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ORIGINAL PAPER

The augment-and-modular-cage revision system for reconstruction of severe acetabular defects—two-year clinical and radiographic results

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Abstract

Purpose Acetabular revision of failed total hip arthroplasty (THA) is often associated with severe bone loss. Therefore, a variety of revision implant systems has been developed during recent years, with the augment-and-modular-cage system being one of the newest additions to this portfolio. Together with biologic downsizing by means of impaction bone grafting, this uncemented system promises a high modularity and versatility to treat all acetabular defects up to Paprosky types IIIa and IIIb without pelvic discontinuity. The aim of the present study was to evaluate first short-term results of its clinical application, both clinical functional and patient-reported as well as radiographic.

Methods Forty-four patients (28 female, 16 male, mean age 70.9 ± 11.5 years) could be followed for a mean of 26 ± 10 months after acetabular revision with a novel augment-and-modular-cage system. Indications for revision included aseptic loosening (68%), septic loosening (16%), or others (16%) with bone loss Paprosky IIa up to IIIb without discontinuity. The modified Harris Hip Score (mHHS) served as a primary outcome parameter. In addition, a number of patient-reported outcome measurements (PROMs) were collected including the Short Form 36 (SF-36), Hip disability and Osteoarthritis Outcome Score (HOOS), and Visual Analogue Scale for Hip Pain (VAS Hip) as well as overall satisfaction. Radiographic changes between the pre- and postoperative center of rotation (COR) and various criteria of implant failure served as secondary outcome parameters.

Results No patients were lost to follow-up. Two implant-associated complications (partial flange breakage) without a need for revision surgery were detected, which represent a failure rate of 4.5%. Functional outcome as measured by mHHS increased from 49.4 ± 2.9 pre-operatively to 74.4 ± 3.1 at the latest follow-up ($p < 0.001$). PROMs showed significant improvements in all pain-related categories, while other quality-of-life measurements only exhibited positive tendencies towards improvement. VAS Hip significantly improved from 6.5 ± 0.7 pre-operatively to 2.2 ± 0.6 at the latest follow-up ($p < 0.001$). Radiographic evaluation showed that reconstruction of the COR was possible, referenced to the contralateral side. The COR could be lateralized by 5.0 mm (n.s.) and caudalized by 10.3 mm ($p < 0.001$) comparing pre-operative and post-operative states, with complete osseointegration in 95% of the cases.

Conclusions Treatment with the augment-and-modular-cage system significantly improved clinical functional and patient-reported outcomes in cases of acetabular revision after failed THA. In addition, a good reconstruction of the COR could also be achieved. Therefore, this highly modular system can be considered as an effective treatment option in almost all cases of acetabular bone loss except for those of pelvic discontinuity. It offers the unique possibility of intra-operative implant customization according to the existing bone defect and host bone quality.

Philip P. Roessler, Max Jaenisch, Sascha Gravius and Dieter C. Wirtz contributed equally to this work.

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Keywords Hip · Acetabulum · Acetabular revision surgery · Modular cup arthroplasty · Augment-and-modular-cage · Uncemented fixation

Introduction

Case numbers of revision surgery following total hip arthroplasty (THA) are increasing worldwide, as indicated by several national registries. Due to an increased population aging, revision rates of up to 12% after ten years are to be expected in the near future [1]. Various special implants and systems have been developed in the past decades to counteract the problems that arise in these cases. Severe bone loss around the acetabulum or at the proximal femur is considered as the most severe problem, since it may hinder proper anchoring of any revision implant [2]. Therefore, major aims of every acetabular revision procedure are reconstruction of these bony defects to enable a primarily stable implant fixation and, wherever possible, a reconstruction of the center of rotation (COR). Traditionally, acetabular defects have either been treated with bone allografts [3] or specially designed cages with or without additional reinforcement rings to achieve these goals [4]. While bone grafting gradually moved from bulk grafts towards a technique of impaction bone grafting [5], more recent developments in implant designs focused on a high modularity with the addition of macroporous metal augments [6]. As bulk grafts have demonstrated a very low overall osseointegration potential and thus failed long-term mechanical stability in various studies, metallic augments have been introduced for craniolateral rim defects. In contrast, cancellous bone chips have been shown to adequately and biologically reconstruct bottom and craniomedial bone stock defects, if impacted thoroughly. This adaption of the so-called Exeter technique for the acetabulum has been demonstrated to be a prerequisite for proper remodeling into stable and viable bone together with mechanical induction over safely fixed antiprotrusion cages. The addition of metal augments, if properly fixed to the cage system, has been shown to reduce implant micromotion and thus premature loosening [7].

