Clin Orthop Relat Res (2015) 473:3770–3778
DOI 10.1007/s11999-015-4348-0

Clinical Orthopaedics and Related Research®
A Publication of The Association of Bone and Joint Surgeons®

CrossMark

SYMPOSIUM: 2014 INTERNATIONAL HIP SOCIETY PROCEEDINGS

Frequent Femoral Neck Osteolysis With Birmingham Mid-head Resection Resurfacing Arthroplasty in Young Patients

Asaad Asaad MD, MSc, Alister Hart MA, MD, Michael M. Y. Khoo BSc, MBBS, Kevin Ilo BSc, Gavin Schaller BSc, Jonathan D. J. Black MBBS, MSc, Sarah Muirhead-Allwood BSc, MBBS

Published online: 16 May 2015

Abstract

Background Mid-head resection total hip resurfacing arthroplasty was promoted as an alternative to traditional total hip resurfacing for patients with poor femoral head bone quality or abnormal femoral head morphology, because those patients are at high risk of failure with traditional total hip resurfacing. It is a large-headed metal-on-metal device that uses a short, bone-conserving stem. Good performance of the implant has been reported at short-term followup, but no information on the implant performance in the mid- or long-term is available.

Questions/purposes In this study, we report (1) on the mid-term implant survivorship and hip scores in a single nondesigner surgeon series. Because of the occurrence of femoral neck osteolysis and pseudotumor in a subgroup of patients, we also investigated the following: (2) Were there any preoperative parameters that are associated with osteolysis? (3) Could we differentiate the osteolysis group from the others on the basis of implant component sizes, positions, and radiologic parameters? (4) Could we differentiate the osteolysis group from the others on the basis of metal ion levels?

Methods Between 2006 and 2011, one surgeon performed a total of 49 Birmingham Mid-head Resection total hip resurfacing arthroplasties in 47 patients. The general indications for this procedure were young patients who were considered suitable for hip resurfacing arthroplasty but had avascular necrosis, large cysts, or severe deformity of the femoral head. Clinical followup including Oxford Hip Score (OHS) and UCLA hip scores were available preoperatively and at a mean of 6 years (range, 3–8 years) on all patients (100%), radiographic followup on 45 of 47 (96%), MRIs on 18 (38%), and metal ion levels on 37 (79%). Mean age at surgery was 50 years. Spearman's correlation was used to test the association between femoral neck osteolysis and preoperative parameters, implant component sizes and positions, and blood metal ion levels.

Results We found 100% survival. Patients' median OHS was 46 of 48 (range, 35–48) and UCLA 8 of 10 (range, 4–10). However, 16% of the hips (seven of 45) demonstrated osteolysis in the femoral neck. Of the preoperative parameters, the osteolysis was associated with low weight ($r = -0.337$, $p = 0.031$) and to a lesser degree with female sex ($r = 0.275$, $p = 0.067$). Radiologically, the osteolysis was strongly associated with the presence of a

Each author certifies that he or she, or a member of his or her immediate family, has no funding or commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.
All ICMJE Conflict of Interest Forms for authors and *Clinical Orthopaedics and Related Research*® editors and board members are on file with the publication and can be viewed on request.

Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.
This work was performed at the London Hip Unit, London, UK.

A. Asaad (✉), G. Schaller, J. D. J. Black, S. Muirhead-Allwood
The London Hip Unit, 30 Devonshire Street, London W1G 6PU, UK
e-mail: asaad.asaad.10@ucl.ac.uk; asaadmarwan@gmail.com

A. Asaad, A. Hart, K. Ilo
Institute of Orthopaedic and Musculoskeletal Science, University College London, The Royal National Orthopaedic Hospital, London, UK

M. M. Y. Khoo
The Royal National Orthopaedic Hospital, London, UK

pseudotumor on MRI (r = 0.663, p = 0.004). We could not differentiate the osteolysis group from the rest of the cohort on the basis of the implant sizes or radiographic implant component positions. The cohort's median whole blood cobalt was 1.77 ppb (range, 0.18–10.27 ppb) and chromium 1.88 ppb (range 0.36–10.09 ppb). There was no difference in the metal ion levels between the osteolysis group and the rest of the cohort.

Conclusions The high rate of silently developing femoral neck osteolysis associated with this implant is concerning and is expected to cause a high rate of failure at longer followup. We have instituted a program of annual clinical and radiologic followup for this group of patients. We have stopped implanting this device and recommend against its use.

Level of Evidence Level IV, therapeutic study.

Introduction

Mid-head resection (MHR) is a bone-conserving total hip resurfacing arthroplasty procedure developed as an alternative to traditional total hip resurfacing implants in young patients who have poor femoral head bone quality or abnormal femoral head morphology [35, 36], because patients with these conditions were found to be at higher risk of failure of traditional hip resurfacing [1, 2, 4, 11, 12, 14, 40, 46]. The level of bone resection in MHR is distal to that of hip resurfacing, thereby offering the opportunity to resect poor quality bone (eg, avascular necrosis [AVN] or large cysts). It differs from other neck-preserving prostheses in that its resection level runs through the middle of the femoral head rather than the head-neck junction. Allowing the load to go through the conically shaped head-neck junction would theoretically prevent stress shielding in the femoral neck [15, 35, 36], a complication reported in other neck-preserving hip implants [7, 18, 23, 30, 38, 45].

