



The Ganz acetabular reinforcement ring shows excellent long-term results when used as a primary implant: a retrospective analysis of two hundred and forty primary total hip arthroplasties with a minimum follow-up of twenty years

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Abstract

Purpose The acetabular reinforcement ring with a hook (ARRH) has been designed for acetabular total hip arthroplasty (THA) revision. Additionally, the ARRH offers several advantages when used as a primary implant especially in cases with altered acetabular morphology. The implant facilitates anatomic positioning by placing the hook around the teardrop and provides a homogenous base for cementing the polyethylene cup. Therefore, the implant has been widely used in primary total hip arthroplasty at our institution. The present study reports the long-term outcome of the ARRH after a minimum follow-up of 20 years.

Methods Two hundred and ten patients with 240 primary THAs performed between April 1987 and December 1991 using the ARRH were retrospectively reviewed after a minimum follow-up of 20 years. Twenty-three of 240 hips were lost to follow-up, 110 patients with 124 THAs had deceased without having a revision surgery performed. This left 93 hips for final evaluation. Of those, 75 hips were assessed clinically and radiographically after a mean follow-up of 23.1 years (range 21.1–26.1 years). In 18 cases, clinical and radiographic assessment was omitted because implant revision had been performed prior to the follow-up investigation. The primary endpoint was defined as revision for aseptic loosening.

Results Out of the 93 hips available for final evaluation, 14 hips were revised for aseptic loosening; another four were revised for other reasons (deep infection $n = 2$, recurrent dislocation $n = 2$). The survival probability of the cup was 0.96 (95% confidence interval 0.93–0.99) after 20 years with aseptic loosening as endpoint. Radiographic analysis of the surviving 75 hips showed at least one sign of radiographic loosening in 24 hips. The mean Merle d'Aubigne score increased from 8 points pre-operatively to 15 points at final follow-up (7.5 ± 1.8 vs 15.0 ± 2.3 , $p < 0.001$). The mean HHS was 85 ± 14 at final follow-up. Radiographic loosening did not correlate with the clinical outcome.

Conclusions The long-term results of the ARRH in primary THA are comparable to results with standard cemented cups and modern cementless cups. We believe that the ARRH is a versatile implant for primary THA, especially in cases with limited acetabular coverage and altered acetabular bone stock where the ARRH provides sufficient structural support for a cemented cup.

Keywords Ganz ring · Acetabular reinforcement ring · THA · Aseptic loosening · Revision

Introduction

The acetabular reinforcement ring with a hook (ARRH) [1] is generally regarded as a revision implant in total hip arthroplasty

(THA). Different from other reinforcement rings, the ARRH comprises an inferior hook, which is placed around the teardrop and facilitates correct positioning in the true acetabulum, thereby preventing medialization and cranialization of the centre of rotation. The ARRH has shown excellent long-term results in revision arthroplasty with contained acetabular defects. In such situations, implant survival rates in revision THA ranged from 92 to 100% after 4.5–16 years [2–8]. Furthermore, the ARRH has been used successfully in developmental dysplasia of the hip (DDH) where it compensates for the lack of acetabular coverage and facilitates positioning of the cemented polyethylene liner [9]. When used as an implant for primary THA, the ARRH proved to

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achieve excellent long-term results with implant survival rates of up to 95–97% after ten to 12 years [10, 11]. These results were similar to results of other acetabular reinforcement rings such as the Burch–Schneider–Ring and the Müller reinforcement ring [12–16].

In this study, we present the results of 240 consecutive primary THAs performed with an ARRH after a minimum follow-up of 20 years. The purpose of this study was to (i) evaluate the long-term results of the ARRH with respect to aseptic loosening and (ii) provide evidence whether the ARRH is a suitable implant for primary total hip arthroplasty.