Newer concepts chose to combine the methods of biologic downsizing by impaction bone grafting with modern modular implant systems to formulate treatment algorithms adapted to the acetabular defect situation and tailored to the patient's needs [8, 9]. Another of these combinations has only recently been popularized as the cage-and-augment principle [10]. In the present study, an advancement of this principle towards an even higher modularity with the addition of multiple degrees of freedom to adjust cup orientation without a need for cementation will be presented. However, implant systems have been developed further ever since and today not only offer sufficient means of defect filling and fixation with a cage, but also a high modularity regarding the reconstruction of individual hip anatomy by multiply adjustable cup components.

The aim of the present study was to evaluate the clinical and radiographic outcomes of the novel augment-and-modular-cage system in the treatment of severe acetabular defects. It was hypothesized that application of this modular implant system could (1) restore the COR as referenced to the contralateral side and thus (2) lead to a significant improvement in functional outcome and pain comparable to that reported in the present literature.

Methods

Study design and patients

This single-center, retrospective cohort study is based on prospectively collected data of patients that underwent acetabular revision with the uncemented augment-and-modular-cage system MRS-TITAN Comfort (MRS-C, Peter Brehm GmbH, Weisendorf, Germany). Data collection was initiated alongside the market launch of the implant system in

Table 1 Patient demographics

Item	Value
Age (year)	70.9 ± 11.5 (range 45–86)
Body mass index (kg/m^2)	27.9 ± 5.6 (range 19.5–46.6)
Sex (no.)	
Male	16 (36%)
Female	28 (64%)
Side (no.)	
Right	24 (55%)
Left	20 (45%)
CCI	
0	13 (30%)
1	7 (16%)
2	7 (16%)
3	9 (20%)
> 4	8 (18%)
ASA	
1	7 (16%)
2	24 (55%)
3	13 (29%)
Charnley Prefix	
A	21 (48%)
B	16 (36%)
C	7 (16%)

preparation of a randomized controlled trial which shall succeed the present cohort. Forty-four consecutive patients who were operated between October 2013 and December 2016 were included in the present study. Inclusion criteria were cases of hip revision with acetabular defects Paprosky type II and higher. Defects Paprosky type IIIa with near complete excavation of the dorsal acetabular rim as well as Paprosky type IIIb with pelvic discontinuity were excluded. Pre-operatively, all patients were graded according to the Charlson Comorbidity Index (CCI) [11], American Society of Anaesthesiologists (ASA) classification, and Charnley Prefix [12]. Demographic patient characteristics are reported in Table 1. Leading concomitant diseases were hypertension ($n = 22$), coronary heart disease ($n = 7$), and type 2 diabetes ($n = 4$).

Implant

The augment-and-modular-cage system MRS-C has been CE-marked in 2014 and combines the principles of recent acetabular antiprotrusion cages (Ganz [4], Burch-Schneider [13, 14]) with a variety of metal buttress augments.

The main component of the MRS-C is a spheric reinforcement cage composed out of pure titanium (Ti) that comes with or without additional cranial flanges in different lengths. Its central outlet allows for bone grafting, even if the cage is already in place, and can be closed with a special lid. Ring fixation screws are polyaxial while flange screws also have an additional locking mechanism. The back of the cage is coated in a Ti vacuum plasma spraying (Ti-VPS) fashion with Rz 170 ± 25 to achieve optimal osseointegration.

Inclination/anteversion of the modular cup component is adjustable in over six different positions (Fig. 1) and has inserts in both ultrahigh molecular weight polyethylene (UHMWPE) and BIOLOX® delta ceramic (CeramTec GmbH, Plochingen, Germany), which also enables the use of a ceramic-on-ceramic (CoC) bearing. PE inserts also come in a 20° elevated rim fashion even allowing for a total of 40° inclination/anteversion in combination with the modular cup. CoC bearings on the other hand can be used after previous ceramic failures, in cases of cement allergies or just because they enable the use of larger ball head sizes relative to the cup size (e.g., 36 mm ceramic ball head starting from 56 mm ceramic liners upwards), which provides a preferential tribology compared to the often limited options that come with UHMWPE liners [15]. Macroporous Ti buttress augments come in four different sizes for each of the three ring positions (A: craniolateral, B: craniodorsal, C: cranio-laterodorsal) allowing multiple geometric variations to achieve optimal formfit within the bony defects (Fig. 2).