The use of conventional long-stemmed large-headed metal-on-metal (LHMoM) hip implants has been discontinued in the United Kingdom as a result of poor results and high failure rates [9, 31, 37, 47]. Recently, a European multidisciplinary consensus study group, endorsed by the European Federation of National Associations of Orthopaedics and Traumatology, the European Hip Society, and the German Osteoarthritis Society, has expressed concerns regarding the safety of metal-on-metal (MoM) hip implants in general and advised close monitoring of both LHMoM conventional hip replacement implants as well as hip resurfacing implants [21]. The Medicines and Healthcare products Regulatory Agency (MHRA) has issued a safety alert and strict management protocols for stemmed LHMoM implants, which are different from their protocols for the management of traditional hip resurfacing implants [37]. However, no followup protocols specifically exist for short-stemmed MoM implants such as the Birmingham Mid-head Resection (BMHR; Smith & Nephew Orthopaedics Ltd, Warwick, UK). BMHR is an LHMoM implant and may be expected to perform similarly to the notorious conventional long-stemmed LHMoM implants. It does, however, use a different fixation (neck-fixed rather than shaft-fixed) and load-bearing concept, and all the currently available studies on BMHR (including those by the authors) report promising short-term results [13, 35, 43, 44]. Little is known about its mid- to long-term performance, and no information about its outcome was provided in the latest report of the UK National Joint Registry [39]. In this study we aimed to better understand the performance of a short-stemmed large-headed MoM bone-conserving hip implant by assessing the mid-term performance of the BMHR in our unit.

In this study, we report (1) on the mid-term implant survivorship and hip scores in a single nondesigner surgeon series. Because of the occurrence of femoral neck osteolysis and pseudotumor in a subgroup of patients, we also investigated the following: (2) Were there any preoperative parameters that are associated with osteolysis? (3) Could we differentiate the osteolysis group from the others on the basis of radiographic implant component positions (cup inclination and stem-shaft angle)? (4) Could we differentiate the osteolysis group from the others on the basis of metal ion levels?

Materials and Methods

This is a retrospective analysis of a prospectively maintained clinical registry supplemented by analysis of radiographs and metal ion levels, which were gathered in the course of routine clinical care.

Between 2006 and 2011, one surgeon (SM-A) performed a total of 49 BMHR total hip resurfacing arthroplasties in 47 patients. The general indications for this procedure were young, active patients who would benefit from a bone-conserving total hip resurfacing arthroplasty, but in whom traditional hip resurfacing was contraindicated because they had AVN, large cysts, or abnormal morphology of the femoral head or acetabulum. The patients' age in our cohort ranged from 24 to 69 years (mean ± SD, 50 ± 9 years) and they included 20 females (41%). Their mean (and SD) height was 171 ± 9.3 cm, weight 74.4 ± 15.3 kg, and body mass index 25.2 ± 4 kg/m^2. The mean followup was 6 years (range, 3–8 years) and in terms of implant survivorship, no patients were lost to followup. The preoperative diagnoses in our cohort were: femoral head AVN (19 cases), osteoarthritis with severe cystic changes in the femoral head (13), severe slipped

Table 1. A breakdown of the BMHR types and sizes used

Characteristic	n = 49 hips
Type of BMHR (number)	
V1	41
VST	8
Acetabular cup/femoral head/stem sizes (number [%])	
62/56/4	2 (4.1)
58/52/4	8 (16.3)
58/52/3	1 (2)
56/50/4	2 (4.1)
56/50/3	2 (4.1)
54/48/3	14 (28.6)
54/48/2	2 (4.1)
52/46/2	1 (2)
50/44/2	17 (34.7)

BMHR = Birmingham Mid-Head Resection; VST = visual stop technology.

upper femoral epiphysis (three), severe hip dysplasia (two), post-Perthes' osteoarthritis (one), severe femoral head deformity secondary to a previous septic arthritis (one), osteoarthritis with a femoral head size that was considered too small for a traditional resurfacing (two), and in eight cases, the decision to perform this procedure was made intraoperatively as a result of finding the femoral head bone quality too poor for traditional resurfacing.

The implants we used were the V1 and visual stop technology (VST) versions of the BMHR. They feature an uncemented titanium alloy stem with a proximal hydroxyapatite (HA)-coated porous surface. The distal part of the stem is not HA-coated and has longitudinal antirotational flutes [15, 35]. The V1 and VST versions of the BMHR are different in that the VST is shorter and has a proximal lipped edge to allow visual confirmation of the complete seating of the stem in the proximal femur intraoperatively, thereby avoiding the need for excessive stem impaction that may risk creating log-splitting fractures [35]. The BMHR uses a MoM bearing surface identical to that of the Birmingham Hip Resurfacing (BHR) [13, 35] and consists of a modular large-diameter cobalt-chrome alloy head articulating with an uncemented cobalt-chrome acetabular component. The modular cobalt-chrome head fits onto a 12/14 titanium alloy stem taper junction [13]. The acetabular cup sizes that we used ranged from 50 to 62, the femoral head sizes from 44 to 56, and stem sizes from 2 to 4 (Table 1).

Preoperatively, patients were assessed using plain AP pelvis and lateral hip radiographs looking for AVN, large cysts, or severe deformity of the femoral head, as advised by the implant developers [13, 35, 36]. Patients with severe hip dysplasia were further assessed and planned using preoperative CT, and where the plain radiographs were suspicious of reduced bone density in the femoral neck, a preoperative dual-energy x-ray absorptiometry scan was performed. In patients in whom the aforementioned investigations were equivocal in deciding the suitability or otherwise for traditional hip resurfacing, patients were consented for both procedures and the assessment was made on the operating table. Preoperative Oxford Hip Score (OHS) [16] and UCLA hip score [51] were recorded in all patients. All operations were performed using a posterior approach. The details of the operative technique and postoperative care have been described previously [43, 44].

