaging 23:779–787