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Original Article

Hip resurfacing arthroplasty for osteonecrosis of the femoral head: Implant-specific outcomes and risk factors for failure

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ABSTRACT

Background: Hip resurfacing arthroplasty (HRA) may be a suitable option for treating osteonecrosis of the femoral head (ONFH). However, concerns regarding the extent of osteonecrosis, amount of defect under the prosthesis, and implant-related complications remain. This study aimed to report implant-specific outcomes and risk factors for failure of HRA in ONFH.

Methods: A total of 202 HRAs (166 patients) performed by a single surgeon were investigated. The stage, size, and location of ONFH were evaluated using preoperative radiographs and magnetic resonance images. Clinical, radiographic results, and serum metal concentrations of articular surface replacement (ASR) and non-ASR devices were compared. Logistic regression analysis was performed to identify the contributors of failures. The mean follow-up duration was 10.6 years.

Results: Twenty-six hips (12.9%) were operated with Birmingham Hip Resurfacing (BHR), 99 (49.0%) with ASR, and 77 (38.1%) with Conserve Plus. The mean Harris Hip Score improved from 52.1 to 93.2 at the final follow-up ($P < 0.001$). Revision-free survivorships of non-ASR and ASR implants were 99.0% and 82.4%, respectively ($P < 0.001$). In multivariate analysis, the use of ASR prosthesis, greater combined necrotic angle, and smaller head size were associated with revision surgery. A large combined necrotic angle was the only independent risk factor for mechanical failure at the femoral side ($P = 0.029$).

Conclusion: HRA for ONFH using BHR and Conserve Plus implants demonstrated favourable clinical outcomes with high revision-free survival rates at 10 years. However, care should be taken for large necrotic lesions that can lead to femoral neck fracture or aseptic femoral loosening.

The translational potential of this article: This study suggests HRA performed for appropriately selected patients with ONFH can show excellent long-term clinical results. Therefore, HRA should remain as one of the treatment options for ONFH, and further development of HRA implants should be continued.

Introduction

Metal-on-metal (MoM) hip resurfacing arthroplasty (HRA) offers several potential advantages over total hip arthroplasty (THA); it helps surgeons achieve important goals of joint reconstruction, including preservation of the bone stock, restoration of native biomechanics, improved stability, and excellent functional outcome [1–6]. HRA also has demonstrated favourable mid- to long-term implant survivorships similar to that of THA, especially for osteoarthritic hips [4,7–9].

Patients with osteonecrosis of the femoral head (ONFH) are usually younger and have a higher predisease activity level than those with osteoarthritis. In this respect, ONFH may be a suitable indication for HRA. However, there are concerns on the risks of implant loosening or femoral neck fracture due to a weak necrotic portion of the femoral head [10–13]. Even if the necrotic lesion is sufficiently removed, the bony surface area available for implant fixation is reduced, whereas the proportion of acrylic cement is increased. Although, several authors have reported favourable results of HRA with ONFH [14–18], data regarding medium- to long-term outcomes remain scarce.

Recently, there has been a widespread concern regarding large-diameter MoM articulations. Since the recall of the articular surface replacement (ASR) (DePuy, Warsaw, IN, USA) and a number of MoM THA systems, the number of HRA procedures has decreased worldwide. However, many experts still advocate performing HRA in young, active

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males, as the design and wear behaviours are different from those of large diameter THAs [19]. To continue performing HRA in patients with ONFH with confidence, we need to look at the outcomes of the best-performing implants compared with that of the recalled one. It is also necessary to understand what factors are associated with failures of HRA.

The aim of this study was to investigate implant-specific outcomes and to analyse risk factors for failures of HRA performed in patients with ONFH after a mean follow-up of 10 years.

Material and methods

Patient cohort

The present study was conducted with the approval of our institutional review board. HRA was considered for patients with persistent hip pain for ONFH, which did not extend to the neck of the femur on magnetic resonance imaging (MRI). Patients with known renal dysfunction, history of allergic reaction to metals, pregnancy plan, and severe acetabular or femoral deformity were excluded. The decision to perform HRA depended on the preference of the patient who had been well informed of the possible risks and benefits of MoM HRA. Before the surgery, we acquired informed consent from all patients with ONFH that the surgical plan may be converted to THA intraoperatively.

A total of 254 consecutive HRAs (215 patients) were performed in our institution between September 2003 and October 2013. We included 211 hips (174 patients) diagnosed with ONFH preoperatively. Two patients (2 hips) died for reasons unrelated to the surgery, whereas 6 patients (7 hips) were lost to follow-up before reaching a minimum of 5 years. Data for the remaining 202 hips (166 patients) were retrospectively reviewed. The Birmingham Hip Resurfacing (BHR) (Smith and Nephew, Memphis, TN, USA), Conserve Plus (CP) (MicroPort, Memphis, TN, USA) and ASR implants were used during the study period. We started HRA using the BHR system first and then applied CP and ASR as they were newly developed. Shortly after the ASR instrument was recalled, import of BHR prostheses to our country was also stopped. As a result, the CP implant remained the only hip resurfacing instrument available in our institution.

