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HIP

Metal-on-metal hip resurfacing arthroplasty: is it safe and reliable? A synopsis of the past, the present, and the future of HRA

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- This paper discusses the existing literature in the field of metal-on-metal (MoM) hip resurfacing arthroplasty (HRA), the background (why was it developed), the past (what was the evidence leading to its rise and fall in clinical use), the present situation (why a potential resurgence), and the future directions for potential improvements.
- All literature relevant to MoM HRA was reviewed and summarized to provide a comprehensive summary. Furthermore, a detailed literature search was performed on PubMeD, MEDLINE, and Google Scholar to identify all clinical studies reporting a minimum 10 years of outcomes for modern MoM HRA devices from February 2018 to February 2023.
- In addition, joint registry data over the same time period, available in the public domain, was examined to extract related information on MoM HRA.
- Metal ions are present in almost all types of hip replacement; on the whole, however, the risk of revision for resurfacing due to metal-related pathologies is very low, but higher than in other types of bearings.
- There are studies that show that some brands of MoM resurfacing prostheses have achieved excellent clinical outcomes in long-term follow-up studies and are still in use although less commonly than in early 2000s.
- Use of alternative bearing surfaces has demonstrated excellent results in the short-term and a very critical long-term follow-up of these cases still will help establish their place in the hip arthroplasty world.
- HRA deserves a permanent place in the armamentarium of orthopedic surgeons and in the hand of experienced surgeons.

Keywords: hip resurfacing arthroplasty; total hip arthroplasty; total hip replacement; metal-on-metal; follow-up; outcomes

Introduction

Total hip arthroplasty (THA) is one of the most successful surgeries performed today and has been described as the 'operation of the century' (1, 2). However, THA can impose significant limitations on returning to high functional activity, and the hip prostheses are subject to wear, especially when used in young and active patients (3). In addition, changes in offset and leg length discrepancy are not uncommon

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post-THA, and these can be associated with pain, limp, patient dissatisfaction, and litigation (4). Hip resurfacing arthroplasty (HRA) is an attractive alternative to standard stemmed THA. HRA are metal-on-metal (MoM) articulations, and various *in vitro* assessments have confirmed a low wear rate with the use of MoM-bearing couple. In addition to the advantage of low volumetric wear, HRA has several other potential benefits over THA, including more closely mimicking natural anatomy and restoration of native hip biomechanics, lower dislocation rates, reduced incidence of limb length discrepancy, preservation of proximal femoral bone stock, easier revision surgery (5, 6), and a higher rate of return to full activity, including sports (7, 8). These perceived advantages led to a huge surge in the usage of MoM HRA from 2000 to 2010, with the vast majority of leading manufacturers introducing a HRA design for clinical use. In 2008, Pandit *et al.* (9) reported a series of pseudotumors associated with MoM HRAs, with similar reports being published by other research groups over the coming years (10). Various researchers reported that some MoM HRA implants and THAs with MoM articulations have unacceptably high failure rates (11, 12). The MHRA product recall and guidance on MoM hip surveillance contributed to a lowering of the threshold for revising MoM hips, thus exacerbating the issue of higher-than-expected revision rates. Although not uniform across various brands, the image of MoM HRA as a viable alternative to conventional THA was tarnished. Over the next few years, almost all HRA devices were withdrawn from the market due to safety concerns and markedly reduced usage. Currently, only two MoM HRA designs are in routine clinical use in the UK, Europe, and Australia (Adept and BHR). When HRA is used for the correct indication and with an implant with a proven track record, the long-term results of HRA have been excellent, which has rekindled the interest of the public and surgeons in HRA.

This review article will provide the reader with an up-to-date synopsis of the relevant history (the past), the current status (the present), and contemplate what the future holds (the future) for HRA.

The past

In 1923, Smith-Petersen implanted glass between the acetabulum and the femoral head, creating the first HRA. However, the prosthesis failed quickly due to material wear and cracking (13). The first prosthetic device to combine the use of two congruent components bonded to the native femoral head and the acetabular cavity appeared in the early 1970s (14). From the 1970s to the 1980s, HRA, consisting of a metal femoral head with a polyethylene acetabulum, became popular. However, the early failure rate was very high due to various causes, including femoral neck fracture, femoral prosthesis loosening, dislocation, acetabular prosthesis wear, fracture, loosening, and severe osteolysis. Building on the knowledge of failed implant designs and a careful examination of large head metal-on-metal McKee Farrar components (some of which had good long-term survival), McMinn and Wagner independently developed the second generation of MoM HRAs in the early 1990s, and brought the hip resurfacing into its modern era (15, 16). Between 2004 and 2006, HRAs accounted for 46% of hip replacements in patients less than 55 years of age in the UK (17) and 29% in Australia (18). However, two key issues led to the loss of popularity of MoM HRAs: early femoral neck fractures and adverse reaction to metal debris (ARMD) also known as pseudotumors.

Femoral neck fractures

Shimmin *et al.* (19) followed up 3497 patients who underwent HRA for an average of 4 years. Among them, 50 patients had sustained a fracture of the femoral neck (#NOF), with an incidence about twice as high in female patients (1.91%) compared to male patients (0.98%). It often occurred in the early postoperative period, with an average time of 15.4 weeks. The key to prevent #NOF is a meticulous surgical technique, optimal patient selection, and correct placement of femoral prosthesis. The exact etiology for #NOF is debated, but broadly speaking, it is either due to interrupted blood supply to the femoral head at the time of surgery (20, 21) or mechanical reasons (22, 23). The main mechanical causes of femoral neck fracture include poor position of the femoral prosthesis, neck notching, excessive penetration of cement into the bone, incomplete coverage of the femoral head by the prosthesis, multiple large cystic areas of the femoral head, lack of good bone support, and postoperative trauma (24). Beaulé *et al.* suggested that maintaining the neck-shaft angle of the femoral prosthesis at 135–140° may be best to minimize the risk of #NOF (25). Patient factors such as postmenopausal osteoporosis and the small size of femoral head could also contribute (19).