Fig. 1 Inclination/anteversion of the MRS-C modular cup component is adjustable in over six different positions (courtesy of Peter Brehm GmbH, Weisendorf, Germany)

Surgery

Implantation of the MRS-C as well as surgical pitfalls have been described in detail recently [16]. Briefly, defect dimensions have to be evaluated prior to implantation and graded according to Paprosky [17]. It is important to understand the indications and limitations of the implant. All defects graded Paprosky I and II can be addressed by the use of different variants and augments. Defects graded Paprosky III, however, need to be evaluated further. In situations Paprosky IIIa with sufficient bone stock at the dorsal acetabular rim, the augment-and-modular-cage system can be used, whereas in cases of near complete excavation of the dorsal acetabular rim it does not provide sufficient stability and other means of treatment (e.g., cups with additional cranial peg) are needed [18]. In situations Paprosky IIIb, representing pelvic discontinuity, the augment-and-modular-cage system cannot be used at all. Here, additional means of fixation (e.g., fracture plating) or individualized partial pelvic replacement should be considered [19]. Most commonly, revision with MRS-C follows either aseptic loosening of a previous implant, two-staged explantation and consolidation of a situation after septic loosening, or other indications such as material failure or structural problems (e.g., hip dysplasia, persistent dislocations).

Procedures were performed through a lateral, transgluteal approach ($n = 43$) or a posterior approach ($n = 1$) by extending the pre-existing approaches in each case. In cases of aseptic loosening, implant removal was performed as required by the manufacturer. Cases of septic loosening were treated according to a two-staged protocol described earlier [9], and before implantation of an augment-and-modular-cage system, infections were consolidated and no signs of inflammation were present. In all cases, thorough intra-operative debridement was performed prior to selection of the final augment-and-modular-cage construction. Dimensions of the so prepared defects were measured with special template implants,

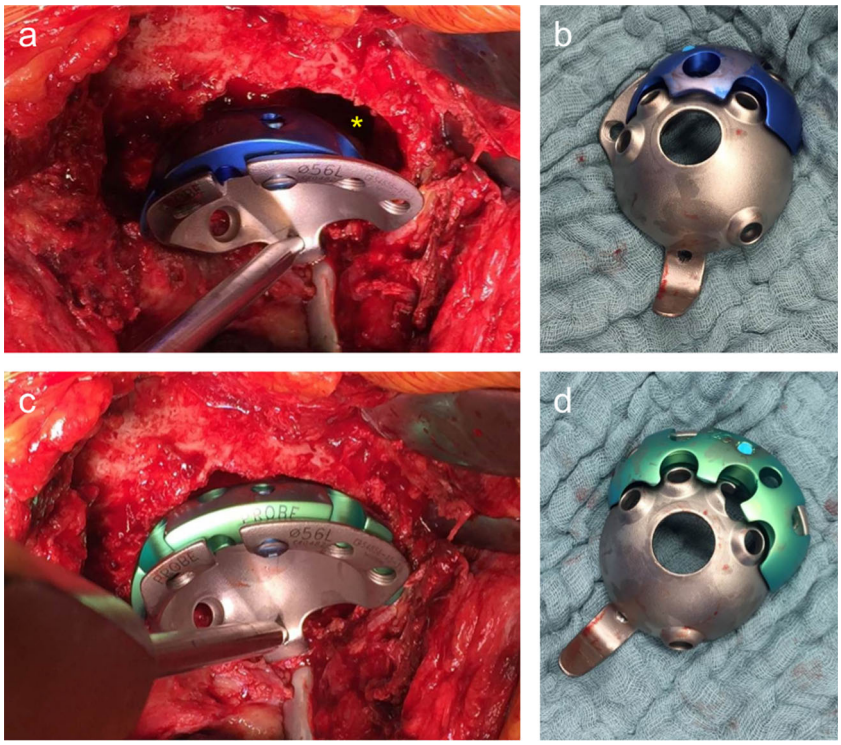

Fig. 2 Additional macroporous Ti buttress augments for the MRS-C come in four different sizes (**a** craniolateral, **b** craniodorsal, **c** craniolaterodorsal) allowing multiple geometric variations to achieve optimal formfit within the bony defects. **a**–**b** In case of a craniolateral and craniodorsal acetabular defect, a type A augment (blue) does not suffice to fill the gap (asterisk). **c**–**d** After fitting a type C augment (high modularity allows for intraoperative customization), the whole defect can be filled in a proper manner and the cage can be fixed without micromotion

because pre-operatively planned sizes and final defect dimensions might differ significantly. Optional impaction bone grafting was performed in a majority of cases ($n = 33$) to achieve biological downsizing of the defect and improve the implant contact area. Modular components were selected depending on the individual defect situation. In cases where impaction bone grafting alone does not provide sufficient defect filling, optional augments were added to the cage construct. Foremost, this applies to defects in load-bearing areas (e.g., cranial and/or dorsal) and segmental defects. Cavitary defects in non-load-bearing areas (e.g., medial and/or craniomedial) where filled in impaction grafting technique. Under all circumstances, a press-fit situation of the cage to the craniolateral and the dorsal acetabular rim had to be ensured to avoid premature loosening. The caudal hook was carefully introduced in the obturator foramen and then spiked into the bony acetabular rim. Polyaxial screws were added in mandatory and optional locations to secure the cage to the pelvic bones. Finally, the proper cup was selected, and its anteversion/inclination freely adjusted to recreate individual anatomy. Depending on indication and previous situation, UHMWPE or ceramic inserts were used to complete the operation.