Patients and methods

Patient demographics

In 210 consecutive unselected patients, 240 primary total hip arthroplasties were performed between April 1987 and December 1991 (Tables 1 and 2). The surgery was performed at two hospitals (Inselspital, Bern University Hospital, Switzerland/Cantonal Hospital Thun, Switzerland). The mean age of the patients at time of surgery was 60.0 years (range 28–91); 134 patients were male and 106 were female. The indication

for total hip arthroplasty were primary osteoarthritis in 128 hip joints (53.3%) and secondary osteoarthritis due to DDH in 38 hip joints (15.8%), avascular necrosis (AVN) of the femoral head in 30 joints (12.5%), femoral neck fracture in 17 (7.1%), rheumatoid arthritis in 15 (6.3%), protrusio acetabuli in 3 (1.2%), and other causes in nine hips (3.8%). There were 45 cases (18.3%) with previous hip surgery of the affected side including ten cases with acetabular pathomorphologies, i.e., hip dysplasia. Twenty-nine (12.1%) were intertrochanteric osteotomies (IOTs), 7 (2.9%) were open reductions and internal fixations of the proximal femur, two (0.8%) were periacetabular osteotomies (PAO), 2 (0.8%) were triple osteotomies, 1 (0.4%) was an acetabular roof plasty, and 3 (1.3%) were combined IO and triple osteotomies.

Twenty-three of 240 hips were lost to the 20-year follow-up, mainly due to migration to foreign countries and inability to perform a visit because of the general medical condition. One hundred ten patients with 124 THAs had deceased. The cause of death was unrelated to the THA in all cases. None of the deceased patients had undergone revision surgery of the THA. Clinical information about these patients was obtained from hospital charts, family doctors, and family members. This left 93 hips for final evaluation. Out of those, 18 hips had undergone implant revision. Thus, 75 hips were evaluated clinically and

Table 1 Patient demographics, overall

	Total	Deceased	Lost to FU	Survivors	Failure
Number of patients	210	110	20	65	18
Number of hips	240	124	23	75	18
Age at surgery	60.0 ± 12.7 (28.4–90.5)	66.3 ± 11.4 (32.1–90.5)	55.3 ± 13.7 (28.4–74.5)	53.3 ± 9.3 (30.2–73.4)	51.0 ± 10.3 (31.0–65.1)
Male hips (%)	134 (55.8)	70 (56.5)	13 (56.5)	43 (57.3)	8 (44.4)
Right hip (%)	135 (56.2)	70 (56.5)	13 (56.5)	40 (53.3)	12 (66.6)
Previous surgery					
None (%)	196 (81.3)	110 (88.7)	20 (87.0)	52 (69.3)	14 (77.8)
Intertrochanteric osteotomy [IOT] (%)	29 (12.0)	11 (8.9)	2 (8.7)	14 (18.7)	2 (11.1)
Triple osteotomy (%)	2 (0.8)	3 (2.4)	0 (0.0)	2 (2.7)	0 (0.0)
Osteosynthesis (%)	7 (2.9)	0 (0.0)	0 (0.0)	3 (4.0)	1 (5.6)
Acetabular roof plasty (%)	1 (0.4)	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.6)
IOT and triple osteotomy (%)	3 (1.2)	0 (0.0)	1 (4.3)	2 (2.7)	0 (0.0)
Periacetabular osteotomy [PAO] (%)	2 (0.8)	0 (0.0)	0 (0.0)	2 (2.7)	0 (0.0)
Diagnosis					
Primary osteoarthritis (%)	128 (53.1)	71 (57.3)	10 (43.5)	41 (54.7)	6 (33.3)
DDH (%)	38 (15.8)	10 (8.1)	6 (26.1)	16 (21.3)	6 (33.3)
Osteonecrosis (%)	30 (12.4)	11 (8.9)	6 (26.1)	11 (14.7)	2 (11.1)
Protrusio (%)	3 (1.2)	2 (1.6)	0 (0.0)	0 (0.0)	1 (5.6)
Post-traumatic (%)	17 (7.1)	9 (7.3)	1 (4.3)	5 (6.7)	2 (11.1)
Rheumatoid arthritis (%)	15 (6.2)	14 (11.3)	0 (0.0)	0 (0.0)	1 (5.6)
Other (%)	9 (3.7)	7 (5.6)	0 (0.0)	2 (2.7)	0 (0.0)

Values are shown as mean ± standard deviation (range) and value *n* (percentage of group total), respectively

Table 2 Patient demographics per treating institution

Parameter	Hospital 1	Hospital 2	Total
Number of hips (% of total)	154 (64.2)	86 (35.8)	240
Age at surgery	57 ± 14 (28–91)	65 ± 8 (46–84)	60 ± 13 (28–91)
Sex (% male)	79 (51)	57 (66)	57
Side (% right)	88 (57)	47 (55)	56
Previous surgery (%)	40 (26.0)	4 (4.7)	44
Pre surgery Mda	7.0 ± 1.9 (3–15)	8.2 ± 1.5 (5–13)	7.5 ± 1.8 (3–15)

radiographically after a minimum follow-up of 20 years. The mean follow-up was 23.1 years (range 21.1–26.1 years). The ethical committee of the canton of Bern, Switzerland approved the study (Ref.-No. KEK-BE: 265/2014).