Surgical characteristics

All surgeries were conducted by a senior surgeon in a single institution through the anterolateral approach [20]. After detaching the anterior one-third of the glutaeus medius muscle and glutaeus minimus tendon from their insertions, the anterior capsule was excised completely. Then, the joint was dislocated anteriorly by mobilising the thigh in external rotation, adduction, and flexion. During the femoral procedure, the surgeon removed all friable necrotic bone and cystic debris using rongeur and curette, until a dense reactive bone was visualised (Fig. 1A). We applied a trial femoral component to identify whether the prosthesis could cover the remaining viable bone (Fig. 1B). If this was not achieved, we converted to THA. We made multiple drill holes on the viable bone, irrigated, and dried it up using a suction drainage to achieve a maximum, clean contact between the bone and cement (Fig. 1C). After this, the femoral component was fixed with acrylic cement, which filled the defect simultaneously. Acetabular components were all press-fitted into the acetabulum without the use of cement.

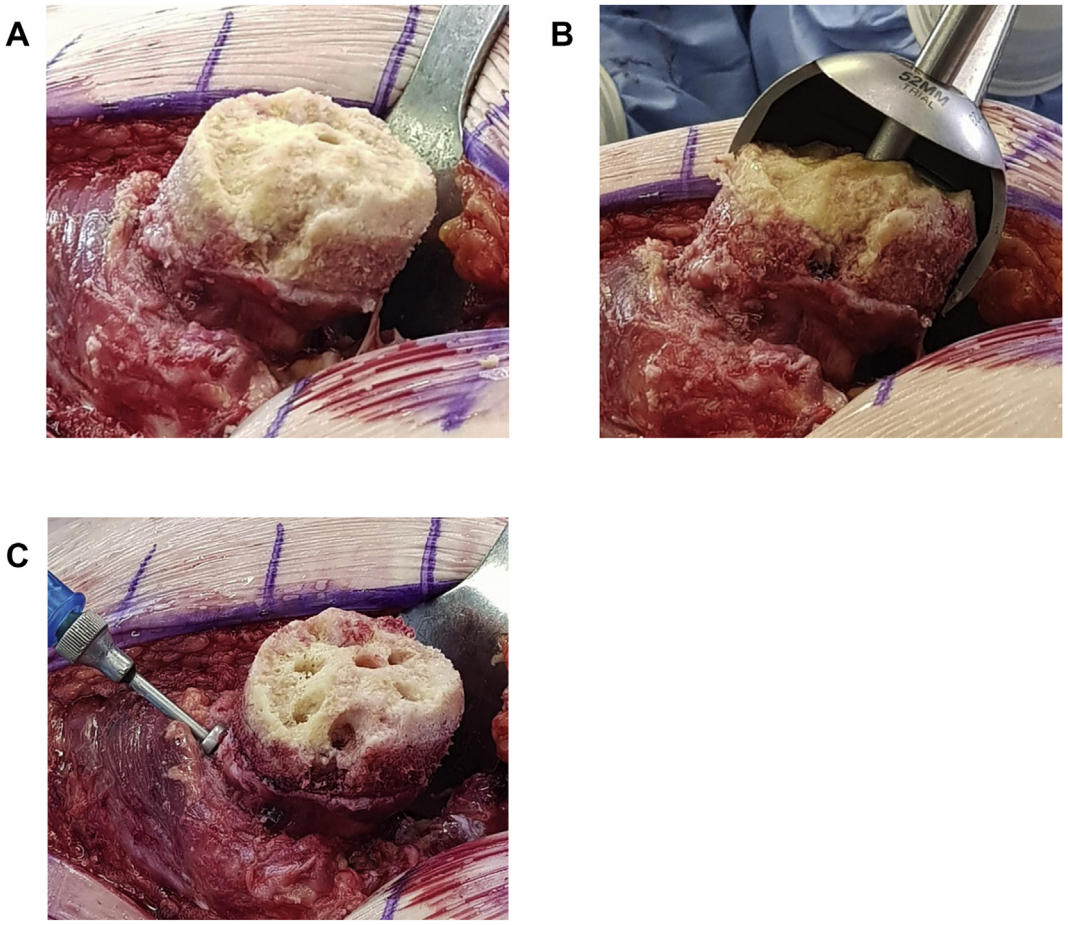

Fig. 1. Photographs showing the surgical procedure of hip resurfacing arthroplasty (HRA) used for osteonecrosis. **(A)** The necrotic bone was removed down to the underlying dense, reactive bone. **(B)** The trial femoral component was applied to determine whether the prosthesis could overlap the surface of the remaining femoral head. **(C)** Additional drill holes were made to increase stability between the viable bone and the acrylic cement.

Clinical evaluation

Clinical scores were collected using the Harris Hip Score (HHS) system and the University of California, Los Angeles (UCLA) activity scale. Postoperative scores were evaluated at each clinical visit, which was scheduled at 2, 6, and 12 months postoperatively and annually thereafter. Patients were questioned on whether noise was generated from the operated hip. We considered the presence of adverse reaction to metal debris (ARMD) when patients presented 2 or more of the following findings: rapidly progressing osteolysis with groin pain, visible metallosis or pseudotumor on imaging studies, or histopathological evidence of perivascular lymphocytes [21,22]. We also identified other complications such as infection, nerve palsy, fracture, dislocation, and implant loosening.

