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# Which factors influence the rate of failure following metal-on-metal hip arthroplasty revision surgery performed for adverse reactions to metal debris?

AN ANALYSIS FROM THE NATIONAL JOINT REGISTRY FOR ENGLAND AND WALES

## Aims

To determine the outcomes following revision surgery of metal-on-metal hip arthroplasties (MoMHA) performed for adverse reactions to metal debris (ARMD), and to identify factors predictive of re-revision.

#### **Patients and Methods**

We performed a retrospective observational study using National Joint Registry (NJR) data on 2535 MoMHAs undergoing revision surgery for ARMD between 2008 and 2014. The outcomes studied following revision were intra-operative complications, mortality and rerevision surgery. Predictors of re-revision were identified using competing-risk regression modelling.

#### Results

Intra-operative complications occurred in 40 revisions (1.6%). The cumulative five-year patient survival rate was 95.9% (95% confidence intervals (Cl) 92.3 to 97.8). Re-revision surgery was performed in 192 hips (7.6%). The cumulative five-year implant survival rate was 89.5% (95% Cl 87.3 to 91.3). Predictors of re-revision were high body mass index at revision (subhazard ratio (SHR) 1.06 per kg/m<sup>2</sup> increase, 95% Cl 1.02 to 1.09), modular component only revisions (head and liner with or without taper adapter; SHR 2.01, 95% Cl 1.19 to 3.38), ceramic-on-ceramic revision bearings (SHR 1.86, 95% Cl 1.23 to 2.80), and acetabular bone grafting (SHR 2.10, 95% Cl 1.43 to 3.07). These four factors remained predictive of re-revision when the missing data were imputed.

## Conclusion

The short-term risk of re-revision following MoMHA revision surgery performed for ARMD was comparable with that reported in the NJR following all-cause non-MoMHA revision surgery. However, the factors predictive of re-revision included those which could be modified by the surgeon, suggesting that rates of failure following ARMD revision may be reduced further.

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The early observations following revision surgery of metal-on-metal hip arthroplasty (MoMHA) performed for adverse reactions to metal debris (ARMD) suggested a high prevalence of short-term complications and rerevisions.<sup>1,2</sup> Following revision for ARMD, the most frequent modes of subsequent failure have been reported as dislocation, recurrent ARMD and acetabular loosening.<sup>3</sup> In addition, implant survival and patient-reported outcomes have been inferior for MoMHAs revised for ARMD compared with other indications, and compared with matched patients undergoing primary total hip arthroplasty (THA).<sup>1</sup> This is most likely to be related to the potentially destructive nature of ARMD.<sup>1,4,5</sup> Furthermore, the ten-year implant rate of survival following ARMD revision was recently reported to be only 56%, with surviving patients continuing to have poor patientreported outcomes at extended follow-up.<sup>6</sup>

Some studies have assessed factors predictive of poor outcomes following revision for ARMD.<sup>5,7,8</sup> However, these studies were small and therefore underpowered for the identification of prognostic factors. There are still many MoMHA patients who are likely to require revision surgery for ARMD in the future.<sup>3</sup> Therefore, it is important that surgeons have information concerning the expected outcomes in order to appropriately counsel patients regarding any potential risks. Furthermore, knowledge of prognostic factors will assist surgeons when making decisions regarding the reconstructive procedure and post-operative surveillance. Large cohort studies are ideally suited to answer these important clinical questions. The National Joint Registry (NJR) for England and Wales was established in 2002 (and began collecting data on hip and knee joint replacements in April 2003) to facilitate the early identification of poorly performing implants.<sup>9</sup> It is the largest arthroplasty registry in the world, and contains the details of two million joint replacement procedures.

We used NJR data to assess the outcomes following revision surgery of MoMHAs performed for ARMD, and to identify factors predictive of re-revision surgery.

## **Patients and Methods**

A retrospective observational study was performed using all data submitted to the NJR up to 14 August 2015. This dataset included details of all primary MoMHAs (THA and hip resurfacing, HR) which subsequently underwent revision surgery for adverse soft-tissue reaction to particulate debris as recorded in the NJR between 01 June 2008 and 14 August 2014 (n = 2567). We have elected to classify this revision indication as ARMD throughout, given that this is currently the most commonly used term in the literature.<sup>10</sup> This dataset did not include primary MoMHAs revised to another MoMHA for non-ARMD indications (such as fracture, loosening, osteonecrosis) before subsequent revision for ARMD,<sup>6</sup> as we did not wish to include patients who had undergone multiple procedures. ARMD was first introduced on the NJR data capture forms as an indication for revision surgery in June 2008. The cut-off date of 14 August 2014 allowed a minimum follow-up period of one year for outcome assessment. Prior to obtaining the dataset the entire NJR database was linked with the Office for National Statistics database, which provides data on allcause patient mortality, using unique patient identifiers.