Patients were routinely reviewed in the clinic at 1, 3, and 12 months after surgery, where they had a clinical examination, a standardized AP pelvis (including both hips) and a crosstable lateral hip radiograph of the operated hip, and hip scores. Thereafter, patients were advised to attend followup every 1 to 2 years. For this study, all patients were contacted and their revision status updated. Those who had not had a clinical and radiographic assessment in the last 12 months were invited for one, and patients living overseas or away from London were contacted by telephone (eight patients) and asked to complete posted hip questionnaires (OHS and UCLA), and a letter was sent to their general practitioners explaining the need for radiographic followup and measurement of the blood metal ions. The digital radiographs and blood metal ions test reports of those who complied with our instructions were forwarded to us for assessment.

Radiographs from the most recent followup were analyzed by two reviewers (SM-A, AA). We have complete radiographic followup on 45 patients (45 hips [96%]). Femoral and acetabular component loosening was assessed according to Amstutz et al. [4] and DeLee and Charnley [17] criteria. Component angles, spot welding, and neck narrowing were assessed using the method described by McMinn et al. [35] and Hing et al. [26].

All patients attending followup after 2 years from surgery were advised to have assessment of their whole blood cobalt and chromium levels. The whole blood samples were taken from the patients by a specialist nurse at The Princess Grace Hospital (London, UK) and sent to HCA Laboratories (London, UK), which, in turn, sent the samples to the Clinical Chemistry Department at Charing Cross Hospital, Imperial Healthcare College NHS Trust, London, UK (a participating laboratory of the Trace Element External Quality Assessment Scheme) for inductively coupled plasma-mass spectroscopy (ICP-MS) analysis of chromium and cobalt concentrations. We have complete metal ions followup on 37 of the 47 patients (79%). Four of those patients had their metal ions tests arranged by their general practitioners and sent to their local laboratories but were also analyzed using ICP-MS analysis of whole blood.

Patients who reported symptoms in or around their operated hip at more than 1 year after surgery, those found to have high blood cobalt or chromium (> 7 ppb), and those with osteolysis on radiographs were further investigated using MRI with metal-artifact reduction sequence (MARS) technology. We have hip MRI followup on 18 patients (38%). All MRIs were analyzed by a consultant musculoskeletal radiologist (MMYK). Pseudotumors were classified using Hart et al.'s system [22], and periarticular muscle atrophy was assessed using Pfirrmann et al.'s grading [42] (Grade 0 = no intramuscular fat; Grade 1 = some intramuscular fat streaks; Grade 2 = evident fat, but less than the muscle tissue; Grade 3 = equal amounts of fat and muscle; Grade 4 = more fat than muscle tissue).

Statistical analysis was performed using IBM SPSS Statistics software Version 21 for Mac (IBM Corp, New York, NY, USA) [29]. The Kaplan-Meier method was used to determine the cumulative survivorship of the implant, considering revision surgery in the form of removal or exchange of any of the BMHR components as the endpoint for survival analysis. The Shapiro-Wilk test was used on relevant data to test for normality. Normally distributed variables were described using the mean and SD, and for variables with skewed distribution, we used the median and the range. The improvement in OHS and UCLA was assessed using a paired t-test and the Mann-Whitney U test was used to compare the postoperative OHS and UCLA scores between males and females. Spearman's correlation was used to test the association between femoral neck osteolysis and the preoperative parameters (patients' age, sex, height, weight, body mass index, and preoperative scores), the association between osteolysis and the implant sizes, positions and radiologic parameters (spot welding and pseudotumors), and the association between osteolysis and the blood metal ions. Spearman's correlation was also used to assess the relationship between blood metal ions, hip scores, patients' demographics, implant sizes, and positioning. The level of significance was set at $p < 0.05$.

Results

Survivorship and Hip Scores

The final outcome of BMHR was obtained for all patients with no loss to followup. Survivorship at mean 6 years (range, 3–8 years) was 100% for both implant revision and reoperation for any reason as endpoints. There was one patient who died of advanced bowel cancer at 5 years after surgery. This patient did not undergo implant revision and had an OHS of 48 at last followup.

Patients' median OHS (using the 48-point OHS) improved from 26 (range, 16–35) preoperatively to 46 (range, 35–48), and UCLA score improved from 5 (range, 2–8) to 8 (range, 4–10) at latest review (paired t-test $p < 0.001$ for both). There was no difference in median OHS scores for males (47; range, 43–48) and females (46; range, 35–48) or in the median postoperative UCLA scores between males (8; range, 5–10) and females (8; range, 4–10) (Mann-Whitney U $p = 0.293$ and $p = 0.115$, respectively).

Radiological Analysis

The median acetabular component inclination for the cohort was 37° (range, 26°–49°) and mean stem shaft angle was 141° (range, 127°–154°). Femoral neck thinning was found in 12 cases (27%), spot welding in 16 (36%), and femoral neck osteolysis in seven (16%) (Table 2). These seven osteolysis cases in seven patients included two males and five females. One of the seven patients did not undergo metal ion testing; none of the other six had elevated metal ions. Only one of the seven osteolysis cases had acetabular osteolysis in DeLee Zone 1. Five were associated with spot welding; and five had pseudotumors on MARS MRIs and ultrasound scan (Tables 3, 4; Fig. 1A–D).

Preoperative Parameters and Osteolysis

The preoperative parameters that had a statistically significant association with the development of osteolysis were low patient's weight ($r = -0.337$, $p = 0.031$), and low body mass index ($r = -0.356$, $p = 0.024$). The female sex showed moderate correlation with osteolysis but this correlation did not reach statistical significance threshold ($r = 0.275$, $p = 0.067$). No statistically significant correlation was found between osteolysis and patients' age, height, or preoperative OHS and UCLA scores (Table 5).