Radiographic measurements

A standard anteroposterior hip radiograph and a cross-table lateral image were obtained preoperatively, immediately after surgery, at the 5th postoperative day, and at each follow-up visit. All radiographic measurements were reviewed twice each by 2 independent orthopedic surgeons who had not participated in the original surgery. The investigators used a picture archiving and communication system (Centricity Enterprise Web V3.0, GE Medical Systems, Barrington, IL). The radiographic stage of ONFH was classified using the Association Research Circulation Osseous (ARCO) staging system [23,24]. Stage 3 was subdivided into 3A and 3B, depending on whether the collapse of the femoral head was 3 mm or greater.

All patients underwent non-contrasted bilateral hip MRI for diagnosis and surgical planning. The location of ONFH was classified using mid-coronal sections of T1-weighted images in accordance with the Japanese Investigation Committee (JIC) classification system [23,24]. The locations were classified into Type A, B, and C as per the amount of lateral extension, based on the three equal areas of the weight-bearing portion of the femoral head. Type C was further divided into C1 and C2, depending on whether the lesion exceeded the acetabular edge. The size of the necrotic lesion was evaluated using the modified Kerboul angle [25], which was calculated by the sum of necrotic arcs measured by the mid-coronal and midsagittal sections of T1-weighted MRI.

The positions of acetabular and femoral components were evaluated using immediate postoperative radiographs. Cup inclination was defined as the angle formed by the interteardrop line and the major axis of cup projection. Cup anteversion was calculated using the ratio between the length of long and short axes of cup projection [anteversion = arcsine (short axis/long axis)] [26]. Stem–shaft angle was measured using the femoral stem axis and the line passing the centres of the diaphysis [27]. A line passing through the centres of the femoral head and neck was used for estimating neck–shaft angle. Presence of osteolysis, bony spur, indentation [20], neck narrowing, and heterotopic ossification were examined using the radiographs obtained at the latest follow-up. We defined osteolytic lesion as the nonlinear appearance of focal bone absorption more than 2-mm wide [28]. Narrowing of the femoral neck was defined as the progressive narrowing of both superior and inferior aspects of the femoral neck [29].

Serum metal concentrations

We recommended all patients to check their blood metal ion levels annually after the operation. The serum metal ion levels were determined in our laboratory using the inductively coupled plasma mass spectrometry method. To avoid any bias, patients with other cobalt- or chromium-containing devices, such as contralateral HRA, THA, or other internal joint prosthesis, were excluded from the analysis. Patients with chronic kidney disease were also excluded, as metal ions in these patients might have accumulated in their body [30,31].

Statistical analysis

The paired *t*-test was used to detect improvement in the clinical scores. The Student *t* test and Wilcoxon rank-sum test were used to compare continuous variables in both groups. Categorical values were compared using the Chi-square or Fisher exact test. A logistic regression model was used to determine potential variables associated with any revisions and revisions due to mechanical failure (i.e., loosening of the femoral component or femoral neck fracture). These variables included age, sex, body mass index, stage, location, lesion size, implant type, head size, cup size, inclination, anteversion, neck–shaft angle, and stem–shaft angle. Covariates with a P-value less than 0.1 in the univariate regression were entered into the multivariate analysis. Implant survival analysis was carried out with the Kaplan–Meier estimator using the end point of revision for any reason. Between-group differences in serial change of serum ion concentrations were analysed by generalised linear model with adjustment for treatment-by-visit interaction. All statistical analyses were performed using SPSS statistics software, version 25.0 (IBM Corp., Armonk, NY, USA). P-values less than 0.05 were considered to be statistically significant.

Results

Baseline characteristics

There were 156 men (189 hips, 93.6%) and 10 women (13 hips, 6.4%) with a mean age of 37.9 (range, 18–65) years during the index operation. The average height was 171.6 (range, 148–188) cm, and the average weight was 73.2 (range, 49.2–109.4) kg. The mean body mass index was 24.8 (range, 16.9–34.1) kg/m^2. Stage, size, and location of ONFH are listed in Table 1. The mean follow-up duration was 10.6 (range, 5–15) years.

Twenty-six HRAs (12.9%) were operated with BHR, 99 (49.0%) with ASR, and 77 (38.1%) with CP. There were no significant differences in patient characteristics, stage, size, and extent of ONFH between the ASR and non-ASR (BHR and CP) groups. The sizes and angles of components were similar, except for stem–shaft angle (P = 0.045) (Table 2).

Table 1
Patient demographics and radiographic characteristics of osteonecrosis.

Characteristics	All (n = 202)	Non-ASR (n = 103)	ASR (n = 99)	*p* value
Age[a] (yr)	37.9 ± 9.9	37.8 ± 9.6	38.0 ± 10.3	0.935
Male gender[b]	189 (93.6%)	95 (92.2%)	94 (94.9%)	0.432
Body mass index[a] (kg/m^2)	24.8 ± 2.7	24.9 ± 2.9	24.6 ± 2.6	0.465
Kerboul angle[a] (°)	239.8 ± 41.8	236.1 ± 38.1	243.6 ± 45.2	0.203
ARCO Stage[b]				0.448
Stage 2	20 (9.9%)	13 (12.6%)	7 (7.1%)	
Stage 3A	134 (66.3%)	69 (67.0%)	65 (65.7%)	
Stage 3B	42 (20.8%)	18 (17.5%)	24 (24.2%)	
Stage 4	6 (3.0%)	3 (2.9%)	3 (3.0%)	
JIC location[b]				0.221
Type B	10 (5.0%)	6 (5.8%)	4 (4.0%)	
Type C1	149 (73.8%)	80 (77.7%)	69 (69.7%)	
Type C2	43 (21.3%)	17 (16.5%)	26 (26.3%)	
Neck–shaft angle[a] (°)	130.7 ± 3.5	130.4 ± 3.4	131.0 ± 3.6	0.212
Preoperative HHS[a]	52.1 ± 10.4	51.1 ± 11.2	53.1 ± 9.4	0.160
Preoperative UCLA score[a]	3.9 ± 1.1	3.8 ± 1.2	4.0 ± 1.1	0.161