Patients were subsequently excluded from the cohort for the following reasons: the ARMD revision was recorded in the NJR as the first stage (excision arthroplasty) of a twostage procedure, but the second stage re-implantation procedure was absent from the NJR (18 hips excluded); the first stage was recorded as performed for ARMD, but the second stage was recorded as performed for non-ARMD indications such as infection (ten hips excluded); it was not possible to determine whether the primary MoMHA was a THA or HR from the recorded component information (four hips excluded). The final cohort for analysis included 2535 primary MoMHAs undergoing revision surgery for ARMD.

Unique patient identifiers allowed linkage of all ARMD revisions to the primary MoMHA and any future re-

revisions. For all procedures, the NJR collects data on patient demographics (age, gender, body mass index (BMI), American Society of Anesthesiologists grade),<sup>11</sup> the surgery performed (indication, venous thromboembolism prophylaxis, surgeon grade, approach, components implanted including bearing surface, size, and fixation), and the occurrence of intra-operative complications (calcar crack, pelvic and/or femoral shaft penetration, trochanteric and/ or femoral shaft fracture, and other complications). In addition, intra-operative findings are recorded for revision procedures. Patient and surgical factors relating to the ARMD revision procedure were used as covariates when assessing predictors of re-revision surgery. Outcomes of interest were intra-operative complications during ARMD revision, and all-cause mortality and all-cause re-revision surgery following ARMD revision.

**Statistical analysis.** All analyses were performed using Stata Version 14.2 (StataCorp LLC, College Station, Texas). The significance level for all analyses was a p-value < 0.05, with 95% confidence intervals (CI) also used. Differences in patient and surgical factors between re-revised and non-re-revised hips were assessed using either unpaired *t*-tests or the Wilcoxon rank-sum test (numerical data), and either the chi-squared test or Fisher's exact test (categorical data). Cumulative patient and implant survival rates following ARMD revision surgery were determined using the Kaplan-Meier method. The endpoint for implant survival was re-revision surgery (removal or exchange of any component). Patients not undergoing re-revision who remained alive were censored on the study end date (14 August 2015).

Fine and Gray<sup>12</sup> competing-risk regression modelling was used to identify predictors of re-revision surgery as mortality can be considered a competing risk. Univariable models explored the association between each predictor and re-revision surgery. Linearity of continuous predictors with outcome (re-revision) was assessed using fractional polynomials, with data grouped if effects were non-linear. The proportional subhazards assumption was satisfied for all predictors. The final multivariable competing-risk regression model was developed using stepwise selection methods. The p-values for the removal and inclusion of predictors in the final multivariable model were  $p \ge 0.20$  and p < 0.10, respectively. The discriminatory ability of the final multivariable model for distinguishing between hips that did or did not undergo re-revision surgery was analysed using the concordance (c) statistic. The c statistic (range 0 to 1; useful prognostic models = 0.60 to 0.85) provides a global assessment of fit for the survival model, and is equivalent to the area under a receiver operating characteristic curve.13,14

There were four covariates with missing data (BMI n = 682; revision procedure n = 5; revision femoral head size n = 29; revision bearing surface n = 119). As a sensitivity analysis, regression models were repeated using a complete dataset where missing data were imputed.

Table I.	Patient	and surgica	al factors	for all	metal-on-	metal hi	ip art	hroplasties	evised f	or adverse	e reactions	to meta	l debris	(ARMD)	with	hips not
underg	oing re-	revision sur	gery con	npared	with thos	e underg	going	re-revision	surgery							