Adverse reaction to metallic debris

In 2008, the Oxford Group reported a new finding in patients who had undergone MoM HRA: swelling and masses around the resurfaced joint, which they termed ‘pseudotumor’ (9). In 2011, Langton *et al.* (10) also reported on a multi-center study of ARMD following HRA. They reported 4226 hips using three implants (the ASR; the BHR; and the Conserve Plus) with a follow-up of 10–142 months. Survival analysis showed a failure rate in the patients with ASR of 9.8% at 5 years, compared with <1% at 5 years for the Conserve Plus and 1.5% at 10 years for the BHR. Subsequently, researchers conducted a series of in-depth studies on ARMD following MoM HRA (10, 26, 27, 28, 29, 30, 31, 32, 33). These studies noted that in majority of cases, high metal ion levels, suggestive of high wear, were responsible for developing ARMD.

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HRAs are not all the same, and the differences in design characteristics of various implants are important in determining *in vivo* wear rates (Table 1). The well-documented early failure and subsequent withdrawal of the ASR implant is the most striking example. Compared to the ADEPT and the BHR, the articular coverage angle and the radial clearance of the components of the ASR were reduced, often leading to raised metal ion levels, ARMD, compounding the risk of edge wear, and remarkably higher early failure rates (34, 35). In addition, other factors that have been shown to significantly affect metal ion concentrations are femoral component diameter (26, 31, 32, 33), acetabular orientation (26, 27, 31, 32, 33), and the head–neck ratio (26, 29). Although it is still not completely clear why metal ions or particles cause periprosthetic problems, including soft-tissue masses and osteolysis, the increased level of metal ions in joint fluid and peripheral blood arising from a MoM articulation can cause local or systemic adverse biological reactions. The biological reactions of different individuals to metal ions appear to be inconsistent in clinical practice. In some sensitive patients, symptomatic soft tissue mass, osteolysis, and other adverse results may occur with normal metal ion levels. However, until now the exact etio-pathogenesis and associated biological mechanism of ARMD has not been clearly defined. As to whether the long-term exposure to excessive metal ions will promote a delayed pseudotumor development, further clinical follow-up and further research are still needed.

The present

In recent years, HRA has seen a resurgence, particularly when treating active and young male patients who wish to maintain high activity levels. Surgeons agree that the three key factors for a successful HRA are: (1) careful patient selection; (2) surgical skill and experience; and (3) optimal implant design, with restricting the use of large size femoral heads and accurate implant positioning (36). In this section, we discuss the literature reporting a minimum of 10 years outcomes for modern MoM HRA devices that are currently in use (Table 2).

Long-term clinical outcomes and Implant-specific HRA survivorship

There are five MoM HR designs that have outcomes reported at a minimum of 10 years (37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50): the ADEPT (MatOrtho, UK; 2004 onward), the Birmingham Hip Resurfacing (BHR; Smith & Nephew, Warwick, UK), the ReCap (Biomet, Warsaw, USA), the Conserve Plus (Wright Medical, Arlington, Tennessee, USA), and the ASR (DePuy Orthopaedics Inc., Indiana, USA).

The BHR is the most widely used HRA, with various studies reporting 90% (or better) 10-year implant survival (38, 39, 41, 42, 43, 45, 46, 48, 49, 50). Even after

Table 1 Design and metallurgy features of different implants.

Implant	Manufacturer	Year introduced and discontinued (If it is not in current use)	Cup size range (mm)	Bearing metallurgy, processing	Coverage angle	Wall thickness at rim (mm)	Radial clearance (μm)	Surface roughness (μm)	Mean deviation of roundness (μm)	
									Head	Cup
ADEPT	Finsbury Orthopaedics; subsequently MatOrtho, UK; 2005 onward	2004	46–58	Cast	160°	3.4	86.37	0.036	2.5	2.2
BHR	Smith & Nephew, Warwick, UK	1997	44–66	Cast	152–165°	3.6	105.10	0.029	0.9	0.9
ReCap	Biomet, Warsaw, USA	2004	44–66	Cast	162°	3.4	120.93	0.031	3.2	1.9
Conserve Plus	Wright Medical, Arlington, Tennessee, USA	1996	42–64	Cast, heat treated	161–163°	3.8	78.90	0.020	3.2	1.8
ASR	DePuy Orthopaedics Inc, Indiana, USA	2003–2010	44–70	Cast, heat treated	147–157°	3.1	49.47	0.025	3.4	3.8

Table 2 Outcomes of different HRA prostheses at a minimum of 10 years follow-up in recent 5 years.

Study	Number of hips (patients)	Implant	Overall survival	Survival in males	Survival in females	Complications (n)	Time to complications (yrs)	Additional findings
Mancino *et al.* (37)	24 (21)	ADEPT	91.7%; MFU: 11.8 years			Neck fracture (2)	Within 6 months postoperatively	The HR Adept implant reported excellent results at 10 years follow-up. The failure rate due to the MoM bearing and ARMD were lower than that reported in the literature
Samuel *et al.* (38)	389 (350)	BHR	96.9%; MFU: 11.3 years	99.0%	90.9%	Pain related to acetabular component malposition (8); fracture (3)	The average time to revision was 6.4 ± 3.1 years	This study demonstrates that BHR resurfacing with a good track record, particularly in younger males with a 99% long-term survivorship.
Bourget-Murray *et al.* (39)	127 (107)	BHR	91.9%; MFU: 12.37 ± 1.4 years	93.8%	87%	Pseudotumors (2) Acetabular cup loosening (2) Femoral loosening (2) Elevated whole-blood metal ions (1) Periprosthetic femur fracture (1) Femoral avascular necrosis with implant subsidence (1) Anterior acetabular impingement (1) Ongoing symptomatology (1)	The average time to revision surgery was 98.6 ± 47 months (8.2 yr; range 48–160 months)	This study support the current evidence regarding the benefits of BHR in active young males with osteoarthritis.
Weegen *et al.* (40)	298 (258)	ReCap	85.9%; MFU: 14.5 years	89.1%	76.3%	Pseudotumors (13) High metal ion levels (3) Neck fracture (8) Acetabular cup loosening (6) Persistent pain (6)		This study indicate that progression or new development of pseudotumors after more than 10 years is unlikely. They suggest that follow-up of these patients can be done with larger intervals.
Partridge (41)	100 (90)	BHR	89% at 20 years	95%	72%	Early fractures (3) Infection at 5 years (1) Adverse reactions to metal debris (six all females) avascular necrosis (1)		BHR has not demonstrated the catastrophic revision rates associated with some metal-on-metal resurfacing and remains a safe option for those who meet the criteria.
Hastie *et al.* (42)	123 (102)	BHR	93.2% at 13 years			ARMD (5) Neck fracture (2) Avascular necrosis (1)		While the implant survivorship in the series is acceptable, the author of this study found a high incidence of ARMD. With regard to the radiological analysis, 34% were found to have ARMD on MR.