ARCO = Association Research Circulation Osseous; JIC = Japanese Investigation Committee; HHS=Harris Hip Score; ASR = articular surface replacement; UCLA = University of California, Los Angeles;

[a] The values are given as the mean and the standard deviation.

[b] The values are given as the number of hips with the percentage in parentheses.

Table 2
Surgical characteristics and duration of follow-up.

Characteristics	All (n = 202)	Non-ASR (n = 103)	ASR (n = 99)	*p* value
Head size (mm)	48.4 ± 2.2	48.6 ± 2.2	48.2 ± 2.2	0.273
Cup size (mm)	54.9 ± 2.5	54.8 ± 2.2	55.0 ± 2.7	0.621
Cup inclination (°)	42.3 ± 3.7	41.9 ± 4.3	42.7 ± 3.0	0.121
Cup anteversion (°)	15.2 ± 3.5	15.3 ± 3.8	15.1 ± 3.2	0.669
Stem–shaft angle (°)	136.1 ± 4.8	135.4 ± 5.1	136.8 ± 4.4	0.045
Follow-up duration (yr)	10.6 ± 2.4	10.8 ± 3.1	10.4 ± 1.1	0.194

The values are given as the mean and the standard deviation.
ASR = articular surface replacement.

Clinical and radiographic results

The overall HHS increased from 52.1 (range, 16–78) preoperatively to 93.2 (range, 55–100) at the final follow-up (P < 0.001). The mean UCLA activity score improved from 3.93 (range, 1–7) to 7.96 (range, 3–10) (P < 0.001). The non-ASR group demonstrated significantly higher postoperative HHS [94.6 versus (vs.) 91.9, P = 0.030] and UCLA activity score (8.2 vs. 7.7, P = 0.017) compared with the ASR group (Table 3). There were more osteolytic lesions in hips with ASR prosthesis (25.3% vs. 8.7%) (P = 0.002) compared with hips with non-ASR prosthesis. The incidence of bony spur, notching, neck narrowing, and heterotopic ossification were not significantly different.

Revisions and implant survivorships

A total of 18 hips (8.9%) were revised during the observation period (Table 4). There was one case of revision surgery in the non-ASR group, which was a case of femoral neck fracture with the CP prosthesis, 4.4 years after the original surgery. No revision was performed in the BHR implant. There were a total of 17 revisions in the ASR group. The reasons for failures of ASR prosthesis were ARMD, aseptic implant loosening, femoral neck fracture, unexplained groin pain, and infection. A conversion to cementless THA was performed for all cases of failure (Fig. 2).

The overall Kaplan–Meier survivorship with an end point of revision for any reason was 90.4% [95% confidence interval (CI), 86.1–94.7%] at 10 years. Kaplan–Meier analysis estimated significantly higher survivorship of non-ASR implant (99.0%) (95% CI, 97.0–100%) than that of ASR implant (82.4%) (95% CI, 74.8–90.0%) at 10 years (log rank, P < 0.001) (Fig. 3).

Risk factors for revision and mechanical failure

In univariate analysis, the use of ASR implant, small-sized head, advanced stage (3B or 4), lateral extension (type C2) of osteonecrosis, and large Kerboul angle were all identified as significant risk factors of revision for any reason (P < 0.05), while female sex reached marginal significance (P = 0.080) (Table 5). When potential confounders in the multivariate analysis were controlled, the use of ASR implant, small femoral head, and large necrotic lesion remained independent risk factors for revision surgery (P < 0.05).

For mechanical failure at the femoral side, JIC type C2 lesion and large Kerboul angle were identified as risk factors in univariate analysis (Table 6). After the multivariate analysis was performed for these covariates, a large necrotic angle remained the only independent risk factor for aseptic femoral failure (P = 0.029). Osteonecrosis with a Kerboul angle of 300° or greater demonstrated an adjusted odds ratio of 34.6 (95% CI, 10.6–113) (P < 0.001) for revision surgery compared with that with an angle of less than 300°.

Table 3
Clinical and radiographic outcomes.