Implant

All THAs reported in this study were performed with the original ARRH made from titanium alloy (Protéma-Tcp) with a smooth electropolished surface also referred to as the “Ganz ring” (ARRH, Zimmer, Warsaw, Ind., formerly Centerpulse, Winterthur, Switzerland, Fig. 1). During the study period, this was the standard acetabular implant for all primary THAs at the authors’ institution independent of the acetabular morphology. No other acetabular implants were used for primary THA during the reported period. ARRH sizes ranged from 46 to 58 mm; size

54 mm was the most frequently used (51%). A low profile standard polyethylene liner was cemented into the ARRH. The polyethylene liner (PE) used was a non-cross-linked Sulene PE (Zimmer). Liners were undersized by 2–4 mm to fit into the ARRH resulting in a size range of 44–58 mm. The size of the femoral head was 32 mm in 75, 28 mm in 71, and 22 mm in 92 hips. The femoral component was a Mueller-type straight stem design (Zimmer) in 216 cases [11]. In 22 hips, a smaller dysplasia stem (Mueller straight stem CDH type) was implanted. For two hips, the operative report could not be retrieved.

Surgical procedure

A direct lateral transgluteal approach [17] was used in all cases except in four patients where a trochanteric osteotomy was performed. In 77 cases (32%), small cavitory acetabular

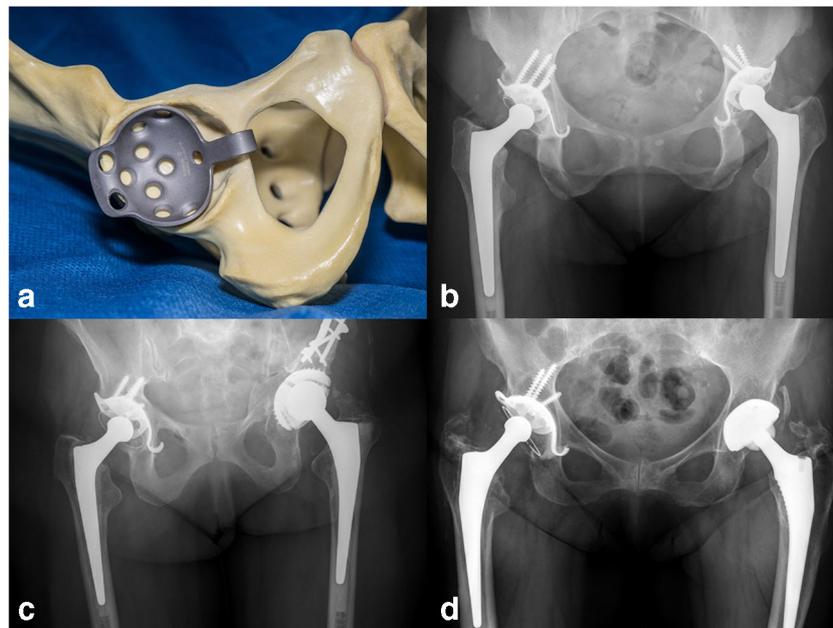


Fig. 1 **a** The acetabular reinforcement ring with a hook (AARRH) placed into the right acetabulum of a sawbone pelvis. The hook of the ARRH is placed around the acetabular notch corresponding to the teardrop figure on plain antero-posterior radiographs. **b–d** Antero-posterior plain radiographs of three study patients with no signs of aseptic loosening are depicted. All surgeries were performed with the ARRH, a cemented standard polyethylene cup, and a monobloc stem with a 22 mm head. **b** Fifty-three-year old female (age at surgery [AaS] 30 years) with a Merle

d’Aubigné (Mda) score of 17 (of 18) and a modified Harris Hip Score (mHHS) of 100 (of 100) at the time of follow-up. **c** Fifty-five-year old female (AaS 32) with a Mda score of 16 and a mHHS of 94. Beginning polyethylene wear 23 years after the surgery is recognized by slight decentralization of the femoral head. **d** Seventy-nine-year old female (AaS 52) with a Mda score of 16 and a mHHS of 100. Twenty-seven years after, the index surgery decentralization of the femoral head demonstrates polyethylene wear of the cup

defects were filled with autologous cancellous bone from the femoral head. In 14 cases (6%), rim deficiencies with limited segmental bone loss (type I according to the AAOS classification) required structural autologous bone grafting.