(Continued)

Table 2 Continued.

Study	Number of hips (patients)	Implant	Overall survival	Survival in males	Survival in females	Complications (n)	Time to complications (yrs)	Additional findings
Palazzuolo *et al.* (43)	152 (122)	BHR	98% at 5 years; 96% at 10 years; 83% at 15 years			ARMD (6) Painful hip with ion elevation (7) Fracture (2) Instability (1)		Survivorship of MoM hip arthroplasty was significantly higher in HRA than in THA at any time point and failure rate due to ARMD was significantly higher in THA.
Amstutz & Le Duff (44)	400 (355)	Conserve Plus	83.5% at 20 years			Acetabular cup loosening (12) Femoral loosening (31) Neck fracture (6) ARMD (6) Infection (2) Recurrent dislocation (1) Acetabular component protrusion (1) Unknown indication (1)	13.2 years 8 years 5.5 years 12.7 years 9.3 years 4.2 years 0.2 years 14.2 years	HRA today is no longer experimental and deserves a permanent place in the armamentarium of orthopaedic surgeons.
Sheridan *et al.* (45)	261	BHR	95.7% at 10 years			Periprosthetic fracture (4) Periprosthetic infection (3) Aseptic loosening (2) ARMD (1) Dislocation (1) Pain due to unknown (1)	The average time to revision was 51 months	The author of this study demonstrated that the BHR is a NICE-compliant implant at 10 years. The ASR performed predictably poorly, falling short of NICE 10-year recommended revision rates in just under 2 years. They also report superior outcomes with high-volume surgeons who are more experienced with this procedure.
Engh *et al.* (46)	280 (253)	BHR	92.9% at 10 years			Femoral neck fracture (3) Femoral loosening (5) Acetabular loosening (1) Pseudotumors (3) Osteolysis (2) A combination of pain, noise, or metal levels (6)		This prospective, multicenter PAS demonstrated BHR is safe and durable. 10-year survivorship for males less than 55 years old is 98.3%.
Kiran *et al.* (47)	72 (66)	ReCap	97.22% at 10 years			Avascular necrosis (1) Progressive neck thinning and implant failure (1)		Strict selection criteria and a well-designed implant result in good long-term functional and radiological results. They did not note any difference between the genders, since all the females in their series had been screened for osteopenia using a DEXA scan.
Jonas *et al.* (48)	54 (51)	BHR	88.9%; MFU: 17.6 years			Femoral component failure (6)		Hip resurfacing remains a valid option for younger male with osteoarthritis. No pseudotumors have been identified in this study.

(Continued)

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Table 2 Continued.

Study	Number of hips (patients)	Implant	Overall survival	Survival in males	Survival in females	Complications (n)	Time to complications (yrs)	Additional findings
Hunter *et al.* (49)	121 (111)	BHR	91% at 10 years	97%	80%	Femoral neck fracture (1) Periprosthetic infection (1) Pain and/or loosening (9)		Their results reflect that of the wider literature in that good outcomes can be obtained with this BHR in a select group of patients. Revisions were most often in patients with smaller component sizes.
Uemura *et al.* (50)	112 (130)	BHR	96.5% at 10 years; 93.6% at 10 years			Femoral component loosening (2) Infection (2) Cup aseptic loosening (1) Femoral neck fracture (1)		ARMD was not observed in these cases during the procedures. Good clinical results were obtained with the BHR at 10- and 15-year follow-up in Japanese patients who have different stature and types of hip diseases as compared with patients in Western countries.

MFU, mean follow-up of patients.

20 years of follow-up, the survival rate of the prosthesis was maintained at 89% (41). The ADEPT has also achieved good clinical results at a minimum of 10 years' follow-up (37). Mancino *et al.* (37) reported a 91.7% overall survivorship for ADEPT HRA at 10 years and 100% survivorship if aseptic loosening or ARMD are considered revision indication. Amstuz *et al.* (44) reported on the first 400 Conserve Plus HRAs implanted between November 1996 and November 2000. A total of 60 hips in 55 patients were revised. Using revision for any indication as the endpoint, the Kaplan–Meier survivorship was 83.5% at 20 years. There were no cases of metal sensitivity associated with revision surgery. Kiran *et al.* (47) reported the results of the ReCap hip resurfacing in a consecutive single surgeon's series. The survivorship of the cohort at minimum 10 years was 97.22% (95% CI: 94.14–99.01%). Weegen *et al.* (40) reported that the ReCap implant survival was 85.9% at 14.5 years (95% CI: 81.9–90.6%). However, the ASR performed predictably poorly, with 26 out of 119 implants having been revised, giving a 78.2% 10-year survival rate (45).

The 10-year survival rate after HRA shows significant variation. For example, Hunter *et al.* (49) and Samuel *et al.* (38) separately reported on the retrospective analysis of BHR patients by a non-designer single surgeon with a minimum of 10 years of follow-up. Hunter *et al.* (49) reported a survival rate of 97% in males and 80% in females at 10 years. The majority of failures had a head size of 46 mm or less (64%), but this was not found to be statistically significant. Samuel *et al.* (38) also reported that gender had a statistically significant relationship with survival rate (males: 99.0%, (95% CI: 97.8–100%); females: 90.9% (95% CI: 84.2–96.4%); $P < 0.001$). Jonas *et al.* (48) demonstrated superior activity levels and better patient-reported outcomes in those patients who underwent HRA compared to THA. At an average clinical follow-up of 18 years in both groups, median University of California, Los Angeles, activity score and Oxford Hip Score were significantly higher in the HRA group.