Outcomes	All (n = 202)	Non-ASR (n = 103)	ASR (n = 99)	*p* value
Postoperative HHS[a]	93.2 ± 8.8	94.6 ± 5.2	91.9 ± 11.3	0.030
Postoperative UCLA score[a]	8.0 ± 1.6	8.2 ± 1.3	7.7 ± 1.8	0.017
Radiographic results[b]				
Osteolytic lesion	34 (16.8%)	9 (8.7%)	25 (25.3%)	0.002
Indentation	8 (4.0%)	6 (5.8%)	2 (2.0%)	0.280
Bony spur	46 (22.8%)	25 (24.3%)	21 (21.2%)	0.604
Neck narrowing	22 (10.9%)	11 (10.7%)	11 (11.1%)	0.922
Heterotopic ossification	29 (14.4%)	14 (13.6%)	15 (15.2%)	0.752

HHS = Harris Hip Score; ASR = articular surface replacement; UCLA = University of California Los Angeles.
[a] The values are given as the mean and the standard deviation.
[b] The values are given as the number of hips with the percentage in parentheses.

Table 4
Complications and reasons for revision surgery.

Outcomes	All (n = 202)	Non-ASR (n = 103)	ASR (n = 99)	*p* value
Dislocation	1 (0.5%)	1 (1.0%)	0 (0.0%)	1.000
Sound generation	13 (6.4%)	4 (3.9%)	9 (9.1%)	0.132
Femoral nerve palsy	1 (0.5%)	1 (1.0%)	0 (0.0%)	1.000
Revision surgery	18 (8.9%)	1 (1.0%)	17 (17.2%)	<0.001
ARMD	8 (4.0%)	0 (0.0%)	8 (8.1%)	
Femoral neck fracture	3 (1.5%)	1 (1.0%)	2 (2.0%)	
Femoral loosening	3 (1.5%)	0 (0.0%)	3 (3.0%)	
Acetabular loosening	1 (0.5%)	0 (0.0%)	1 (1.0%)	
Unexplained pain	2 (1.0%)	0 (0.0%)	2 (2.0%)	
Infection	1 (0.5%)	0 (0.0%)	1 (1.0%)	

The values are given as the number of hips with the percentage in parentheses.
ARMD = adverse reaction to metal debris; ASR = articular surface replacement.

Serum metal concentrations

Serum cobalt and chromium concentrations are listed in Table 7. The overall metal ion level peaked at 2 years (mean, 5.06 μg/L for cobalt and 6.40 μg/L for chromium) postoperatively and then decreased gradually (Figs. 4 and 5). In the ASR group, serum cobalt level was higher at 2 years, and chromium level was higher at 1-year and 2-year postoperatively compared with the non-ASR group. There were no significant differences in the serial trends of cobalt and chromium concentrations between the two groups when adjusting group-by-time interaction effects.

Discussion

Young, active patients with intractable ONFH can be favourable candidates for HRA. However, the safety of HRA for patients with ONFH has been debated over the years [32,33]. Some investigators are concerned about the weak necrotic portion of the femoral head that may result in early implant loosening or femoral neck fracture. Another great concern is the use of MoM articulating surface itself. The number of HRA procedure has decreased since the recall of the ASR implant. However, in accordance with the registry data, the result of HRA is highly dependent on implant choice [7]. BHR and CP implants are the two most successful resurfacing devices, demonstrating favourable mid- to long-term outcomes comparable with that of THA prosthesis. However, most of the indications of HRA in the Western cohorts were osteoarthritis [32].

In this study, we retrospectively reviewed 202 consecutive HRAs performed in patients with ONFH using three different implant types. The overall implant survival rate was 90.4% at an average follow-up of 10.6 years. After excluding the ASR implant, the survivorship was remarkably high at 99%, even including the earliest surgeries performed in our institution with the BHR system. This result may be due to the surgical principle we applied. We removed as much of the weak necrotic bone as possible until normal or reactive bone was observed. The femoral component was fixed by cementing onto the dense white bone with additional anchoring holes. Using this technique, several other groups have also reported favourable outcomes of HRA for ONFH. Nakasone