The inferior hook of the ARRH was positioned around the infero-medial lip of the bony acetabulum, which is generally referred to as the teardrop [18] and then impacted into the acetabulum. The ARRH was fixed with an average of four (range 3–6) fully threaded 6.5 mm titanium screws. Finally, a low profile standard polyethylene liner was cemented into the ARRH. Patients were mobilized with partial weight bearing of 10–15 kg (foot-flat) for six weeks. Antibiotics were administered for 24 hours post-operatively.

Follow-up evaluation

Clinical and radiological follow-up was performed at standard intervals of one, five, ten, 15, and 20 years after surgery. Patients not returning for the 20-year follow-up were individually contacted and invited for a follow-up evaluation at least 20 years after surgery. Based on the data obtained from the final follow-up the Merle d'Aubigne and Harris Hip Scores were calculated. Additionally, a questionnaire was designed to assess data on analgesic medication, pain, walking distance, and working ability. The Merle d'Aubigne score was rated as excellent (18 points), good (15–17 points), fair (13–14 points), and poor (< 13 points) according to Matta [19]. The Harris Hip Score was considered as excellent (90–100 points), good (80–89 points), fair (70–79 points), and poor (< 70 points). For the deceased patients, the last treating family doctor and family members were contacted in order to gain information about any revision surgery performed on the index hip. This information was included into the statistical analysis to evaluate implant survival probability according to Kaplan and Meier [20].

Radiographic analysis

Radiographic follow-up was performed postoperatively, at five, ten and 20 years. The inclination and anteversion of the reinforcement ring and the polyethylene liner was measured.

The follow-up radiographs were screened for radiolucent lines and for changes in position of the implant compared to the post-operative X-rays. As previously reported, the acetabular components were analyzed according to the Johnston criteria [21]. Radiographic loosening was defined as one or more of the following criteria according to Gerber et al. [3] (1) greater than 2 mm of movement of the centre of rotation vertically or horizontally, (2) greater than 3 degrees of rotation of the polyethylene cup, (3) progressive radiolucency around the ring and screws, and/or (4) implant failure (broken hook or broken screw). The Müller system was used to identify the presence and degree of acetabular migration [22]. In brief, a

horizontal line was drawn between the inferior margins of the acetabulum as a reference for vertical migration. A second vertical line, bisecting the inferior margin of the acetabulum, was used as a reference for horizontal migration. The wear of the polyethylene liner was assessed according to the Livermore's technique [23]. Heterotopic bone formation was documented according to the classification of Brooker et al. [24].

Statistical analysis

Primary endpoint was revision surgery for aseptic loosening of the ARRH and secondary endpoint was revision of the ARRH for any reason (i.e., recurrent dislocation, periprosthetic fracture, periprosthetic joint infection). The survival time was the time between the implantation and the time of revision surgery. Patients without revision surgery were censored at the time of their last follow-up or the date of death. Survivorship of the implant was calculated with the Kaplan–Meier survivor analysis [20]. The Cox proportional hazards regression model was used to identify multivariate risk factors predictive of failure [25]. Differences were considered statistically different when *p* value was less than 0.05. Statistical analysis was performed with SPSS (Version 21 for Windows, IBM Inc., USA).

Results

Clinical and radiographic evaluation

Seventy-five hips were evaluated after a mean follow-up of 23.1 years (range 21.1–26.1 years, Table 3). The mean Merle d'Aubigne increased from 8 (range 3–15) points preoperatively to 15 (range 9–18) points at final follow-up (*p* < 0.001). The HHS reached a mean of 85 ± 14 after a minimum follow-up of 20 years. Pre-operative HHS was not documented. According to the HHS, 77% of the hips achieved good or excellent clinical results, 23% showed a fair or poor outcome. Twenty-six hips experienced some discomfort, of which ten patients with 11 hips required painkillers on a regular basis due to chronic pain. Forty-four hips reported a pain-free walking distance of more than 1000 m. Four patients were bedridden, one of which due to pulmonary insufficiency. Symptomatic limping was present in 34 hips; out of those, 14 hips showed a positive Trendelenburg gait.