The 2022 Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) annual report indicates that the implant survival rates for BHR are 93.5% at 10 years, 90.5% at 15 years, and 88.1% at 20 years, while for ADEPT, the rates are 94.6% at 10 years and 92.6% at 15 years (51). From the UK National Joint Registry 2022 annual report data, the cumulative revision (95% CI) for BHR are 7.26% at 10 years, 10.26% at 15 years, and for ADEPT, they are 7.73% at 10 years, and 10.56% at 15 years (52).

Other than ADEPT and BHR, no other MoM HRAs are in routine clinical use at present. The current manufacturers of ADEPT and BHR recommend a target demographic for the BHR, which includes male patients younger than 65 years and has

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restricted the available head sizes. For ADEPT, head sizes are available between 46 and 58 mm. For these head sizes, the cumulative revision rates for ADEPT are 4.5% at 10 years (UK National Joint Registry 2021 data). BHR manufacturers recommend a femoral head size of ≥50 mm. ADEPT has 13A ODEP rating and BHR has 15A* ODEP rating (53), demonstrating their suitability for continued clinical use. In addition, when used as intended, metal ion levels consistently remain within the guidelines (MDA 2017/18), thereby confirming their safety (54).

Patient selection and surgeon experience

Several investigations have highlighted the importance of patient selection in HRA (6, 36, 55, 56, 57), with the use of HRA to be limited to those with pre-operative diagnosis of osteoarthritis, male sex, larger femoral head size, and age less than 60 years. Female sex alone may be not a direct cause of HRA failure. Amstutz *et al.* (44) demonstrated that female sex was not a risk factor after adjustment for hip dysplasia and there was only one femoral failure in their case-cohort operated over 20 years ago. Uemura *et al.* also reported good clinical results at 10- and 15-year follow-ups in Asian countries where there is a high prevalence of osteonecrosis, DDH, and females with small femoral head sizes. They argued that sex, femoral component size, and type of hip disease were not predictors of implant survivorship (50).

Based upon the evidence of a lower rate of complications and revision in men following HRA (38, 39, 40, 41, 49), most manufacturers recommend the use of MoM HRA to be restricted to young and active men with pre-operative diagnosis of osteoarthritis. This should be borne in mind when joint registry data is examined. The 2022 AOANJRR report indicates that HRA for osteoarthritis has a lower rate of revision compared to developmental dysplasia from 6 months up to 5 years. There is a higher rate of revision for osteonecrosis compared to osteoarthritis. Females have a higher rate of revision compared to males. Males aged ≥ 65 years have a higher rate of revision compared to males aged 55–64 years for the first 6 months only, and for the first 1 year compared to males aged < 55 years (51). Typically, the data includes revision rates across the entire cohort of HRA without taking into consideration indication for surgery, surgeon experience, implant sizes, and threshold for revision surgery. Single center/single surgeon series can overcome these issues but often have limitations related to sample size and the extent to which these results could be generalized. Stoney *et al.* (58) tried to overcome some of the limitations of joint registry data by comparing the difference in cumulative percent revision, reasons for revision, and types of revision for procedures reported to the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) using the BHR prosthesis (femoral-head size > 50 mm) and three conventional THA prostheses identified as having the lowest 10-year cumulative percent revision in the currently recommended BHR target population. There were 4790 BHR procedures and 2696 conventional THA procedures in the study group. The mean (±s.d.) age for BHR procedures was 52 ± 7.8 years and 56 ± 7.1 years for conventional THA procedures. The maximum follow-up was 18.7 years for both groups with a mean follow-up of 11.9 years for the BHR and 9.3 years for the conventional THA group. Revision rates were determined using Kaplan–Meier estimates of survivorship to describe the time to the first revision, with censoring at the time of death or closure of the database at the time of analysis. The BHR prosthesis had a statistically higher rate of all-cause revision at 17 years than the selected conventional THA prostheses (HR: 2.77 (95% CI: 1.78–4.32]; $P < 0.001$). The revision diagnoses differed between the groups, with the BHR demonstrating a higher revision rate for loosening after 2 years than the conventional THA prostheses (HR: 4.64 (95% CI: 1.66–12.97); $P = 0.003$), as well as a higher fracture rate during the entire period (HR: 2.57 (95% CI: 1.24–5.33); $P = 0.01$). There was a lower revision rate for infection for the BHR compared with the THA group in the first 5 years, with no difference between the two groups after this time. Although a better approach, this study still has some significant limitations, such as varied surgeon experience, subjective reasoning for revision surgery, using implant survival as an endpoint rather than patient satisfaction/activity levels, and not able to include data on risk of dislocation, a relatively common complication for THA as compared to HRA.

Risk of developing symptomatic ARMD in the second decade post HRA

The complications and causes for revisions found in the different literatures of recent 5 years have been extracted from the articles and are listed in Table 2. Aseptic component loosening and ARMD remain the main complications and causes of revision of MoM HRA (37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50). Sørensen *et al.* (59) believed that although the revision rate for MoM bearings may be decreased by better prostheses design, surgery performed only by high-volume surgeons, and careful selection of the right prostheses types for the patients, the metal debris will still be a major cause of failure. In 2021, Hastie *et al.* (42) reported the rate of ARMD in HRAs at a minimum 13-year follow-up. They reported 34% of cases to have ARMD on cross-sectional imaging. However, the majority of these hips with MRI-detected ARMD were asymptomatic, and they are unlikely to require revision or cause progressive soft tissue damage. Actually, metal ions are present in almost all types of joint replacement, especially with TKA. Lukas *et al.* (60) concluded that the increase in metal ion release after knee arthroplasty is as high as after hip resurfacing at the 1 year follow-up. The authors suggested that monitoring this parameter probably should not be recommended in cases of good

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clinical outcomes. Weegen *et al.* (40) indicated that the new development of pseudotumors after more than 10 years is unlikely.