Radiologic Parameters and Implant Component Sizes and Osteolysis

No association was found between femoral neck osteolysis and the radiographic parameters of cup inclination, stem-shaft angle, or spot welding; and no association was found between femoral neck osteolysis and the sizes of the implant femoral head, cup, or stem (Table 6). However, osteolysis was strongly associated with the presence of pseudotumors on MARS MRI scans ($r = 0.663$, $p = 0.004$).

Metal Ion Levels and Osteolysis

With the numbers available, there was no correlation between metal ion levels and the occurrence of femoral neck osteolysis. No statistically significant correlation was

Table 2. Radiographic findings

Radiographic parameter	Acetabular/ femoral loosening	Femoral neck thinning	Spot welding	Femoral neck osteolysis	Acetabular osteolysis	Radiographic evidence of impingement
Number of cases	0	12	16	7	1	3
Prevalence	0%	27%	36%	16%	2%	7%
Details and breakdown		All in V1	V1: 15 VST: 1	V1: 6 VST: 1	In DeLee Zone 1	Anterior cortex: 1 (symptomatic); lateral cortex: 2 (asymptomatic)

VST = visual stop technology.

Table 3. Demographic and clinical details of the seven osteolysis cases

Case number/sex/ age (years)	Height (cm)/weight (kg)/BMI (kg/m^2)	Followup (years)	BMHR indication	Cup/head/ stem size	Cobalt / chromium (ppb)	OHS/ UCLA
1/M/55	179/84.0/26.2	6.7	Slipped upper femoral epiphysis	58/52/4	1.36/2.29	48/9
2/F/63	157/53.5/21.7	5.7	Poor bone at surgery	50/44/2	3.13/1.82	44/10
3/F/51	163/60.4/22.7	5.6	Severe dysplasia	54/48/3	1.95/2.55	48/8
4/F/55	167/53.0/19.0	5.6	Poor bone at surgery	54/48/3	1.95/1.56	48/8
5/F/64	160/60.0/23.4	5.6	Head too small†	50/44/2	Not available	39/4*
6/F/38	170/69.7/24.1	5.5	Large femoral cysts	50/44/2	2.83/3.38	46/8
7/M/40	181/64.0/19.5	2.9	Slipped upper femoral epiphysis	54/48/3	1.95/2.6	48/8

* Patient 5 related her low OHS and UCLA to the severe scoliosis for which she is awaiting corrective surgery, not to her asymptomatic hip; †head too small for traditional resurfacing; BMI = body mass index; BMHR = Birmingham Mid-head Resection; OHS = Oxford Hip Score; M = male; F = female.

Table 4. MRI findings in the osteolysis cases

Case number	Muscle atrophy grade (0–4) [35]					Any tendon disruption?	Pseudotumor		
	Iliopsoas	Gluteus minimus	Gluteus medius	Gluteus maximus	Short external rotators		Type [18]	Site	Size (cm)
1	1	1	0	0	1	No	2B	Anterior	1 × 1.5 × 3.5
2	0	2	0	0	3	No	2B	Anterior, inferior, and intrapelvic	4.4 × 4.4 × 12.7
3	0	1	1	0	1	No	1	Anterior	1.4 × 1.5 × 5.2
4	0	2	0	0	1	No	No pseudotumour	N/A	N/A
5	Ultrasound scan (US) was used. No MRI					No	Cystic pseudotumour on US		
6	0	2	0	0	1	No	2B	Anterior	2.8 × 3.6 × 4.3
7	0	1	0	0	0	No	No pseudotumour	N/A	N/A

N/A = not applicable.

found between osteolysis and the whole blood cobalt level (r = 0.11, p = 0.535) or chromium level (r = 0.094, p = 0.592). In the osteolysis group the median cobalt level was 1.94 ppb (range, 1.36–3.13 ppb) and the median chromium level was 2.42 ppb (range, 1.56–3.38 ppb), whereas the patients with no osteolysis had median cobalt of 1.76 ppb (range, 0.18–10.27 ppb) and median chromium of 1.82 ppb (range, 0.36–10.09 ppb). Comparing the two groups showed no statistically significant difference in the levels of cobalt or chromium (Mann-Whitney U p = 0.551 and p = 0.593, respectively). The cohort's median cobalt was 1.77 ppb (range, 0.18–10.27 ppb) and chromium 1.88 ppb (range, 0.36–10.09 ppb). Only one patient in the cohort had raised cobalt and chromium (10.27 and