The average inclination of the polyethylene liner was 39.2° (range $20\text{--}58^\circ$). Average liner anteversion was 12.3° (range $0\text{--}44^\circ$) as measured on cross-table hip radiographs. Polyethylene cup wear averaged 0.07 mm per year (range 0–0.3 mm/year). Thirteen patients were identified with cup migration and 24 with osteolysis. In four hips, broken screws were observed. Twenty-four out of 75 hips showed at least one sign of radiographic loosening according to Johnston's criteria. The

Table 3 Clinical and radiographic results per treating institution

Parameter	Hospital 1	Hospital 2	Total
Number of followed up hips (%)	44 (28.6)	31 (36.1)	75 (31.2)
Lost to follow-up (%)	16 (10.4)	7 (8.1)	23 (9.6)
Death before 20-year follow-up (%)	81 (52.6)	43 (50)	124 (51.7)
Failures (%)	13 (8.4)	5 (5.8)	18 (7.5)
Harris Hip Score	78 ± 21 (18–100)	90 ± 10 (59–100)	83 ± 18 (18–100)
Merle d'Aubigné Score	14.4 ± 2.5 (9–18)	15.9 ± 1.8 (12–18)	15.0 ± 2.3 (9–18)
Excellent result (% of followed up hips)	15 (34.1)	21 (67.7)	36 (48.0)
Good result (% of followed up hips)	8 (18.2)	5 (16.1)	13 (17.3)
Fair result (% of followed up hips)	9 (20.5)	4 (12.9)	13 (17.3)
Bad result (% of followed up hips)	12 (27.3)	1 (3.2)	13 (17.3)
Migration head x-axis (mm)	0.82 ± 0.60 (0.2–2.0)	1.38 ± 0.85 (0–3.5)	1.25 ± 0.82 (0–3.5)
Migration head y-axis (mm)	1.38 ± 1.16 (0.2–3.0)	1.42 ± 1.01 (0–3.5)	1.41 ± 1.03 (0–3.5)
Polyethylen wear (mm)	1.57 ± 1.16 (0–4.1)	0.88 ± 0.67 (0–2.5)	1.22 ± 1.00 (0–4.1)
Brooker 0	18	9	27
Brooker I	15	8	23
Brooker II	3	11	14
Brooker III	7	3	10
Brooker IV	1	0	1

presence of radiographic signs of cup loosening did not correlate with the clinical outcome measured with the HSS and Merle d'Aubigné score ($p = 0.14$ (HSS), $p = 0.72$ (MDA)). HSS/MDA scores were 79.7 ± 21.1 (18–100)/ 14.6 ± 2.6 (8–18) in cases without signs of radiographic loosening and 87.4 ± 12.7 (55–100)/ 15.6 ± 2.0 (11–18) in cases with signs of radiographic loosening, respectively (Chi² test, HSS: radiographic loosening vs. no radiographic loosening $p = 0.94$ MDA: HSS: radiographic loosening vs. no radiographic loosening $p = 0.99$).

Revisions

A total of 18 hips (7.5%) had revision surgery (Table 4). Aseptic loosening was the major cause for revision in 14 hips. In five cases (2.1%), the acetabular component was revised due to aseptic loosening of the ARRH only. In another five cases, the acetabular and femoral implants had to be revised due to aseptic loosening. In four cases (1.7%), only the femoral component had to be revised due to aseptic loosening. In two cases each, revision of total implant was required due to recurrent dislocation and periprosthetic joint infection, respectively. Revision surgery was performed at a mean of 15.7 years (range 7.4–24.9 years) after implantation.

Complications

Early post-operative complications included one trochanteric fracture three weeks post-surgery, which was treated conservatively, intra-operative nerve injuries (sciatic nerve $n = 1$, femoral

nerve $n = 1$, lateral femoral cutaneous nerve $n = 2$). Three out of four nerve lesions resolved within two years; one lateral femoral cutaneous lesion required revision due to a painful neuroma. Five cases (2.1%) of deep vein thrombosis and two cases (0.8%) of pulmonary embolism required prolonged warfarin therapy. Fourteen patients showed a Trendelenburg gait, which was considered a consequence of the detachment of the abductor muscles from the greater trochanter during the transgluteal approach to the hip. However, the Trendelenburg gait may, at least in part, have been due to unidentified damages to the superior gluteal nerve.