The future

HRA clearly has a place in the surgical armamentarium in the management of symptomatic hip arthritis in young and active adults. Two implants (Adept and BHR) will continue to be used and are likely to become more common. Both designs have a proven track record with minimal risk of developing ARMD if implanted optimally for the correct indication. Some authors have reported slightly better survivorship with cementless femoral component resurfacing. In a large series of more than 1000 uncemented Biomet, Gross and Liu (61) found excellent survivorship with cementless femoral components. Moreover, when they compared cemented femoral components (740 cases) and cementless devices (1300 cases), they noticed better survivorship in the cementless group (99 vs 98% at 2 years). Also, experience with the Conserve Plus cementless device confirmed this conclusion. In a series of 94 cementless Conserve Plus implants in 90 patients, with a short follow-up of 13.1 months (5), cementless 'fit and fill' femoral-side fixation should be considered for future resurfacing device production.

At present, the arthroplasty community is focused on controlling surgical factors, such as improving prosthesis position through the use of computer-assisted navigation and robots (62, 63). Improving the prosthesis position will help minimize the risk of edge loading and secondary impingement. However, patients display varying tolerances to metallic debris. The problem of sometimes, although rare, very aggressive pseudotumors with an enormous loss of musculature is somewhat underestimated in patients with metal hypersensitivity. In these rare cases, the outcome of revisions are very disappointing, especially considering that many patients with MoM resurfacing are young. In 2022, Langton *et al.*(64) published a paper about 'the influence of HLA genotype on the development of metal hypersensitivity following joint replacement'. They used a computer algorithm to predict allergic responses to metal debris based on a patient's genes, age, and gender. The algorithm was performed with sufficient accuracy in clinical practice to guide patient and implant selection preoperatively. It seems to be useful and points us in a new direction for improvement.

The current generation of HRA components has MoM-bearing surface, which have the potential to create metal debris or allergic reaction to the metal debris in some patients. It is therefore desirable to eliminate the generation of metal debris altogether. The choice of HRA materials will be decided by either the preference for a hard-on-hard (ceramic on ceramic) or hard-on-soft (ceramic or metal on highly cross-linked polyethylene) articulation. It is also possible to change the bearing surface from Co–Cr to Titanium or Oxinium (oxidized zirconium) (5). In 2019, Treacy *et al.* (65) reported preliminary clinical results with metal-on-highly cross-linked polyethylene (XLPE) HRA. This observational study of 88 consecutive HRAs performed in 84 patients from 2015 to 2018 suggests that metal-on-XLPE HRA is successful in the short term without any actual or impending revision or reoperation. In 2022, Lin *et al.* (66) reported preliminary clinical results with novel ceramic-on-ceramic hip resurfacing in Australia. This observational study included 209 patients treated between September 2018 and April 2021. The results in this study suggest that ceramic-on-ceramic HRA is successful in the short term (1 to 2-year follow-up), with no early radiological or clinical complications related to the prosthesis. However, these results are preliminary, with only a 1–2 year follow-up, and merely indicate future development directions. If a new hip resurfacing implant design needs to be widely used, it should to be highly scrutinized by surgeons, regulatory agencies, and patients alike with longer-term follow-up.

Conclusion

Recent literature has confirmed that patients with certain types of MoM (BHR and ADEPT) HRA are no more likely to require early revision than those with conventional THA. Data does not show an increasing rate of further surgery at the 20-year mark. These metal-on-metal hip resurfacing prostheses have achieved excellent clinical outcomes in long-term follow-up studies. The reason why other types of MoM implants have higher failure rates are, however, not completely understood. Although patient selection and surgeon experience remain important, modest expansion of the patient population, such as including female patients or patients those with small femoral head sizes, also results in good clinical outcomes, but more data are needed (50). HRA today probably deserves a permanent place in the armamentarium of orthopedic surgeons, but critical patient selection and follow-up are mandatory. Surgeons should also be very experienced with the technique. Although the overall revision rate of metal-on-metal hip resurfacing is very low, ARMD remains one of the major causes of prosthetic failure and deserves our attention. The development of the the next generation hip resurfacing implants, especially with alternative bearing materials (e.g. ceramic-on-ceramic), is showing promising short-term results, and the coming years may see a resurgence in the usage of HRA.

ICMJE Conflict of Interest Statement
The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the study reported.

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https://doi.org/10.1530/EOR-23-0099

References

1 Evans JT, Evans JP, Walker RW, Blom AW, Whitehouse MR & Sayers A. How long does a hip replacement last? A systematic review and meta-analysis of case series and national registry reports with more than 15 years of follow-up. *Lancet* 2019 **393** 647–654. (https://doi.org/10.1016/S0140-6736(18)31665-9)

2 Learmonth ID, Young C & Rorabeck C. The operation of the century: total hip replacement. *Lancet* 2007 **370** 1508–1519. (https://doi.org/10.1016/S0140-6736(07)60457-7)

3 Wroblewski BM, Fleming PA & Siney PD. Charnley low-frictional torque arthroplasty of the hip. *The Journal of Bone and Joint Surgery* 1999 **81** 427–430. (https://doi.org/10.1302/0301-620x.81b3.9521)

4 Pyrko P & Zuckerman J. Leg length discrepancy in primary total hip arthroplasty. *Bulletin of the Hospital for Joint Disease* 2016 **74** 82–87.