Clinical evaluation and complication assessment

All patients were clinically assessed pre-operatively (baseline) and postoperatively at the latest available follow-up. For objective evaluation, the modified Harris Hip Score (mHHS) [20] was obtained and considered as the primary outcome parameter. In addition, patient-reported outcome measurements (PROMs) like Short Form 36 (SF-36) [21], Hip disability and Osteoarthritis Outcome Score (HOOS) [22] as well as Visual Analogue Scale for Hip Pain (VAS Hip) [23] were recorded at baseline and the latest follow-up.

Peri- and post-operative complications were recorded from the patient management database and either defined as general or implant-associated. All implant-associated complications—even if left unrevised—as well as radiographic signs of migration were defined as implant failure, which served as a secondary outcome parameter as described in the following paragraph.

Radiographic evaluation

Plain radiographs (pelvis a.p. standing and involved hip axial according to Lauenstein) were assessed pre-operatively and at the latest post-operative follow-up. Evaluations were performed in pelvis a.p. standing radiographs with IMPAX EE (Agfa HealthCare GmbH, Bonn, Germany) to assess osseointegration or the occurrence of radiolucent lines per DeLee zones [24], periarticular ossifications (PAOs) according to Brooker [25], and a reconstruction of the hip COR as described in detail in Fig. 3. Radiographic changes of the COR comparing the pre-operative (Pre-op) to the post-operative (Post-op) state served as secondary outcome parameter in this study. In addition, the anatomic contralateral ($Anat_{CL}$) COR was measured and compared to the results.

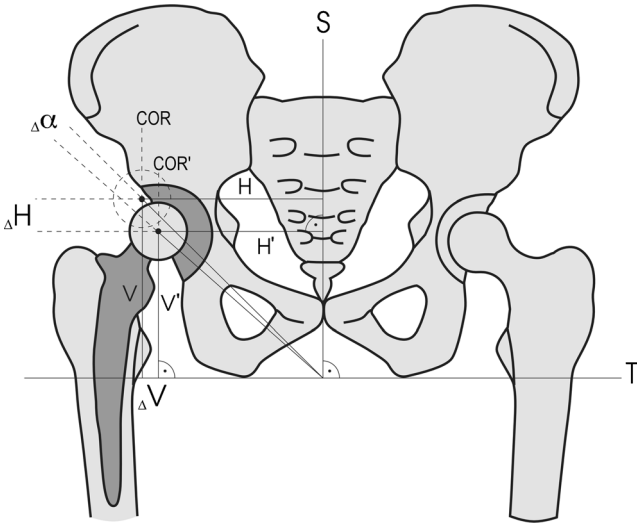

Fig. 3 Schematic illustration of radiographic measurements to determine the hip center of rotation (COR). Mid-sagittal line (S) and a tangent of both ischial tuberosities (T) hereby define the *y*- and *x*-axis, while the center of the femoral ballhead determined the COR. H (H′) represents the horizontal distance from S to COR, whereas V (V′) represents the vertical distance from T to COR. Alpha represents an angle between T and a line originating from its intersection with S through the COR. It is 45° if H (H′) and V (V′) have the same length. Depending on measurements of H (H′) and V (V′), alpha decreases or increases, respectively, indicating a shift of the COR. In direct comparison of two radiographs, $\Delta H = H - H'$ and $\Delta V = V - V'$ define the movement of the COR in the horizontal and vertical planes. Depending on the results of this equation, cranialization/caudalization or lateralization/medialization with respect to the referenced state could be located on the grid

Implant failure was defined by either an increasing inclination (> 5°), an increasing distance to the previous (anatomical) COR (> 4 mm), screw/material failure, or a combination of these factors according to Bonnomet [26].

Osseointegration of the cage was defined as either a complete absence of radiolucent lines in the implant-to-bone interface or radiolucent lines < 2 mm as long as they proved stable during follow-up. All cases with progressive radiolucent lines > 2 mm over time regardless of the DeLee zone were considered as failed osseointegration. Radiolucent lines in the graft-to-host-bone interface were classified by bone resorption relative to the size of the grafted area. Bone resorption of > 25% was considered as failed impaction bone grafting.

Statistical analysis

All analyses were performed using Graph Pad Prism 7 (Graph Pad Inc., La Jolla, CA, USA). Data are given as means ± standard deviation (SD) and ranges if not indicated otherwise. The level of significance was set at $p < 0.05$.