Beak Bar and the set of	Covariate	All ARMD hip revisions (n = 2535) (100%)	ARMD hip revisions not undergoing re-revision surgery (n = 2343) (92.4%)	ARMD hip revisions undergoing re-revision surgery (n = 192) (7.6%)	p-value
Appendix problemDefinition of the part o	Gender, n (%)	1509 (59 5)	1209 (50.2)	101 (62.0)	0.205
<table-container>Math diam The set of the set of</table-container>	Age at revision (yrs)	1509 (59.5)	1366 (59.2)	121 (63.0)	0.305
Name Description <thd< td=""><td>Mean (SD)</td><td>63.6 (10.1)</td><td>63.7 (10.0)</td><td>62.3 (11.0)</td><td>0.1045</td></thd<>	Mean (SD)	63.6 (10.1)	63.7 (10.0)	62.3 (11.0)	0.1045
Binane discrimentation of the sector of t	Mean (SD)	29.0 (5.1)	28.9 (5.1)	30.1 (5.7)	0.0179
There and probate of the start of the st	Bilateral revisions for ARMD, n (%)	224 (8.8)	206 (8.8)	18 (9.4)	0.784
im mar mar be and m	Primary arthroplasty, n (%)	1716 (677)	1572 (671)	144 (75.0)	0.024
TheoremHorem11 <th< td=""><td>HR</td><td>819 (32.3)</td><td>771 (32.9)</td><td>48 (25.0)</td><td>0.024</td></th<>	HR	819 (32.3)	771 (32.9)	48 (25.0)	0.024
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she of of the function of the	≤ 36 38 to 44	470 (18.5) 751 (29.6)	429 (18.3) 696 (29.7)	41 (21.4) 55 (28.7)	0.737
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Image and the set of the se	≥ 52	212 (8.4)	198 (8.5)	14 (7.3)	
Advinue de la facta de la	Mean (SD)	5.2 (1.8)	5.3 (1.8)	4.7 (1.9)	< 0.0001
14%6%6%6%9% <td>ASA grade at revision, n (%)</td> <td></td> <td></td> <td></td> <td></td>	ASA grade at revision, n (%)				
a makowaa makowaa main a mathema a strain a	1	476 (18.8)	438 (18.7)	38 (19.8) 139 (72.4)	0.769
VTE - density in the intermediate interm	2 3 or above	232 (9.2)	217 (9.3)	15 (72.4)	
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<table-container>None30 (a)20 (a)20</table-container>	Other	922 (36.4)	62 (2.7) 852 (36.4)	6 (3.7) 70 (36.5)	
VTC - mechanical, nt %3VAT (96.6)Val (95.6)Val (95.6)Val (95.6)Val (95.7)Val (95.7)Va	None	236 (9.3)	210 (9.0)	26 (13.5)	
Number Number Number Number Number Number Number Number Number Number Number Number Number Number Number Number Number Number Number 	VTE – mechanical, n (%)	2447 (06 5)	2262 (06 6)	104 (05.0)	0.504
<table-container>Median energy ords, not set and the set of the se</table-container>	Number of ARMD hip revision procedures performed by each	of 237 centres	2203 (90.0)	164 (35.6)	0.564
Consult working2430 (95.9)2437 (95.9)18 (95.3)0.833Singlei approxi2084 (82.2)129 (82.3)155 (80.7)0.87Postarior vis other0.64 (63.3)144 (63.9)150 (67.7)0.81PARISON Indicationatina-operative findinga, n(%)156 (80.7)62 (82.3)0.812 65 indicationatina-operative findinga156 (80.7)62 (82.3)0.812 65 indicationatina-operative findinga156 (80.7)62 (82.3)0.81ARMO only258 (100)234 (100)152 (100)NAApplin554 (21.9)252 (22.3)15 (6.8)0.332Aspetic lossening (any)12 (8.4)06 (8.7)15 (6.8)0.332Astatuluir lossening (any)12 (8.4)166 (21.1)15 (6.7)0.332Actatuluir lossening11 (4.4)164 (4.4)64 (3.1)0.332Actatuluir lossening10 (4.3)16 (4.7)6 (3.1)0.332Actatuluir lossening10 (4.3)16 (3.7)0.332Actatuluir component wear43 (17.0)16 (12.7)14 (10.0)0.332Actatuluir component wear43 (17.1)16 (12.7)10 (12.1)10 (12.1)10 (12.1)Actatuluir component wear43 (17.1)10 (12.3)10 (12.1)10 (12.1)10 (12.1)10 (12.1)10 (12.1)Actatuluir component wear40 (13.1)10 (12.1)10 (12.1)10 (12.1)10 (12.1)10 (12.1)10 (12.1)10 (12.1)10 (12.1)10 (12.1)10 (12.1)10 (12.1)10 (12.1)10 (12.	Median (range) Revision surreon grade, n. (%)	28 (1 to 169)	28 (1 to 169)	34 (1 to 169)	0.0532