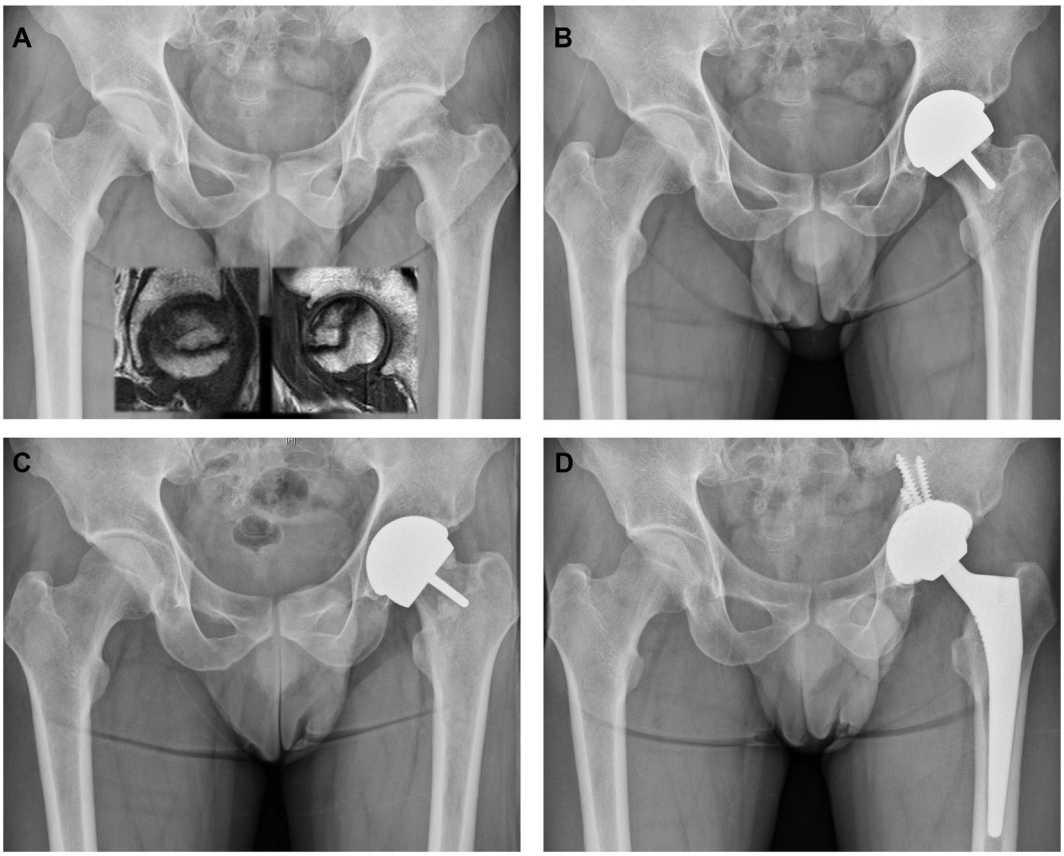

Fig. 2. **(A)** Anteroposterior radiograph of a 34-year-old man with Association Research Circulation Osseous (ARCO) Stage 3B osteonecrosis of the left hip. By using magnetic resonance imaging (MRI), the lesion was classified as Japanese Investigation Committee (JIC) Type C2, and the combined necrotic angle was measured at 316°. **(B)** Hip resurfacing was performed using the articular surface replacement (ASR) device. The measured cup inclination and anteversion angles were 43.6° and 15.2°, respectively. **(C)** The patient had progressive groin pain without trauma at 6 years postoperatively. Follow-up radiograph showed a varus tilt of the femoral component. **(D)** In the revision operation, the femoral implant was loosened without signs of infection or adverse reaction to metallic debris (ARMD). A conversion to cementless total hip arthroplasty was performed.

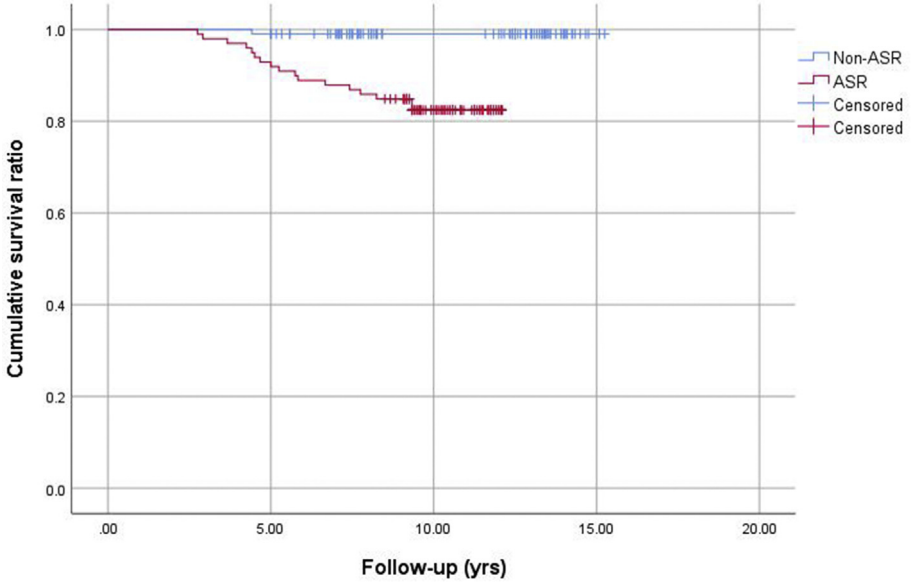

Fig. 3. Kaplan–Meier survival curves with end points of revision for any reason. Implant survival rate of the non-ASR group (99.0%) [95% confidence interval (CI), 97.0–100%] was significantly higher than that of the ASR group (82.4%) (95% CI, 74.8–90.0%) at 10 years (log rank, $P < 0.001$).
ASR = articular surface replacement.

Table 5
Univariate and multivariate logistic regression analyses for any revision.

Variables	*p* value (univariate)	Adjusted OR	95% CI	*p* value (multivariate)
Age	0.216	1.03	0.98–1.08	
Female gender	0.080	3.48	0.86–14.03	0.638
Body mass index	0.903	0.99	0.84–1.17	
Stage (3B, 4)	0.002	4.80	1.77–13.0	0.251
Location of lesion (Type C2)	<0.001	14.5	4.79–43.8	0.523
Lesion size (Kerboul angle)	<0.001	1.05	1.03–1.07	<0.001
Implant (ASR)	0.003	21.2	2.76–162	0.003
Head size	0.032	0.79	0.64–0.98	0.008
Cup size	0.179	0.88	0.73–1.06	
Cup inclination	0.511	1.04	0.92–1.17	
Cup anteversion	0.112	1.12	0.97–1.30	
Neck–shaft angle	0.978	1.00	0.87–1.15	
Stem–shaft angle	0.274	1.06	0.96–1.17	

OR = odds ratio; CI = confidence interval; ASR = articular surface replacement.

et al. [16] reported 2 revisions among 39 HRAs using BHR after a mean follow-up of 8 years, whereas Amstutz et al. [15] reported 90.3% of implant survivorship at 15 years using the CP design. However, this technique does not necessarily guarantee the success of HRA, particularly for large lesions. In such a condition, substantial amount of the weight-bearing portion in the femoral head has to be replaced by acrylic cement. Sakagoshi et al. [34] revealed that the extent of cement replacing the defect correlates with the strain at the bone–cement interface.