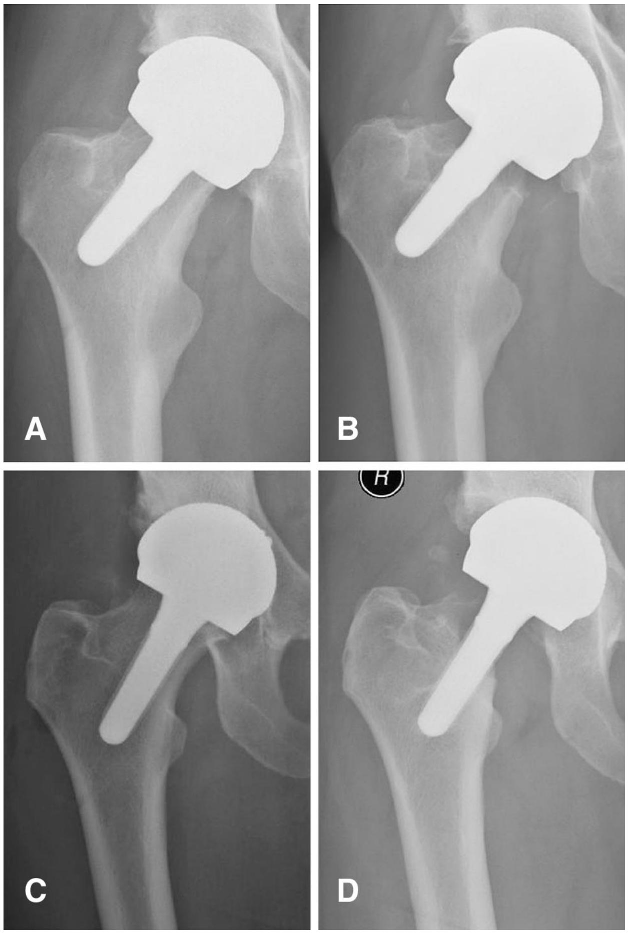

Fig. 1A–D Plain hip radiographs of two patients taken immediately postoperatively (**A** and **C**) and at 3 years (**B**) and 6 years (**D**) followup showing femoral neck osteolysis. The patient in **A** and **B** had the VST version, and the patient in **C** and **D** had the V1 version of the BMHR.

10.09 ppb, respectively) but was asymptomatic with OHS 48 and no adverse radiographic features. His MARS MRI showed a 2-cm-diameter area of osteolysis in the superior pubic ramus but no pseudotumor and no acetabular or femoral neck osteolysis. A positive correlation was found between patients' activity level (postoperative UCLA score) and the levels of cobalt ($r = 0.447$, $p = 0.004$) and chromium ($r = 0.346$, $p = 0.042$) in the blood. No correlation was found between the blood levels of cobalt and chromium and the implant components sizes, positions, and patients' demographic characteristics.

Discussion

The BMHR device was introduced to provide a bone-conserving alternative to THA in patients who would otherwise be candidates for hip resurfacing. For example, young patients who have poor femoral head bone quality or abnormal femoral head morphology [35, 36] might be considered, because patients with these conditions were found to be at higher risk of failure of traditional hip resurfacing [1, 2, 4, 11, 12, 14, 40, 46]. The level of bone resection in mid-head resection is distal to that of hip resurfacing, thereby offering the opportunity to resect poor quality bone (eg, AVN or large cysts). It differs from other neck-preserving prostheses in that its resection level runs through the middle of the femoral head rather than the head-neck junction. This design sought to overcome the problems of other short-stemmed hip implants, especially proximal femoral neck stress-shielding [7, 18, 23, 30, 35, 36, 38, 45]. In this study we set out to assess the performance of BMHR at mid-term followup. We found a high rate of femoral neck osteolysis, which was contrary to what the implant design and intended load-bearing concept had sought to achieve. We then investigated whether there were any patient-related, implant size- or positioning-related, or metal ion related factors associated with the development of this osteolysis.

Study Limitations

This is a single-surgeon highly selected patient group. Therefore, we may not be able to generalize our results to other surgeons and other patients. In fact, a less selected group may produce far worse results. The small size of the osteolysis group prevented further statistical analysis (such as logistic regression), which would have been helpful in establishing a hazard model for developing osteolysis. We did not have annual radiographic followup of the patients with osteolysis before discovering it during the course of this study. We could not, therefore, establish when the osteolysis started and how fast it had progressed. A longer followup would help in assessing the natural history and fate of the osteolysis cases, but even with the current study findings, we were able to set an early alarm and advise surgeons using this implant on closely monitoring their patients and perhaps using a different design with better established results. Another limitation was that four of 37 patients had their metal ions checked at different laboratories. Although the same analysis technique had been used, we accept that an interlaboratory observer error in those four cases may have had a slight effect on our overall metal ion results. As a result of the small number of cases affected and the large p values of the correlation between the metal ions and osteolysis, we do not think that this limitation would have changed our findings.

At average followup of 6 years, our cohort showed good functional outcome (mean OHS 46 and UCLA 8) and 100% implant survivorship. These functional results are

Table 5. Correlation between femoral neck osteolysis and preoperative parameters

Preoperative parameter		Age	Sex	Height	Weight	BMI	Preoperative OHS	Preoperative UCLA
Osteolysis	R	0.071	0.275	−0.160	−0.337	−0.356	0.130	0.087
	p value	0.644	0.067	0.324	0.031	0.024	0.394	0.594

BMI = body mass index; OHS = Oxford Hip Score.

Table 6. Correlation between femoral neck osteolysis and implant sizes and radiographic parameters

Implant-related parameters		Cup inclination	Stem-shaft angle	Cup size	Femoral head size	Stem size
Osteolysis	R	−0.137	−0.215	−0.12	−0.12	−0.66
	p value	0.381	0.156	0.431	0.431	0.669

comparable to the BMHR results of the implant developers at 3.5 years followup [35]. They are also comparable to the mid-term functional and survivorship results of various currently used, traditional hip resurfacing systems [3, 8, 25, 41, 49] and far better than the mid-term survivorship and functional results of conventional MoM THA [9, 31, 32, 47]. So, despite the fact that the BMHR is technically considered a stemmed LHMoM implant, its design, fixation (neck-fixed), and loading-bearing concepts [35, 36] appear to produce a clinical performance that is better than the notorious traditional stemmed LHMoM THAs and comparable to traditional resurfacing arthroplasties at mid-term.

The radiological analysis, however, revealed a high rate of femoral neck thinning (27%) and osteolysis (16%). The only available BMHR study to which we can compare our results is McMinn et al.'s [35], who reported no osteolysis in their BMHR cohort and five hips (4%) with stress shielding out of a total 115 V1 and VST hips. Their neck thinning rate (6.1%) was much lower than ours too. This may be because of the longer followup of our cohort (mean, 6 versus 3.5 years). Neck thinning has been widely reported in different types of resurfacing implants with incidence rates of up to 77% [26] and 90% [48] and no adverse effects on patients. Femoral neck osteolysis, on the other hand, was the main concerning radiological feature. Seven patients (16%) in our cohort had osteolysis affecting 50% to 75% of the length of their femoral necks (between the center of the femoral head and the intertrochanteric line), all of whom were asymptomatic. The etiology of this osteolysis is uncertain and with the number of cases available, we could only try to assess its association with the various preoperative and postoperative parameters.