Survival

With revision due to aseptic loosening of the ARRH as endpoint, the cumulative 20-year survivorship of the ARRH was 0.958 (95% confidence interval [95% CI] 0.924–0.992, Fig. 2). Estimated mean survival time with aseptic loosening as endpoint was 25.3 years (95% CI 24.9–25.8). The cumulative 20-year survivorship of the ARRH with revision for any reason was 0.931 (95% CI 0.889–0.974) with an estimated mean survival time of 25.0 years (95% CI 24.4–25.5). Age at surgery and femoral head size were associated with survival of the ARRH. Patients aged 65 years and younger at the time of surgery had a significantly lower survivorship of the ARRH as compared to patients older than 65 years (0.898 versus 1.000, $p = 0.047$). Femoral head sizes of 32 mm were associated with a decreased survival as compared to head sizes 28 mm and 22 mm (22 mm: 0.946, 28 mm: 0.971,

Table 4 Details of hips requiring revision surgery

Case	Primary diagnosis	Age at index surgery (years)	Time to revision (years)	Reason for revision	Components revised	Components reimplanted
1	Rheumatoid arthritis	65	0.7	Infection	Total	None (Girdlestone)
2	DDH	46	7.4	Aseptic loosening	Cup	unknown
3	Trauma	38	8	Infection	Total	ARRH
4	Degenerative Arthritis	58	8.6	Aseptic loosening	Stem	Modular revision stem
5	Degenerative Arthritis	63	8.6	Aseptic loosening	Stem	Modular revision stem
6	DDH	52	9.1	Aseptic loosening	Cup	ARRH
7	Degenerative Arthritis	46	12.7	Aseptic loosening	Stem	Porous coated revision stem
8	DDH	45	13.9	Aseptic loosening	Total	ARRH, cemented straight stem
9	Degenerative Arthritis	61	17.1	Aseptic loosening	Total	unknown
10	Protrusio	56	17.5	Aseptic loosening	Cup	unknown
11	DDH	61	18	Dislocation	Total	ARRH, cemented straight stem
12	Degenerative Arthritis	59	18.9	Aseptic loosening	Total	ARRH
13	DDH	58	19.5	Aseptic loosening	Stem	Primary pressfit cup
14	AVN	31	19.7	Dislocation	Total	ARRH, modular revision stem
15	Degenerative Arthritis	47	20.2	Aseptic loosening	Cup	TM revision cup without augment
16	Trauma	46	20.6	Aseptic loosening	Total	TM revision cup with augment
17	AVN	32	20.7	Aseptic loosening	Cup	ARRH
18	DDH	54	24.9	Aseptic loosening	Total	Primary pressfit cup, porous coated revision stem

AVN avascular necrosis, DDH developmental dysplasia of the hip, TM Trabecular Metal™

32 mm: 0.818, $p = 0.029$ 22 mm versus 32 mm, $p = 0.008$ 28 versus 32 mm).

Cox regression analysis identified femoral head size ($p = 0.035$) as the only risk factors for aseptic loosening. Femoral head sizes with a diameter of 32 mm were associated with an increased risk of aseptic loosening of the ARRH as compared to 28 mm and 22 mm femoral heads (HR 5.04, 95% CI 1.41–18.21, $p = 0.013$). With revision for any reason as endpoint, head size ($p = 0.048$) and age at surgery ($p = 0.025$) were risk factors for failure of the ARRH. Other covariates such as gender, age, primary disease, acetabular pathomorphology, inclination and anteversion of the liner, polyethylene thickness, and the use of bone grafting were not associated with an increased risk of aseptic loosening or overall survival of the ARRH.

Discussion

Primary total hip arthroplasty has been proven to be one of the most successful interventions in orthopaedic surgery today. However, the long-term outcome of THA has not changed significantly over the past two decades despite major changes

in implant designs and surgical techniques. In fact, excellent long-term survival rates have been reported for cemented acetabular implants, which is in opposition to the observed trend towards uncemented implants [1, 26].