For simple comparisons between means (clinical outcome parameters), an unpaired two-tailed *t* test was performed. For multiple comparisons between means (radiographic outcome parameters), a one-way ANOVA with Tukey's correction was performed. Moreover, an a priori power analysis based upon the short-term results of the previous generation of this implant [9] was conducted using a two-tailed *t* test for dependent samples with a significance level of $p = 0.05$. A power or 98% for detecting significant differences between baseline and follow-up for the proposed primary outcome parameter could already be reached starting from a sample size as low as $n = 4$.

Results

Clinical outcome and complications

Mean follow-up time was 26 ± ten months (range 12–52). No patient was lost to follow-up. Indications and defect classification are depicted in Table 2. Mean surgical time was 214 ± 68 minutes (range 124–477) for acetabular revisions only and 247 ± 61 min (range 134–354) for complete THA revisions, while mean hospitalization in acute care was 19 ± 14 days (range 6–82). All patients participated in an inpatient rehabilitation program following this period.

Objective primary outcome as measured by mHHS is reported in Table 3. Additional subjective outcome as reported by various PROMs is reported in Table 4. Interestingly, pain is significantly improved between baseline and latest follow-up on all tested scales, whereas quality-of-life measurements like the SF-36 subscale or HOOS subscale QoL only show insignificant changes.

The only recorded peri-operative complication was a situation of hemorrhagic shock due to iatrogenic injury of the A. gluteus medius during flange preparation followed by successful cardiopulmonary reanimation, transfusion, and vascular surgical repair ($n = 1$; 2%). The patient was monitored on the ICU thereafter and was otherwise well without any late effects. Post-operative general complications included transitory neurologic symptoms (e.g., femoralgia or sciatic nerve palsy due to renewed leg lengthening following previous Girdlestone situations) ($n = 4$), recurrent instability ($n = 3$; 7%), and subfascial haematoma ($n = 2$; 5%). In the five last cases, surgical re-revision with either haematoma evacuation ($n = 2$; 5%) or an exchange of mobile parts together with an offset increase ($n = 3$; 7%) was required. This equals a re-revision rate of 11%. The only recorded implant-associated complication was partial flange breakage ($n = 2$; 5%) without a need for revision surgery, which represents a failure rate of 4.5%.

Radiographic outcome

Radiographic secondary outcome parameters are depicted in Table 5. No significant changes to the COR could be

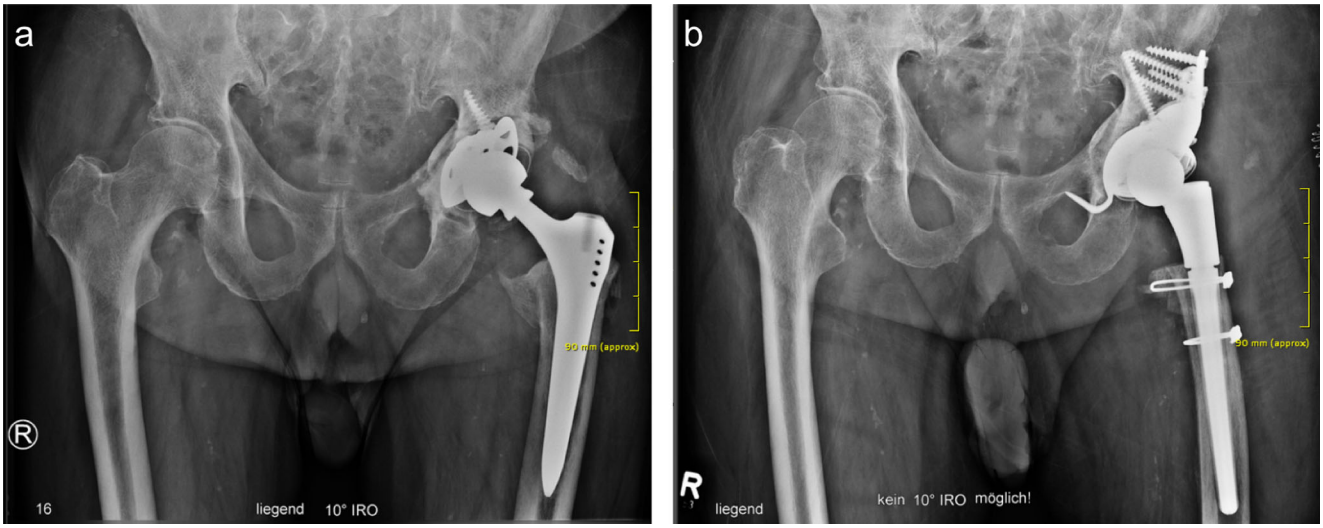

Fig. 4 Radiographic case study of a 78-year-old male patient after two-staged THA revision. For acetabular reconstruction, a 56-mm triflanged MRS-C with a 32-mm ceramic liner and an additional type A-14 mm buttress augment with impaction bone grafting were used in this craniolateral defect (Paprosky IIIa) after septic loosening of the previous cage. Upon explantation of the previous components, a Girdlestone procedure was performed and anti-infective treatment carried out until consolidation of the situation which was proven by tissue sampling prior to revision. **a** Initial situation of septic loosening, pelvis a.p. standing. **b** Post-operative situation after two-staged revision, pelvis a.p. standing

noted in the horizontal direction. In the vertical direction, there was a significant difference between the pre-operative and anatomical COR as referenced to the contralateral side, indicating severe cranialization ($p < 0.001$). This pre-operative state could be reconstructed to a near anatomic condition by significant caudalization as shown by the latest post-operative ($p < 0.001$) follow-ups. Delta alpha, indicating a shift of the COR, changed accordingly in all comparisons (Figs. 4 and 5).