Of the preoperative parameters, only low patient weight has shown a statistically significant association with osteolysis ($r = -0.356$, $p = 0.024$). The female sex was moderately associated too but did not reach statistical significance ($r = 0.275$, $p = 0.067$). We believe that a larger cohort size may accentuate the association between osteolysis and female sex. We could not explain the association between low patient weight and the development of osteolysis, but there have been several reports in the literature associating female sex with adverse reaction to metal debris (ARMD) [19, 34, 47], which may be the etiology of osteolysis in BMHR too.

In terms of radiologic parameters, we found strong association between osteolysis and pseudotumors found on MRI scans ($r = 0.663$, $p = 0.004$). This adds weight to the theory that the osteolysis is a feature of ARMD. The metal debris in BMHR may come from the wear of the bearing surface or the corrosion of the BMHR taper junction. Cobalt, chromium, and titanium have been shown to affect bone turnover in animal studies by decreasing bone formation and inducing resorption [20, 24], and all three metal ions can be released from the BMHR device. However, all patients with osteolysis in our series had normal blood metal ion levels; and pseudotumors have been found common in well-functioning low-wearing MoM hips with no osteolysis [22, 33]. In addition, in ARMD, one would expect the osteolysis to affect both the acetabular and the femoral neck bone, a finding noted in previous papers on osteolysis associated with MoM hips [10, 28]. In our series the osteolysis only affected the femoral neck, except in one case (the most severe case) in which it did affect the acetabular bone (Fig. 1D). This suggests an additional element of stress shielding affecting the femoral neck or a design-related mechanism concentrating the osteolysis in the femoral neck bone. McMinn et al. [35], who reported five cases of stress shielding in patients who received the V1 version of BMHR, theorized that the stress shielding had happened because the relatively long V1 stem had approached the femoral cortices and caused spot welding and subsequent preferential load-bearing passing through the metal stem directly to the spot welding regions, grossly bypassing and stress-shielding the proximal femoral neck. He found no stress shielding in the cases that received the newer shorter VST version. In our cohort, one of the osteolysis cases had a VST stem, and we found no statistically significant association between spot welding and osteolysis. With regard to the implant design, the HA coating in BMHR is restricted to the proximal part of the short stem [13, 35, 36]; and there is no HA coating on the inside of the femoral head component. Joint fluid (containing metal debris) may, therefore, ingress between the femoral head component and the underlying exposed cancellous bone of the cut femoral head. This is less likely to happen in the acetabular bed as a result of the HA coating of the acetabular cup, which seals the implant-bone interface. Zicat et al. [52] and Urban et al. [50] have noted an increased risk of osteolysis in the periprosthetic bone of non-MoM implants that had an incomplete or no osseointegration with the uncemented implant as a result of deficient porous coating. Aspenberg et al. [5, 6] proposed an increased fluid pressure in the bone-implant interface that communicates with the hip (eg, as a result of deficient osseointegration) as an inducer of osteocyte death and bone resorption. The cancellous bone of the femoral head and neck in BMHR is subject to both mechanisms as a result of the absent HA coating from the inside of the femoral head component, and both mechanisms may contribute to the osteolysis that was noted radiographically to preferentially affect the femoral neck in BMHR.

With regard to metal ion levels, we found no association between osteolysis and the whole blood levels of cobalt and chromium and there was no difference in the median cobalt and chromium levels between the osteolysis group and the rest of the cohort. Only one case (3%) in our cohort had metal ion levels higher than the MHRA's cutoff level of 7 ppb [37]. Given the small numbers in our cohort, and comparing our 3% prevalence of exceeding the 7-ppb threshold to the 5% prevalence reported in the BHR followup study by Holland et al. [27], no remarkable difference can be seen bearing in mind that the bearing surfaces of both devices have identical characteristics [13, 35] and that the BMHR has an additional potential source of metal ions: the modular head-stem junction.

Conclusion

At mid-term followup, we found excellent results in terms of pain relief and restoration of function. However, despite optimal patient selection of young, fit subjects, we found an alarming rate of osteolysis of the femoral neck. We are highly concerned about the prospect of impending failure and other potential unknown sequelae in patients affected by this as well as the remainder of our cohort. As such, we have instituted a program of annual clinical and radiologic followup for this group of patients. We have stopped implanting this device and recommend against its use.

Acknowledgments We thank Michelle Mote, Danielle Buckley, and Sacha O'Shea for their help in organizing this study and the followup appointments.