The ARRH has been designed as a reinforcement ring for acetabular THA revision. However, it offers several advantages when used as a primary implant especially in cases with altered acetabular morphology such as those cases of the current study with developmental dysplasia of the hip and protrusio acetabuli. The hook of the implant, which is placed around the teardrop, facilitates correct positioning of the ARRH preventing medialization and cranialization of the centre of rotation. Due to the reinforcement of the anterior and posterior walls acetabular reaming can be limited to preserve bone stock especially in dysplastic hips. Furthermore, the liner can be cemented into the ARRH in whichever orientation required. This is particularly important in cases with malorientation of the acetabulum such as retroversion and anterior or posterior wall deficiencies.

The present study aimed at investigating the long-term results of the ARRH with respect to aseptic loosening and function. Although this investigation benefits from a relatively large group of patients with extended follow-up, there are

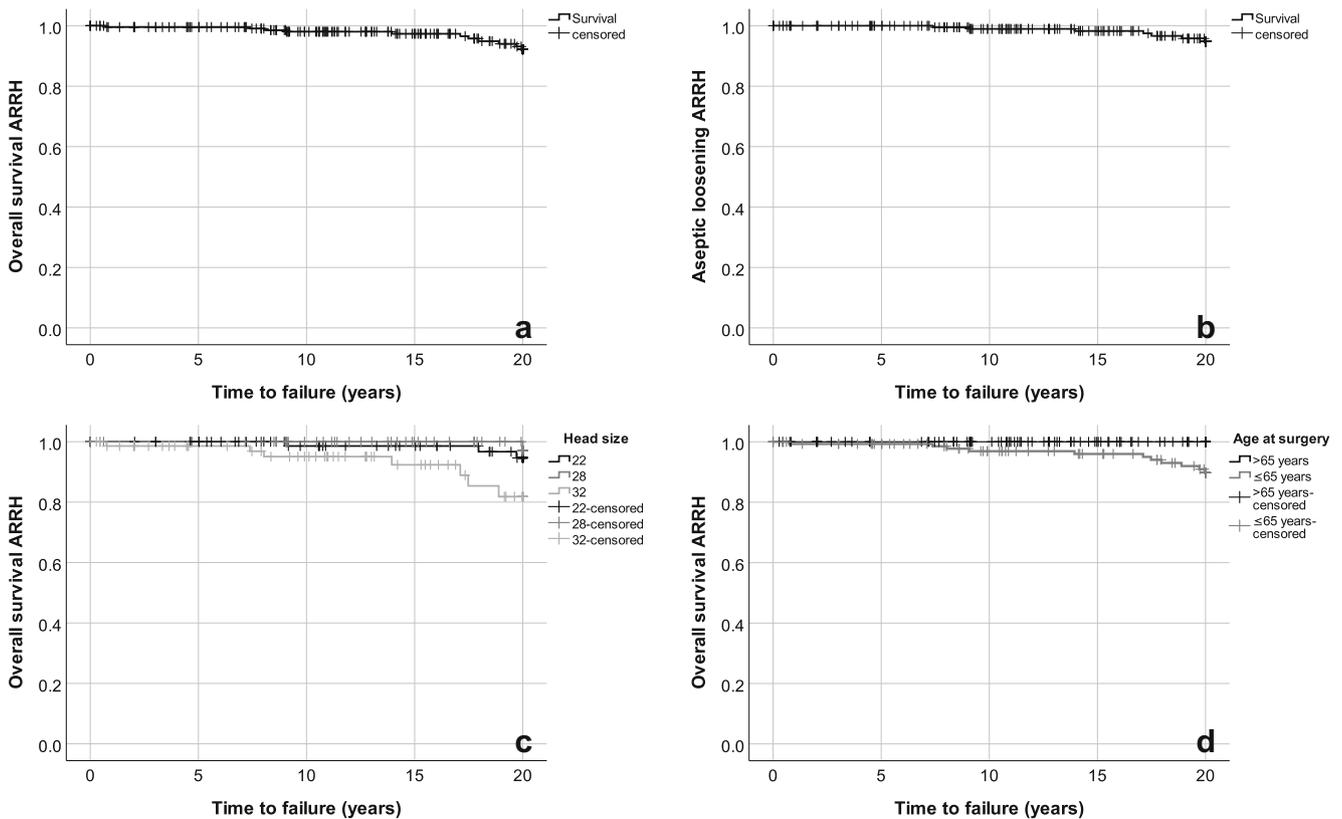


Fig. 2 Estimated Kaplan–Meier survival for the ARRH. **a** Overall survival with revision for any reason. **b** Survival with aseptic loosening as endpoint. **c** Overall survival of femoral head sizes of 22 mm, 28 mm, and 32 mm. **d** Overall survival of age groups ≤ 65 years and > 65 years at the time of primary THA