To the best of our knowledge, no study has reported the upper threshold regarding the extent of ONFH safe for HRA. Our question was whether the extent and location of the ONFH influenced failures of HRA. We used preoperative MRI and plain radiographs to determine the stage, size, and location of ONFH. As a result, greater combined necrotic angle (modified Kerboul angle) and lateral extension (JIC Type C2) of the necrotic lesion were found to be contributors of mechanical failure in the univariate analysis. However, these two measurements are strongly associated with each other. For a lesion with large combined necrotic angle, there is a higher chance of extension to the lateral pillar of the weight-bearing dome (JIC Type C2). After performing multivariate analysis, the modified Kerboul necrotic angle remained as the sole lesion-related risk factor, with odds ratio significantly high for lesions with an angle greater than 300°. Several authors classified large necrotic lesions as having a Kerboul angle greater than 300° [25,35]. Therefore, we can consider that a large necrotic lesion is associated with greater risk of mechanical failure of the femoral components of HRA.

However, the interpretation of this result requires some care. It is important to note that 5 of the 6 mechanical failures of femoral implant occurred in the ASR group. The design-related problems, such as increased wear rate and edge-loading, cup deflection, and instability, may have additionally contributed to the failure of HRA [36]. Apart from that, the ASR group also demonstrated worse clinical scores, more osteolytic lesions, and higher metal concentrations compared with that of the other implants. Although the differences in metal levels between the 2 groups appeared to decrease over time, these results were affected by the exclusion of poorly functioning ASR devices revised in the earlier period. Excessive metal ion release from such device was responsible for the high standard deviation of metal concentrations found in the ASR group at 1 year and 2 years. Although most of the surviving ASR implants

Table 6
Univariate and multivariate logistic regression analyses for mechanical failure at the femoral side.

Variables	*p* value (univariate)	Adjusted OR	95% CI	*p* value (multivariate)
Age	0.368	1.04	0.96–1.13	
Female gender	0.999	—	—	
Body mass index	0.332	1.15	0.87–1.52	
Stage (3B, 4)	0.995	—	—	
Location of lesion (Type C2)	0.006	20.8	2.36–183	0.178
Lesion size (Kerboul angle)	0.001	1.04	1.02–1.06	0.029
Implant (ASR)	0.126	5.43	0.62–47.3	
Head size	0.306	0.84	0.59–1.18	
Cup size	0.889	1.02	0.73–1.43	
Cup inclination	0.901	0.99	0.79–1.23	
Cup anteversion	0.498	1.09	0.86–1.37	
Neck–shaft angle	0.315	0.89	0.70–1.12	
Stem–shaft angle	0.392	0.94	0.80–1.09	

OR = odds ratio; CI = confidence interval; ASR = articular surface replacement.

Table 7
Serial concentrations of serum cobalt and chromium (μg/L).

Cobalt	All	Non-ASR	ASR	*p* value[a]	*p* value[b]
1 year	3.08 ± 10.4 (*n* = 107)	1.39 ± 1.02 (*n* = 49)	4.50 ± 13.9 (*n* = 58)	0.096	0.231
2 years	5.06 ± 16.2 (*n* = 113)	1.57 ± 0.85 (*n* = 45)	7.38 ± 20.6 (*n* = 68)	0.023	
4 years	2.87 ± 5.05 (*n* = 122)	1.96 ± 3.69 (*n* = 57)	3.67 ± 5.90 (*n* = 65)	0.054	
6 years	2.26 ± 3.44 (*n* = 104)	1.67 ± 1.63 (*n* = 45)	2.71 ± 4.30 (*n* = 59)	0.092	
8 years or more	1.90 ± 1.61 (*n* = 104)	1.59 ± 1.00 (*n* = 40)	2.09 ± 1.87 (*n* = 64)	0.080	
Chromium	**All**	**Non-ASR**	**ASR**	***p* value[a]**	***p* value[b]**
1 year	4.96 ± 2.73 (n = 96)	2.60 ± 1.65 (*n* = 45)	7.05 ± 12.4 (*n* = 51)	0.014	0.274
2 years	6.40 ± 15.4 (*n* = 112)	3.00 ± 1.37 (*n* = 44)	8.60 ± 19.4 (*n* = 68)	0.021	
4 years	4.67 ± 5.72 (*n* = 120)	3.62 ± 4.12 (*n* = 55)	5.56 ± 6.69 (n = 65)	0.055	
6 years	4.07 ± 4.70 (*n* = 104)	3.26 ± 2.33 (*n* = 45)	4.69 ± 5.85 (*n* = 59)	0.091	
8 years or more	3.65 ± 2.88 (*n* = 104)	3.17 ± 1.33 (*n* = 40)	3.96 ± 3.50 (*n* = 64)	0.107	

The values are given as the mean and the standard deviation.
ASR = articular surface replacement.
[a] *p* value by between-group comparison at each follow-up.
[b] *p* value by generalised linear mixed model with adjustment for group-by-time interaction.