Barbar particularSolver129 (82.3)155 (80.7)057Particular volutions164 (8.3.2)144 (2.9)130 (6.7)0.81AMM on (8.6.7)235 (100)235 (100)120 (100)NAARM on (8.6.7)235 (100)236 (100)120 (100)NAARM on (8.6.7)235 (100)232 (2.2.3.1)13 (6.8.7)0.382Aspito (bosening (any)219 (8.6)205 (2.3.7)13 (6.8.7)0.382Aspito (bosening (any)12 (4.4)165 (6.0)7 (3.7.7)0.582Catesbular (bosening (any)10 (4.3.7)166 (7.1)15 (6.8.7)0.582Froncel (bosening (any)10 (4.3.7)164 (3.1)0.582Froncel (bosening (any)10 (4.3.7)164 (3.1)0.582Froncel (bosening (any)10 (4.3.7)164 (3.1)0.582Froncel (bosening (any)10 (4.3.7)164 (3.1)0.582Froncel (bosening (any)13 (1.6.7)10 (1.7)1.6.70.582Froncel (bosening (any)10 (4.3.7)164 (3.1)0.5820.582Froncel (bosening (any)10 (4.3.7)164 (3.1)0.5820.582Froncel (bosening (any)10 (4.3.7)164 (3.1)0.5820.582Froncel (bosening (any)164 (3.1)164 (3.1)0.5820.582Froncel (bosening (any)164 (3.1)164 (3.1)0.5820.582Froncel (any)16 (4.1)16 (4.1)16 (4.1)0.6820.582Froncel (any)16 (4.1)16 (4.1)16 (4.1)0.5	Consultant vs other	2430 (95.9)	2247 (95.9)	181 (95.3)	0.693
Berlia indicational indicati	Posterior vs other	2084 (82.2)	1929 (82.3)	155 (80.7)	0.577
ARM0 only1604 (63.3)1474 (62.9)10 (677)0.182 06 indications1636.7)0680 (37.1)02 (32.3)0.18ARM0253 (100)252 (22.3)02 (16.7)0.070Aseptic loosening (any)219 (8.6)026 (8.8)13 (6.8)0.338Actabular loosening12 (4.4)105 (4.5)13 (5.7)0.892Detoxysis (any)112 (4.4)106 (4.1)115 (7.7)0.898Catabular loosening110 (4.3)164 (4.4)61 (3.1)0.330Actabular loosening10 (4.3)164 (4.4)61 (3.1)0.390Catabular loosening10 (4.3)15 (1.4)0.3010.302Catabular loosening10 (4.3)16 (3.7)0.3900.302Actabular loosening10 (4.3)16 (3.7)0.3900.302Catabular loosening10 (4.3)10 (4.4)61 (3.1)0.390Actabular loosening10 (4.0)10 (3.1)0.3900.392Catabular loosening10 (4.0)10 (3.1)0.3900.392Detox stor war40 (7.7)2.91 (7.7)1.91 (7.9)0.390Detox stor war10 (4.7)10 (3.9)1.91 (7.9)0.390Detox stor war10 (4.7)10 (4.9)1.91 (7.9)0.390Detox stor war10 (4.7)10 (4.9)1.91 (7.9)0.390Detox stor war10 (4.1)10 (4.1)1.91 (4.1)0.390Detox stor war10 (4.1)10 (4.1)1.91 (4.1)1.91 (4.1)Detox stor war	Revision indications/intra-operative findings, n (%)				
A b S inclusion         So 1 (Se J, /         NA           ARMO         255 (100)         224 (100)         120 (100, ///////////////////////////////////	ARMD only	1604 ( <i>63.3</i> )	1474 (62.9)	130 (677)	0.185
Pain54 (21.9)52 (22.3)21 (6.7)0.70Apatic losening (any)13 (6.8)13 (6.8)038Apatic losening (any)15 (4.9)106 (4.6)13 (5.7)0.392Bernaral losening12 (4.4)106 (4.5)14.570.392Octo dysis (any)10 (4.2)106 (4.7)16 (3.7)0.392Actabular oscening10 (4.0)104 (4.7)6 (3.7)0.393Femoral oscening10 (4.0)104 (4.7)6 (3.7)0.393Pentral oscening10 (4.0)104 (4.7)6 (3.7)0.393Other abnormal findings85 (3.4)81 (3.7)6 (3.7)0.402Other abnormal findings85 (3.4)15 (3.7)6 (3.7)0.402Other abnormal findings85 (3.4)76 (3.2)4 (3.7)0.402Actabular oscening93 (1.7)76 (3.2)1.0021.002Fracture43 (1.7)39 (1.7)8 (4.2)0.005Incertos insido scening94 (1.7)94 (1.7)94 (1.7)0.002Incertos insido scening94 (1.7)94 (1.7)0.0020.002Incertos insido scening <td>ARMD</td> <td>2535 (100)</td> <td>2343 (100)</td> <td>192 (100)</td> <td>NA</td>	ARMD	2535 (100)	2343 (100)	192 (100)	NA