References

1. Adili A, Trousdale RT. Femoral head resurfacing for the treatment of osteonecrosis in the young patient. *Clin Orthop Relat Res.* 2003;417:93–101.
2. Amstutz HC, Antoniades JT, Le Duff MJ. Results of metal-on-metal hybrid hip resurfacing for Crowe type-I and II developmental dysplasia. *J Bone Joint Surg Am.* 2007;89:339–346.
3. Amstutz HC, Ball ST, Le Duff MJ, Dorey FJ. Resurfacing THA for patients younger than 50 year: results of 2- to 9-year followup. *Clin Orthop Relat Res.* 2007;460:159–164.
4. Amstutz HC, Beaule PE, Dorey FJ, Le Duff MJ, Campbell PA, Gruen TA. Metal-on-metal hybrid surface arthroplasty: two to six-year follow-up study. *J Bone Joint Surg Am.* 2004;86:28–39.
5. Aspenberg P, van der Vis H. Fluid pressure may cause periprosthetic osteolysis. Particles are not the only thing. *Acta Orthop Scand.* 1998;69:1–4.
6. Aspenberg P, Van der Vis H. Migration, particles, and fluid pressure. A discussion of causes of prosthetic loosening. *Clin Orthop Relat Res.* 1998;352:75–80.
7. Banerjee S, Pivec R, Issa K, Harwin SF, Mont MA, Khanuja HS. Outcomes of short stems in total hip arthroplasty. *Orthopedics.* 2013;36:700–707.
8. Bisseling P, Smolders JMH, Hol A, van Susante JLC. Metal ion levels and functional results following resurfacing hip arthroplasty versus conventional small-diameter metal-on-metal total hip arthroplasty; a 3 to 5 year follow-up of a randomized controlled trial. *J Arthroplasty.* 2015;30:61–67.
9. Bolland BJ, Culliford DJ, Langton DJ, Millington JP, Arden NK, Latham JM. High failure rates with a large-diameter hybrid metal-on-metal total hip replacement: clinical, radiological and retrieval analysis. *J Bone Joint Surg Br.* 2011;93:608–615.
10. Carr AM, DeSteiger R. Osteolysis in patients with a metal-on-metal hip arthroplasty. *ANZ J Surg.* 2008;78:144–147.
11. Daniel J, McBryde C, Pradhan C, Ziaee H. Results of Birmingham Hip Resurfacing in different diagnoses. In: McMinn DJW, ed. *Modern Hip Resurfacing*. London, UK: Springer London; 2009:357–370.
12. Daniel J, Pradhan C, Ziaee H. Patient selection and timing of operation. In: McMinn DJW, ed. *Modern Hip Resurfacing*. London, UK: Springer London; 2009:163–166.
13. Daniel J, Pradhan C, Ziaee H, McMinn DJ. A clinicoradiologic study of the Birmingham Mid-Head Resection device. *Orthopedics.* 2008;31(Suppl 2). pii: orthosupersite.com/view.asp?rID=37186.
14. Daniel J, Pradhan C, Ziaee H, McMinn DJW. Management of complex anatomy. In: McMinn DJW, ed. *Modern Hip Resurfacing*. London, UK: Springer London; 2009:333–347.
15. Daniel J, Pradhan C, Ziaee H, McMinn DJW. Birmingham Mid-Head Resection—the versatile conservative alternative for the complex case. In: Malhotra R, ed. *Total Hip Arthroplasty*. New Delhi, India: Jaypee Brothers Medical; 2012:223–240.
16. Dawson J, Fitzpatrick R, Carr A, Murray D. Questionnaire on the perceptions of patients about total hip replacement. *J Bone Joint Surg Br.* 1996;78:185–190.
17. DeLee JG, Charnley J. Radiological demarcation of cemented sockets in total hip replacement. *Clin Orthop Relat Res.* 1976;121:20–32.