5 Girard J. Hip resurfacing: international perspectives. *HSS Journal* 2016 **13** 7–11. (https://doi.org/10.1007/s11420-016-9511-y)

6 Gani MH, Zahoor U, Hanna SA & Scott G. Metal-on-metal hip resurfacing arthroplasty provides excellent long-term survivorship and function in patients with a good-sized femoral head. *Bone and Joint Open* 2022 **3** 68–76. (https://doi.org/10.1302/2633-1462.31.BJO-2021-0135.R1)

7 Rueckl K, Liebich A, Bechler U, Springer B, Rudert M & Boettner F. Return to sports after hip resurfacing versus total hip arthroplasty: a mid-term case control study. *Archives of Orthopaedic and Trauma Surgery* 2020 **140** 957–962. (https://doi.org/10.1007/s00402-020-03414-6)

8 Morse KW, Premkumar A, Zhu A, Morgenstern R & Su EP. Return to sport after hip resurfacing arthroplasty. *Orthopaedic Journal of Sports Medicine* 2021 **9** 23259671211003521. (https://doi.org/10.1177/23259671211003521)

9 Pandit H, Glyn-Jones S, McLardy-Smith P, Gundle R, Whitwell D, Gibbons CLM, Ostlere S, Athanasou N, Gill HS & Murray DW. Pseudotumours associated with metal-on-metal hip resurfacings. *The Journal of Bone and Joint Surgery* 2008 **90** 847–851. (https://doi.org/10.1302/0301-620X.90B7.20213)

10 Langton DJ, Joyce TJ, Jameson SS, Lord J, Van Orsouw M, Holland JP, Nargol AV & De Smet KA. Adverse reaction to metal debris following hip resurfacing: the influence of component type, orientation and volumetric wear. *The Journal of Bone and Joint Surgery* 2011 **93** 164–171. (https://doi.org/10.1302/0301-620X.93B2.25099)

11 de Steiger RN, Hang JR, Miller LN, Graves SE & Davidson DC. Five-year results of the ASR XL acetabular system and the ASR hip resurfacing system. *The Journal of Bone and Joint Surgery* 2011 **93** 2287–2293. (https://doi.org/10.2106/JBJS.J.01727)

12 Smith AJ, Dieppe P, Vernon K, Porter M & Blom AW. 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. (https://doi.org/10.1016/S0140-6736(12)60353-5)

13 Smith-Petersen MN. Evolution of mould arthroplasty of the hip joint. *The Journal of Bone and Joint Surgery* 1948 **30B** 59–75. (https://doi.org/10.1302/0301-620X.30B1.59)

14 Trentani C & Vaccarino F. The Paltrinieri-Trentani hip joint resurface arthroplasty. *Clinical Orthopaedics and Related Research* 1978 **134** 36–40.

15 Wagner M & Wagner H. Preliminary results of uncemented metal on metal stemmed and resurfacing hip replacement arthroplasty. *Clinical Orthopaedics and Related Research* 1996 329 S78–S88. (https://doi.org/10.1097/00003086-199608001-00008)

16 McMinn D, Treacy R, Lin K & Pynsent P. Metal on metal surface replacement of the hip. *Clinical Orthopaedics and Related Research* 1996 329 S89–S98. (https://doi.org/10.1097/00003086-199608001-00009)

17 National Joint Registry. 8th Annual Report [Internet]. In *National Joint Registry*. London: National Joint Registry, 2011. Available at: www.njrcentre.org.uk

18 Australian Orthopaedic Association National Joint Replacement Registry. Annual Report [Internet]. Adelaide: Australian Orthopaedic Association (AOA), 2009. Available at: https://aoanjrr.sahmri.com/annual-reports-2009

19 Shimmin AJ & Back D. Femoral neck fractures following Birmingham hip resurfacing. *The Journal of Bone and Joint Surgery* 2005 **87–B** 463–464. (https://doi.org/10.1302/0301-620X.87B4.15498)

20 Steffen R, O'Rourke K, Gill HS & Murray DW. The anterolateral approach leads to less disruption of the femoral head-neck blood supply than the posterior approach during hip resurfacing. *The Journal of Bone and Joint Surgery* 2007 **89–B** 1293–1298. (https://doi.org/10.1302/0301-620X.89B10.18974)

21 Steffen RT, De Smet KA, Murray DW & Gill HS. A modified posterior approach preserves femoral head oxgenation during hip resurfacing. *Journal of Arthroplasty* 2011 **26** 404–408. (https://doi.org/10.1016/j.arth.2009.12.018)

22 Steffen RT, Athanasou NA, Gill HS & Murray DW. Avascular necrosis associated with fracture of the femoral neck after hip resurfacing. *The Journal of Bone and Joint Surgery* 2010 **92–B** 787–793. (https://doi.org/10.1302/0301-620X.92B6.23377)

23 Steffen RT, Smith SR, Urban JPG, McLardy-Smith P, Beard DJ, Gill HS & Murray DW. The effect of hip resurfacing on oxygen concentration in the femoral head. *The Journal of Bone and Joint Surgery* 2005 **87–B** 1468–1474. (https://doi.org/10.1302/0301-620X.87B11.16780)

24 Anglin C, Masri BA, Tonetti J, Hodgson AJ & Greidanus NV. Hip resurfacing femoral neck fracture influenced by valgus placement. *Clinical Orthopaedics and Related Research* 2007 **465** 71–79. (https://doi.org/10.1097/BLO.0b013e318137a13f)

25 Beaul PE, Schmalzried TP, Campbell P, Dorey F & Amstutz HC. Duration of symptoms and outcome of hemiresurfacing for hip osteonecrosis. *Clinical Orthopaedics and Related Research* 2001 **385** 104–117. (https://doi.org/10.1097/00003086-200104000-00018)

26 Murray DW, Grammatopoulos G, Gundle R, Gibbons CLMH, Whitwell D, Taylor A, Glyn-Jones S, Pandit HG, Ostlere S, Gill HS, *et al.* Hip resurfacing and pseudotumour. *Hip International* 2011 **21** 279–283. (https://doi.org/10.5301/HIP.2011.8405)

27 Grammatopoulos G, Pandit H, Glyn-Jones S, McLardy-Smith P, Gundle R, Whitwell D, Gill HS & Murray DW. Optimal acetabular orientation for hip resurfacing. *The Journal of Bone and Joint Surgery* 2010 **92-B** 1072–1078. (https://doi.org/10.1302/0301-620X.92B8.24194)