some limitations to this retrospective study. First, our series reports a diverse group of patients including an unusual high proportion of patients with secondary osteoarthritis due to DDH. Second, due to the retrospective nature of the study, information on whether deceased patients had undergone revision of the ARRH had to be obtained from the family physician and family members. Third, there was no control group available to compare the performance of the ARRH with standard acetabular components for primary THA. Fourth, data on function of the hips was gathered at the time of follow-up only. Therefore, it is not possible to draw conclusions about potential changes of hip function during the long-term follow-up period, which may be influenced by factors associated with the implants or patient-specific factors such as activity level and ageing.

Aseptic loosening remains the single most important mode of failure in THA. Implant survival of standard cemented and uncemented acetabular components has been reported to range from 72 to 94% and 70 to 92%, respectively, after ten to 20 years [27–30]. Long-term survival of acetabular reinforcement rings has been reported to range between 80 and 92% in revision THA when revision surgery due to aseptic loosening was the selected endpoint [2, 3, 5]. As reinforcement rings have not been designed as implants for primary THA, there is little data available on their long-term performance when

used for this purpose. Own data have shown favourable ten year survival rates of the ARRH when used as a primary implant on total hip arthroplasty [10]. More recently, Sirka et al. [7] demonstrated a survival rate of the Müller reinforcement ring of 93% after 20 years. The present study showed that the longevity of the ARRH was similar to that observed in cemented and cementless acetabular components designed for primary THA. At 20 years after implantation, the survival probability of the ARRH was 96% for aseptic loosening and 93% for revision for any reason.

Risk factors associated with aseptic loosening of the ARRH were femoral head sizes of 32 mm when compared to head sizes of 22 mm and 28 mm and patient age at implantation of 65 years and younger. Patient age and head size were shown to be associated with decreased implant survival of cemented and cementless acetabular components previously indicating that the ARRH does not have a different mode of failure when compared to standard cemented and cementless acetabular components [31–35]. However, it has to be kept in mind that the ARRH was used together with standard polyethylene liners. Recent studies have shown that larger head sizes may not be associated with increased rates of aseptic loosening when modern, highly cross-linked polyethylenes are used [36, 37]. Thus, our finding that a head size of 32 mm increased the likelihood of aseptic loosening may not

translate to today's use of the ARRH with highly cross-linked polyethylene liners. Approximately one third of the cups showed radiographic signs of loosening at the final follow-up. Thus, the study endpoint of acetabular revision due to loosening may underestimate the true failure rate of the ARRH. However, the presence of signs of radiographic loosening did not correlate with the functional outcome of the hips, indicating that radiographic signs of loosening may not be a reliable parameter to assess the failure of the procedure.

Besides the long-term outcome of primary implants, their revisability is becoming more important. With this in mind, the analysis of the long-term performance of classic implants is of major interest. Furthermore, the implants should be critically reviewed with respect to factors affecting future revision surgery such as ease of implant removal and bone loss due to implant removal. Revision of the ARRH is uncomplicated. After screw removal, the reinforcement ring can be removed from the acetabulum with limited bone loss because the ARRH does not integrate into the host bone. This is confirmed by the cases that required acetabular revision in the current study. Only two cases required the use of a Trabecular Metal™ revision cup, whereas nine revisions were performed with standard primary pressfit cups or new reinforcement rings.

In conclusion, the long-term survivorship of the ARRH in primary THA is comparable to results with standard cemented cups and modern cementless cups. The ARRH is a versatile implant for primary THA, especially in cases with limited acetabular coverage and altered acetabular bone stock where the ARRH provides sufficient structural support for a cemented cup.

Compliance with ethical standards

The ethical committee of the canton of Bern, Switzerland approved the study (Ref.-No. KEK-BE: 265/2014).

Conflict of interest statement The authors declare that they have no conflicts of interest.

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