18. Gilbert RE, Salehi-Bird S, Gallacher PD, Shaylor P. The Mayo Conservative Hip: experience from a district general hospital. *Hip Int.* 2009;19:211–214.
19. Glyn-Jones S, Pandit H, Kwon YM, Doll H, Gill HS, Murray DW. Risk factors for inflammatory pseudotumour formation following hip resurfacing. *J Bone Joint Surg Br.* 2009;91:1566–1574.
20. Goodman S, Aspenberg P, Song Y, Knoblich G, Huie P, Regula D, Lidgren L. Tissue ingrowth and differentiation in the bone-harvest chamber in the presence of cobalt-chromium-alloy and high-density-polyethylene particles. *J Bone Joint Surg Am.* 1995;77:1025–1035.
21. Hannemann F, Hartmann A, Schmitt J, Lutzner J, Seidler A, Campbell P, Delaunay CP, Drexler H, Ettema HB, Garcia-Cimbrelo E, Huberti H, Knahr K, Kunze J, Langton DJ, Lauer W, Learmonth I, Lohmann CH, Morlock M, Wimmer MA, Zagra L, Gunther KP. European multidisciplinary consensus statement on the use and monitoring of metal-on-metal bearings for total hip replacement and hip resurfacing. *Orthop Traumatol Surg Res.* 2013;99:263–271.
22. Hart AJ, Satchithananda K, Liddle AD, Sabah SA, McRobbie D, Henckel J, Cobb JP, Skinner JA, Mitchell AW. Pseudotumors in association with well-functioning metal-on-metal hip prostheses: a case-control study using three-dimensional computed tomography and magnetic resonance imaging. *J Bone Joint Surg Am.* 2012;94:317–325.
23. Hayaishi Y, Miki H, Nishii T, Hananouchi T, Yoshikawa H, Sugano N. Proximal femoral bone mineral density after resurfacing total hip arthroplasty and after standard stem-type cementless total hip arthroplasty, both having similar neck preservation and the same articulation type. *J Arthroplasty.* 2007;22:1208–1213.
24. Haynes DR, Rogers SD, Hay S, Pearcy MJ, Howie DW. The differences in toxicity and release of bone-resorbing mediators induced by titanium and cobalt-chromium-alloy wear particles. *J Bone Joint Surg Am.* 1993;75:825–834.
25. Hing CB, Back DL, Bailey M, Young DA, Dalziel RE, Shimmin AJ. The results of primary Birmingham hip resurfacings at a mean of five years: an independent prospective review of the first 230 hips. *J Bone Joint Surg Br.* 2007;89:1431–1438.
26. Hing CB, Young DA, Dalziel RE, Bailey M, Back DL, Shimmin AJ. Narrowing of the neck in resurfacing arthroplasty of the hip: a radiological study. *J Bone Joint Surg Br.* 2007;89:1019–1024.
27. Holland JP, Langton DJ, Hashmi M. Ten-year clinical, radiological and metal ion analysis of the Birmingham Hip Resurfacing: from a single, non-designer surgeon. *J Bone Joint Surg Br.* 2012;94:471–476.
28. Holloway I, Walter WL, Zicat B, Walter WK. Osteolysis with a cementless second generation metal-on-metal cup in total hip replacement. *Int Orthop.* 2009;33:1537–1542.
29. IBM. IBM SPSS Statistics. 2014. IBM Corporation. Available at: http://www-01.ibm.com/software/analytics/spss/products/statistics/. Accessed February 18, 2014.
30. Ishaque BA, Donle E, Gils J, Wienbeck S, Basad E, Sturz H. [Eight-year results of the femoral neck prosthesis ESKA-CUT] [in German]. *Z Orthop Unfall.* 2009;147:158–165.
31. Langton DJ, Jameson SS, Joyce TJ, Gandhi JN, Sidaginamale R, Mereddy P, Lord J, Nargol AV. Accelerating failure rate of the ASR total hip replacement. *J Bone Joint Surg Br.* 2011;93:1011–1016.
32. Matharu GS, Theivendran K, Pynsent PB, Jeys L, Pearson AM, Dunlop DJ. Outcomes of a metal-on-metal total hip replacement system. *Ann R Coll Surg Engl.* 2014;96:530–535.
33. Matthies AK, Skinner JA, Osmani H, Henckel J, Hart AJ. Pseudotumors are common in well-positioned low-wearing metal-on-metal hips. *Clin Orthop Relat Res.* 2012;470:1895–1906.
34. McBryde CW, Theivendran K, Thomas AM, Treacy RB, Pynsent PB. The influence of head size and sex on the outcome of Birmingham hip resurfacing. *J Bone Joint Surg Am.* 2010;92:105–112.
35. McMinn DJ, Pradhan C, Ziaee H, Daniel J. Is mid-head resection a durable conservative option in the presence of poor femoral bone quality and distorted anatomy? *Clin Orthop Relat Res.* 2011;469:1589–1597.
36. McMinn DJW. Birmingham Mid-Head Resection prosthesis and its implantation. In: McMinn DJW, ed. *Modern Hip Resurfacing*. London, UK: Springer London; 2009:301–317.
37. MHRA. Medical Device Alert: All metal-on-metal (MoM) hip replacements (MDA/2012/036). 2012. Medicines and Healthcare products Regulatory Agency (MHRA). Available at: http://www.mhra.gov.uk/Publications/Safetywarnings/MedicalDeviceAlerts/CON155761. Accessed December 22, 2014.
38. Morrey BF, Adams RA, Kessler M. A conservative femoral replacement for total hip arthroplasty. A prospective study. *J Bone Joint Surg Br.* 2000;82:952–958.
39. National Joint Registry for England Wales and Northern Ireland. 11th Annual Report. 2014. Available at: http://njrcentre.org.uk. Accessed April 26, 2015.
40. Nunley RM, Della Valle CJ, Barrack RL. Is patient selection important for hip resurfacing? *Clin Orthop Relat Res.* 2009;467:56–65.
41. Ollivere B, Duckett S, August A, Porteous M. The Birmingham Hip Resurfacing: 5-year clinical and radiographic results from a District General Hospital. *Int Orthop.* 2010;34:631–634.
42. Pfirrmann CW, Notzli HP, Dora C, Hodler J, Zanetti M. Abductor tendons and muscles assessed at MR imaging after total hip arthroplasty in asymptomatic and symptomatic patients. *Radiology.* 2005;235:969–976.
43. Rahman L, Muirhead-Allwood SK. The Birmingham mid-head resection arthroplasty—minimum two year clinical and radiological follow-up: an independent single surgeon series. *Hip Int.* 2011;21:356–360.
44. Sandiford NA, Muirhead-Allwood S, Skinner J, Kabir C. Early results of the Birmingham mid-head resection arthroplasty. *Surg Technol Int.* 2009;18:195–200.
45. Santori FS, Santori N. Mid-term results of a custom-made short proximal loading femoral component. *J Bone Joint Surg Br.* 2010;92:1231–1237.
46. Schmalzried TP, Silva M, de la Rosa MA, Choi ES, Fowble VA. Optimizing patient selection and outcomes with total hip resurfacing. *Clin Orthop Relat Res.* 2005;441:200–204.
47. Smith AJ, Dieppe P, Vernon K, Porter M, Blom AW, National Joint Registry of England and Wales. Failure rates of stemmed metal-on-metal hip replacements: analysis of data from the National Joint Registry of England and Wales. *Lancet.* 2012;379:1199–1204.
48. Spencer S, Carter R, Murray H, Meek RM. Femoral neck narrowing after metal-on-metal hip resurfacing. *J Arthroplasty.* 2008;23:1105–1109.
49. Su EP, Housman LR, Masonis JL, Noble JW Jr, Engh CA. Five year results of the first US FDA-approved hip resurfacing device. *J Arthroplasty.* 2014;29:1571–1575.
50. Urban RM, Jacobs JJ, Gilbert JL, Galante JO. Migration of corrosion products from modular hip prostheses—particle microanalysis and histopathological findings. *J Bone Joint Surg Am.* 1994;76:1345–1359.
51. Zahiri CA, Schmalzried TP, Szuszczewicz ES, Amstutz HC. Assessing activity in joint replacement patients. *J Arthroplasty.* 1998;13:890–895.
52. Zicat B, Engh CA, Gokcen E. Patterns of osteolysis around total hip components inserted with and without cement. *J Bone Joint Surg Am.* 1995;77:432–439.