28 Grammatopolous G, Pandit H, Kwon YM, Gundle R, McLardy-Smith P, Beard DJ, Murray DW & Gill HS. Hip resurfacings revised for inflammatory pseudotumour have a poor outcome. *The Journal of Bone and Joint Surgery* 2009 **91–B** 1019–1024. (https://doi.org/10.1302/0301-620X.91B8.22562)

29 Grammatopoulos G, Pandit H, Murray DW & Gill HS. The relationship between head-neck ratio and pseudotumour formation in metal-on-metal resurfacing arthroplasty of the hip. *The Journal of Bone and Joint Surgery* 2010 **92-B** 1527–1534. (https://doi.org/10.1302/0301-620X.92B11.24640)

30 Langton DJ, Sprowson AP, Joyce TJ, Reed M, Carluke I, Partington P & Nargol AV. Blood metal ion concentrations after hip resurfacing arthroplasty. *The Journal of Bone and Joint Surgery* 2009 **91-B** 1287–1295. (https://doi.org/10.1302/0301-620X.91B10.22308)

31 Langton DJ, Jameson SS, Joyce TJ, Hallab NJ, Natu S & Nargol AVF. Early failure of metal-on-metal bearings in hip resurfacing and large-diameter total hip replacement. *The Journal of Bone and Joint Surgery* 2010 **92-B** 38–46. (https://doi.org/10.1302/0301-620X.92B1.22770)

32 Langton DJ, Jameson SS, Joyce TJ, Webb J & Nargol AVF. The effect of component size and orientation on the concentrations of metal ions after resurfacing arthroplasty of the hip. *The Journal of Bone and Joint Surgery* 2008 **90-B** 1143–1151. (https://doi.org/10.1302/0301-620X.90B9.20785)

33 Langton DJ, Joyce TJ, Mangat N, Lord J, Van Orsouw M, Smet KD & Nargol AVF. Reducing metal ion release following hip resurfacing arthroplasty. *Orthopedic Clinics of North America* 2011 **42** 169–180. (https://doi.org/10.1016/j.ocl.2011.01.006)

34 Heisel C, Kleinhans JA, Menge M & Kretzer JP. Ten different hip resurfacing systems: biomechanical analysis of design and material properties. *International Orthopaedics* 2009 **33** 939–943. (https://doi.org/10.1007/s00264-008-0607-y)

35 Van Quickenborne D, Van Der Straeten C & De Smet K. Randomized controlled trial comparing 9 different hip resurfacing designs with a follow-up of 5 years. *Annals of Joint* 2019 **4** 47–47. (https://doi.org/10.21037/aoj.2019.12.04)

36 Van Der Straeten C & De Smet KA. Current expert views on metal-on-metal hip resurfacing arthroplasty. Consensus of the 6thAdvanced hip resurfacing course, Ghent, Belgium, May 2014. *Hip International* 2016 **26** 1–7. (https://doi.org/10.5301/hipint.5000288)

37 Mancino F, Finsterwald MA, Jones CW, Prosser GH & Yates PJ. Metal-on-metal hips: ten-year clinical and radiographic outcomes of the ADEPT metal-on-metal hip resurfacing and modular total hip arthroplasty. *Journal of Clinical Medicine* 2023 **12** 889. (https://doi.org/10.3390/jcm12030889)

38 Samuel LT, Zuke WA, Mahmood S, Munim MA, Alamir PB & Brooks PJ. Hip resurfacing: a single surgeon U.S. series with minimum ten-year follow-up. *Journal of Arthroplasty* 2022 **37** 1799–1808. (https://doi.org/10.1016/j.arth.2022.04.008)

39 Bourget-Murray J, Watt Kearns SJ, Piroozfar S, Lukenchuk J, Johnston K & Werle J. Birmingham Hip Resurfacing for osteoarthritis — a Canadian retrospective cohort study with a minimum 10-year follow-up. *Canadian Journal of Surgery* 2022 **65** E296–E302. (https://doi.org/10.1503/cjs.013320)

40 van der Weegen W, Hoekstra H, Brakel K & Sijbesma T. Limited need for screening of metal-on-metal hip resurfacing patients beyond 10 years of follow-up. *Hip International* 2020 112070002091793. (https://doi.org/10.1177/1120700020917939)

41 Partridge T. The 20-year results of Birmingham hip resurfacing: consecutive cohort series, 1998–2001. In *Orthopaedic Proceedings*, vol. **104**(Supp_4), pp. 24–24. The British Editorial Society of Bone and Joint Surgery, 2022.

42 Hastie GR, Collinson SC, Aqil A, Basu S, Temperley DE, Board TN & Wynn-Jones H. Study to assess the rate of adverse reaction to metal debris in hip resurfacing at a minimum 13-year follow-up. *Journal of Arthroplasty* 2021 **36** 1055–1059. (https://doi.org/10.1016/j.arth.2020.09.056)

43 Palazzuolo M, Antoniadis A, Delaune L, Tornare I & Wegrzyn J. Comparison of the long-term cause of failure and survivorship of four hundred and twenty seven metal-on-metal hip arthroplasties: resurfacing versus large head total hip arthroplasty. *International Orthopaedics* 2021 **45** 3075–3081. (https://doi.org/10.1007/s00264-021-05044-y)

44 Amstutz HC & Le Duff MJ. The 20-year results of the first 400 conserve plus hip resurfacing arthroplasties. *The Bone and Joint Journal* 2021 **103–B**(Supplement B) 25–32. (https://doi.org/10.1302/0301-620X.103B7.BJJ-2020-2256.R1)

45 Sheridan GA, Kelly R, Mc K, Walsh F, O'Byrne JM. Birmingham hip resurfacing and the ASR at a minimum of 10 years: a prospective cohort study. *Acta Orthopaedica Belgica* 2021 **86** 1–6.