Complete osseointegration of the MRS-C in the implant-to-bone interface could be noted as follows: DeLee zone I ($n = 43$; 98%), DeLee zone II ($n = 42$; 95%), and DeLee zone III ($n = 44$; 100%). Radiolucent lines > 2 mm were detectable in a total of two cases and distributed as follows: DeLee zone I ($n = 1$; 2%), DeLee zone II ($n = 2$; 4.5%), and DeLee zone III ($n = 2$; 4.5%).

Bone resorption < 25% of the impaction bone graft was noted as follows: DeLee zone I ($n = 3$; 7%), DeLee zone II ($n = 3$; 7%), and DeLee zone III ($n = 5$; 11%). No bone resorption > 25% could be noted and thus there was no failed impaction bone grafting. The overall incidence of PAOs was reduced from 25% pre-operatively to 18% at the latest follow-up, with six cases classified as Brooker I and two cases as Brooker II.

Table 2 Operative patient characteristics

Item	Value
Indication for revision (no.)	
Aseptic loosening	30 (68%)
Septic loosening	7 (16%)
Other	7 (16%)
Type of surgery (no.)	
Acetabular revision	28 (64%)
THA revision	16 (36%)
Paprosky Type (no.)	
IIa	6 (14%)
IIb	7 (16%)
IIc	8 (18%)
IIIa	11 (25%)
IIIb	12 (27%)

Table 3 Modified Harris Hip Score (mHHS)

Measure	Pre-op	Post-op	Sig (p)
Pain	18.6 ± 1.5	35.0 ± 1.7	< 0.001
Function: gait			
Limp	5.9 ± 0.6	6.9 ± 0.6	n.s.
Support	4.7 ± 0.6	6.2 ± 0.6	n.s.
Distance	4.7 ± 0.5	7.5 ± 0.5	< 0.001
Functional activities			
Stairs	1.4 ± 0.2	1.9 ± 0.2	0.03
Socks/shoes	2.3 ± 0.2	3.0 ± 0.2	0.007
Sitting	3.1 ± 0.3	4.4 ± 0.2	< 0.001
Public transportation	0.6 ± 0.1	0.8 ± 0.1	n.s.
Deformity	3.6 ± 0.2	4.0 ± 0.0	0.03
Motion	4.5 ± 0.1	4.8 ± 0.1	< 0.001
Total	*49.4 ± 2.9*	*74.4 ± 3.1*	*< 0.001*

Table 4 Patient-reported outcome measurements (PROMs)

Measure	Pre-op	Post-op	Sig (*p*)
SF-36			
Physical functioning	34.0 ± 7.4	39.3 ± 6.7	n.s.
Role-physical	19.0 ± 8.8	40.9 ± 9.7	n.s.
Bodily pain	30.5 ± 6.8	62.8 ± 6.6	0.001
General health	48.8 ± 5.3	56.4 ± 4.5	n.s.
Vitality	43.3 ± 4.8	56.4 ± 4.9	n.s.
Social functioning	62.5 ± 7.0	73.9 ± 6.7	n.s.
Role-emotional	54.0 ± 10.9	62.1 ± 9.1	n.s.
Mental health	61.9 ± 4.7	69.1 ± 4.9	n.s.
HOOS			
Pain	53.3 ± 6.8	70.7 ± 4.5	0.04
Symptom	46.8 ± 7.5	74.8 ± 5.9	0.005
ADL	43.4 ± 7.6	64.4 ± 5.6	0.03
Sport/Rec	32.4 ± 8.8	36.7 ± 7.6	n.s.
QoL	35.7 ± 7.3	42.2 ± 6.3	n.s.
Overall satisfaction			
Pain	2.4 ± 0.7	7.3 ± 0.8	< 0.001
Function	2.5 ± 0.7	6.0 ± 0.8	0.003
VAS Hip	6.5 ± 0.7	2.2 ± 0.6	< 0.001

Discussion

The most important finding of the present study is that a significant improvement in function and pain as measured by mHHS, and various PROMs could be achieved in cases of acetabular revision with a novel augment-and-modular-cage system over a short-term follow-up.