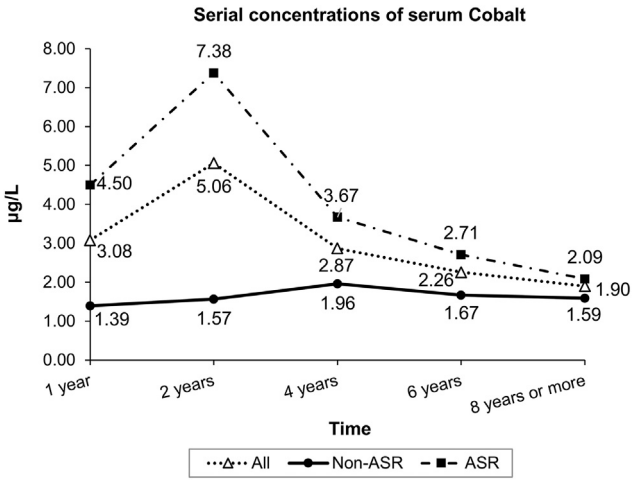

Fig. 4. Serial serum cobalt concentrations (μg/L) at each postoperative year. The mean concentration was higher in the ASR group at 2 years (P = 0.023). ASR = articular surface replacement.

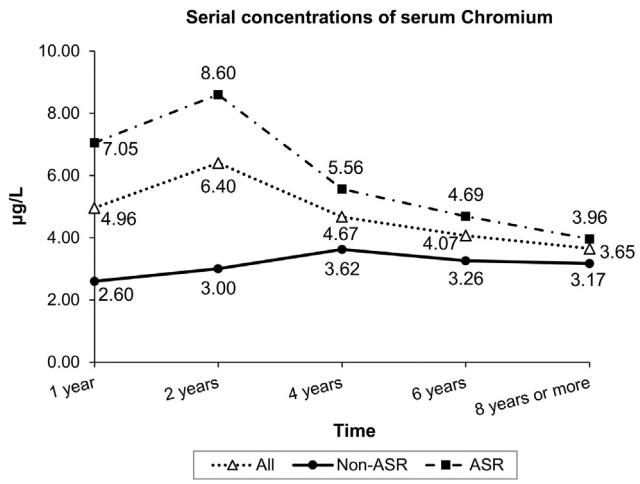

Fig. 5. Serial serum chromium concentrations (μg/L) at each postoperative year. The mean concentrations were higher in the ASR group at 1 year (P = 0.014) and 2 years (P = 0.021).
ASR = articular surface replacement.

demonstrated acceptable metal concentrations [37], longer observations are required to determine whether these levels are maintained and do not lead to complications.

In recent years, the great success of highly cross-linked polyethylene as a bearing surface brought about scepticisms on the role for MoM HRA. Many surgeons argue that HRA is technically demanding and costly, with only a slight improvement in the functional outcome [7]. This may be true for patients with osteoarthritis; however, ONFH often involves very young patients. The mean age of patients in this cohort was only 38 years. Unlike gradually progressing characteristics of osteoarthritis, ONFH develops rapidly and becomes symptomatic suddenly. It is especially beneficial for these patients to return to predisease status, as they have usually been leading a healthy, unlimited life. Moreover, HRA may be a good bone-salvaging strategy for the future for these young patients. Female sex, smaller head size, and patient with a history of metal hypersensitivity are well-known patient-related risk factors for failures of MoM HRA. In this study, female sex reached marginal significance in univariate analysis, partially because of the small number of females in the study population. Considering these factors, HRA is currently considered in our institution for men younger than 45 years with high functional demand when the combined necrotic angle is less than 300°. The following outcomes may be improved after applying this indication.

There are several limitations in the present study. First, owing to its retrospective study design, several patients were lost to follow-up, and some of the metal concentrations were unavailable. Second, the measurement of necrotic lesion using cross-sectional images can be inaccurate, as size can vary greatly depending on the slice thickness of the imaging devices. For more accurate measurements, quantitative computation is required using a standardised three-dimensional MRI [38]. Third, each implant was used in different periods. We used the latest devices in expectation of better results as more advanced instruments were developed. However, it was rewarding to know that the BHR prosthesis used during the surgeon's earliest learning curve period demonstrated more favourable results than any other implants. Fourth, we did not measure the contact patch to rim distance, which had been known as one of the strongest predictors for edge-loading on MoM bearings [39,40]. Finally, for these very young patients, 10 years of observation may not be sufficient; a future study with longer follow-up duration is required.

In conclusion, resurfacing arthroplasty for ONFH using BHR and CP implants demonstrated favourable clinical outcomes, with high revision-free survival rates at a mean follow-up of 10 years. The use of ASR implant, smaller head size, and larger necrotic lesion were responsible for early revision surgery. For mechanical failure of the femoral component, a large combined necrotic angle was found to be the only independent risk factor. Care should be taken in the case of large necrotic lesion that can lead to femoral neck fracture or aseptic loosening of the femoral component.

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Conflict of interest statement

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