46 Engh CA, Ho H, Bhal V, Housman LR, Masonis JL, Noble JW, Hopper RH & Su EP. Ten-year results of the first US FDA-approved hip resurfacing device. *Orthopaedic Proceedings* 2020 **102–B** 20. (https://doi.org/10.1302/1358-992X.2020.10.020)

47 Kiran M, Santhapuri S, Moeen S, Merchant I, Arvinte D & Sood M. 10-year results of ReCap hip resurfacing arthroplasty: a non-designer case series. *Hip International* 2019 **29** 393–397. (https://doi.org/10.1177/1120700019832260)

48 Jonas SC, Whitehouse MR, Bick S, Bannister GC & Baker RP. An 18-year comparison of hybrid total hip replacement and Birmingham hip resurfacing in active young patients. *Hip International* 2019 **29** 630–637. (https://doi.org/10.1177/1120700018814710)

49 Hunter TJA, Moores TS, Morley D, Manoharan G, Collier SG & Shaylor PJ. 10-year results of the Birmingham Hip Resurfacing: a non-designer case series. *Hip International* 2017 **28** 50–52. (https://doi.org/10.5301/hipint.5000518)

50 Uemura K, Takao M, Hamada H, Sakai T & Kenji Ohzono SN. Long-term results of Birmingham hip resurfacing arthroplasty in Asian patients. *Journal of Artificial Organs* 2017 **21** 117–123.

51 Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR). In *Hip, Knee & Shoulder Arthroplasty: 2022 Annaual Report* [Internet]. Adelaide, Australia: AOA, 2022. Available at: https://aoanjrr.sahmri.com/annual-reports-2022

52 National Joint Registry. 19th Annual Report [Internet]. National Joint Registry. 27A Harley Place, London: UK NJR; 2022. Available at: https://reports.njrcentre.org.uk

53 Methodology for Hips [Internet]. NEC ODEP, 2021. Available at: https://www.odep.org.uk/methodology/methodology-for-hips/

54 Van Der Straeten C. Hip resurfacing arthroplasty in young patients: international high-volume centres' report on the outcome of 11,382 metal-on-metal hip resurfacing arthroplasties in patients ≤50 years at surgery. *Hip International* 2020 **32** 353–362.

55 Aulakh TS, Jayasekera N, Singh R, Patel A, Roulahamin N, Kuiper JH & Richardson JB. Efficacy of hip resurfacing arthroplasty: 6 year results from an international multisurgeon prospective cohort study. *Acta Orthopaedica Belgica* 2015 **81** 197–208.

56 Börnert S, Lützner J, Beyer F, Günther KP & Hartmann A. Revision rate and patient-reported outcome after hip resurfacing arthroplasty: a concise follow-up of 1064 cases. *Journal of Arthroplasty* 2015 **30** 2190–2195. (https://doi.org/10.1016/j.arth.2015.06.041)

57 Matharu GS, McBryde CW, Pynsent WB, Pynsent PB & Treacy RBC. The outcome of the Birmingham hip resurfacing in patients aged <50 years up to 14 years post-operatively. *The Bone and Joint Journal* 2013 **95–B** 1172–1177. (https://doi.org/10.1302/0301-620X.95B9.31711)

58 Stoney J, Graves SE, de Steiger RN, Rainbird S, Kelly TL & Hatton A. Is the survivorship of Birmingham hip resurfacing better than selected conventional hip arthroplasties in men younger than 65 years of age? A study from the Australian Orthopaedic Association National Joint Replacement Registry. *Clinical Orthopaedics and Related Research* 2020 **478** 2625–2636. (https://doi.org/10.1097/CORR.0000000000001453)

59 Ras Sørensen SAL, Jørgensen HL, Sporing SL & Lauritzen JB. Revision rates for metal-on-metal hip resurfacing and metal-on-metal total hip arthroplasty: a systematic review. *Hip International* 2016 **26** 515–521. (https://doi.org/10.5301/hipint.5000444)

60 Lukas S, Martinot P, Putman S, Lons A, Drumez E, Migaud H & Girard J. Metal ion release after hip resurfacing arthroplasty and

EFORT Open Reviews (2024) **9** 751–761
https://doi.org/10.1530/EOR-23-0099

knee arthroplasty: a retrospective study of one hundred ninety-five cases. *International Orthopaedics* 2024 **48** 119–126. (https://doi.org/10.1007/s00264-023-05915-6)

61 Gross TP & Liu F. Metal-on-metal hip resurfacing with an uncemented femoral component. *The Journal of Bone and Joint Surgery* 2008 **90**(Supplement 3) 32–37. (https://doi.org/10.2106/JBJS.H.00614)

62 Gunaratne R, Levy B, D'Souza H & Taheri A. Is robotic arm assisted total hip arthroplasty more bone preserving than conventional hip replacements and hip resurfacing? *Open Journal of Orthopedics* 2022 **12** 259–267. (https://doi.org/10.4236/ojo.2022.126025)

63 Sato R, Takao M, Hamada H, Sakai T & Marumo K. Clinical accuracy and precision of hip resurfacing arthroplasty using computed tomography-based navigation. *International Orthopaedics* 2018 **43** 1807–1814.

64 Langton DJ, Bhalekar RM, Joyce TJ, Rushton SP, Wainwright BJ, Nargol ME, Shyam N, Lie BA, Pabbruwe MB, Stewart AJ, *et al*. The influence of HLA genotype on the development of metal hypersensitivity following joint replacement. *Communications Medicine* 2022 **2** 73. (https://doi.org/10.1038/s43856-022-00137-0)

65 Treacy RBC, Holland JP, Daniel J, Ziaee H & McMinn DJW. Preliminary report of clinical experience with metal-on-highly-crosslinked-polyethylene hip resurfacing. *Bone and Joint Research* 2019 **8** 443–450. (https://doi.org/10.1302/2046-3758.810.BJR-2019-0060.R1)

66 Lin D, Xu J, Weinrauch P, Yates P, Young D & Walter W. One- and two-year results of a novel ceramic-on-ceramic hip resurfacing implant in Australia. *Orthopaedic Proceedings* 2023 **105–B**(Supplement 2) 106. (https://doi.org/10.1302/1358-992X.2023.2.106)