Secondly, radiographic evaluation indicated that reconstruction of a near anatomical COR was possible and could be maintained throughout the follow-up period. Therefore, our two previously stated hypotheses could be accepted.

In the present study, the overall mHHS was improved from very poor to fair results ($p < 0.001$). Subgroup analysis revealed that there were no significant differences in functional outcomes between acetabular revisions only (71.5 ± 4.2) and complete THA revisions (78.3 ± 4.36). Although only fair mHHS scores could be reached in most of the patients, the results are perfectly comparable to those of other revision implants that generally do not reach values of primary THA [9, 27]. Various studies have been published reporting clinical results of comparable cup and cage constructs or reinforcement rings. Friedrich et al. reported a short-term follow-up of a cage construct without flanges in cases of acetabular revision with severe bone loss. An improvement of mHHS from a mean 44.7 pre-operatively to 82.2 points at the latest follow-up was recorded. Osseointegration rates of up to 91% could be achieved, as well as a maintained COR. Only 9% of cases showed positive migration criteria at the latest follow-up [28]. Marx et al. obtained comparable results for the classic Burch-Schneider antiprotrusion ring in a 20-year long-term follow-up. Here, the mHHS improved from a mean 39.9 pre-operatively to 73.6 at the latest follow-up. Pain levels were considerably reduced and—like in the present study—patients reported a good to excellent overall satisfaction with the surgical results. Re-revision rates were comparable with around 7% [13]. Ilyas et al. reported a seven year mid-term follow-up of the classic Burch-Schneider reinforcement ring. Here, revision rates were 12%, which is comparable to the present study [14]. Fink et al. reported short-term results for the new Burch-Schneider reinforcement ring, which is basically a cage construct with anatomical flanges. An improvement of mHHS from a mean 46.6 pre-operatively to 75.9 points at the latest follow-up was recorded, which is in line with all other reported studies as well as the present data. The complication profile reported matches those of the present study, with mainly transitory neurological or instability issues [29].

Regarding PROMs, there is not as much data in the present literature as there is for multiply validated and relatively old classification systems as the HHS. Mahmoud et al. reported comparable results for the pre- and post-operative HOOS over a period of five years in a case series comprised of various cup-cage constructs with an addition of metal augments [30]. Schmolders et al. also reported the strongest significant improvement of the HOOS subcategory pain from 33.3 preoperatively to 87.7 at the latest follow-up; however, that study cohort was a primary setting in patients younger than 50 years [31].

Generally, THA revision surgery is only beginning to see an increased application of patient-reported outcomes at the

Table 5 Comparison of radiographic centers of rotation (COR)

	H (mm)		*V* (mm)		Alpha (°)	
Measures	Δ Means	Sig (*p*)	Δ Means	Sig (*p*)	Δ Means	Sig (*p*)
$Anat_{CL}$ vs. Pre-op	− 0.1	n.s.	− 14.2	< 0.001	− 5.4	< 0.001
$Anat_{CL}$ vs. Post-op	− 5.1	n.s.	− 3.9	n.s.	0.0	n.s.
Pre-op vs. Post-op	− 5.0	n.s.	10.3	< 0.001	5.4	< 0.001

H horizontal distance to mid-sagittal line, *V* vertical distance to tangent of ischial tuberosities, *Alpha* COR angle, *CL* contralateral side

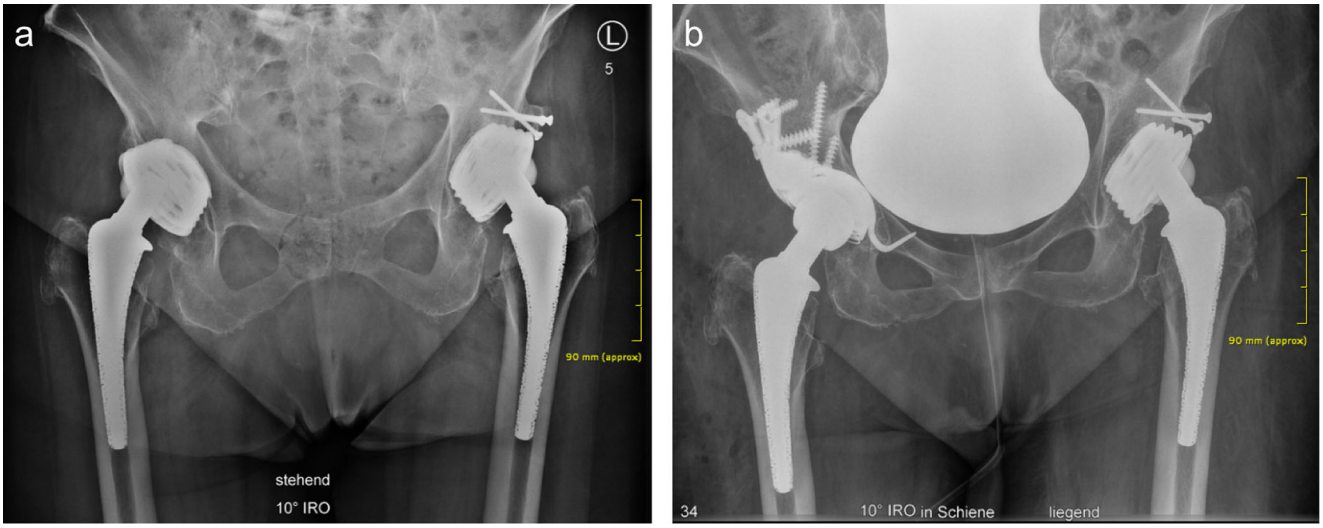

Fig. 5 Radiographic case study of an 80-year-old female patient after acetabular revision. For acetabular reconstruction, a 52-mm triflanged MRS-C with a 32-mm ceramic liner and an additional type A-24 mm buttress augment with impaction bone grafting were used in this craniolateral defect (Paprosky IIIa) following aseptic loosening and polyethylene granuloma. **a** Pre-operative situation, pelvis a.p. standing. **b** Post-operative situation, pelvis a.p. standing

moment. As for the SF-36, significant improvements could be noted in the physical subcategory, mainly because of a reduction in bodily pain, from 33 points pre-operatively to 39 points at the latest follow-up for cases of acetabular revision with porous cups. No significant improvement could be noted in the mental subcategory, which is in line with the present study [32]. The same could be shown for a mid-term follow-up of porous trabecular metal augments in combination with impaction bone grafting. Patient overall satisfaction and improvement of pain levels also were in line with the present study [33]. The HHS is a questionnaire designed and validated for the use in THA. The question remains if PROMs like especially the SF-36, which was designed for a much broader use in multiple settings, sufficiently covers the mental issues related to hip revision surgery. Validation studies show that there is a strong correlation between HHS and the physical subcategory of the SF-36, but hardly any correlation of HHS and the mental subcategory, which is perfectly in line with the present findings [34].

Primary stability of the cage construct has been recognized as one essential aspect of all of these comparable clinical outcomes. Particular attention has to be paid to a proper fixation of the caudal flange to the ischium, either by screws or by spiking with an osteotome [35]. Gerber et al. demonstrated that insufficient cage fixation significantly increased the risk of failure over a long-term follow-up period [36]. Besides implant-associated complications like screw breakage, multiple conditions have to be met to classify migration of a cage and thus treatment failure as described by Bonnomet [26]. Inclination could not be assessed reliably in the present study due to the highly modular nature of the implant. Regarding the other two factors, as well as our definition of failed osseointegration, two patients had to be considered as treatment failures overall—both with implant-associated failures (partial flange breakage) and subsequent missed osseointegration. Controversially, those two patients showed good clinical functional results at the latest follow-up, as well as reduced pain levels as compared to the baseline and thus were not considered for re-revision yet. All other implants had to be considered as stable, based on the clinical functional results, reduced pain levels, and a lack of Bonnomet migration criteria. Radiolucent lines presented themselves constantly during the follow-up and were therefore correlated with partial bone graft resorption. In accordance, 23% of patients reported by Marx et al. exhibited radiolucent lines in at least one DeLee zone around the implant and 10% of patients also showed an increased vertical implant migration that did, however, not correlate with clinical functional outcome or overall satisfaction [13]. The present study has some limitations that need to be discussed. Although being based on prospectively collected data, the present still represents an uncontrolled cohort study along with its restricted grade of evidence. The sample size is relatively small but equals comparable studies about newly introduced implants. Various types of acetabular defects were treated in the present study, and a defect subgroup analysis was not performed due to a lack of power regarding small sample sizes. This, however, has to do with the implant system, which is designed to serve in all cases of extended acetabular bone loss despite pelvic discontinuity. Due to this, the present study was designed in a way that would cover a reality-based patient selection without strong restrictions in terms of in-/exclusion criteria.

In conclusion, 10 years after Paprosky's expert opinion on the abilities and limitations of cages [2], implant designs have

rapidly developed and triflanged cups are available off-the-shelf today with various modular optional components to choose from. The newest addition to this portfolio, the augment-and-modular-cage system, has been shown to provide favorable clinical functional outcomes and pain reduction paired with the ability to reconstruct the hip COR in all types of acetabular defects but pelvic discontinuity due to its highly modular composition.

Compliance with ethical standards

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

Ethical approval All procedures performed in this study were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. For this type of study, formal consent is not required. All data obtained is part of in-house quality assessment in accordance with National Register procedures. Additional approval for this study was obtained from the institutional review board of our hospital (study no. 369/17).

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