Aseptic losening (any)219 (8.6)206 (8.6)10 (8.6)0.338Asetabular losening12 (4.4)105 (4.5)7 (3.7)0.392Femoral losening112 (4.4)105 (4.5)7 (3.7)0.589Osteolysis (any)10 (4.3)106 (4.7)6 (3.1)0.593Actabular losening10 (4.3)04 (4.4)6 (3.1)0.527Other abnormal findings5 (3.4)5 (3.4)6 (3.2)4Other abnormal findings5 (3.4)3 (3.2)40.278Actabular component wear43 (1.7)40 (1.7)40.533Actabular component wear3 (1.7)9 (1.7)8 (4.2)0.663Dialocation/subluxation3 (1.6)9 (1.2)8 (4.2)0.606Indertoning9 (0.4)9 (0.4)0.6010.00Indertoning9 (0.4)9 (0.4)0.0010.00Indertoning tracture6 (0.2)0.0010.000.00Indertoning tracture103 (4.6)1071 (4.6.3)24 (4.2)0.031Actabular component (whead + liner + taper adapter)78 (3.1)73 (3.1)4 (3.2)0.01Femoral component (whead + liner + taper adapter)78 (3.1)73 (3.1)4 (3.2)0.157Aratbular component (whead + liner + taper adapter)78 (3.1)73 (3.1)4 (3.2)0.157Femoral component (whead + liner + taper adapter)78 (3.1)73 (3.1)4 (3.2)0.157Aratbular component (whead + liner + taper adapter)78 (3.1)73 (3.1)15 (6.2)0.	Pain	554 (21.9)	522 (22.3)	32 (16.7)	0.070
Acta Bull 100 Setting         125 (4.9)         116 (5.0)         7 (5.7)         0.532           Dete objesia (any)         177 (6.9)         166 (7.7)         11 (5.7)         0.479           Acta Bull or steolysis         101 (4.3)         104 (4.4)         6 (3.7)         0.479           Acta Bull or steolysis         101 (4.3)         104 (4.4)         6 (3.7)         0.527           Other abornal findings         85 (3.4)         13 (3.5)         4         0.278           Acta Bull or steolysis         101 (4.7)         40 (7.7)         4         0.563           Dialocation/isubluxation         70 (5.1)         29 (1.2)         8 (4.2)         0.063           Dialocation/isubluxation         20 (0.9)         19 (0.8)         4         0.50           Infection         20 (0.9)         9 (0.4)         8 (0.3)         0 (0)         0.52           Infection         9 (0.4)         9 (0.4)         9 (0.4)         0.00         0.53           Infection         102 (4.8)         6 (8.3)         0 (0)         1.00           Relativiar component (serving adapter)         163 (4.6.0)         0 (10)         1.00           Relativiar component (serving adapter)         163 (4.6.0)         0 (14.5.0)         2 (4.4.2.1)	Aseptic loosening (any)	219 (8.6)	206 (8.8)	13 (6.8)	0.338
Östedivisi (any)         177 (6.9)         165 (7.1)         1(5.7)         0.479           Acatabular osteolysis         101 (4.3)         104 (4.4)         6 (3.7)         0.390           Cher banornal findings         80 (3.4)         81 (3.5)         4         0.405           Other abnornal findings         80 (3.4)         81 (3.5)         4         0.405           Other abnornal findings         80 (3.4)         81 (3.2)         4         0.405           Acatabular component wear         43 (1.7)         30 (1.7)         4         0.506           Fracture         43 (1.7)         30 (1.7)         8 (4.2)         0.006           Indection/subluxation         37 (1.5)         29 (1.2)         8 (4.2)         0.006           Indection         20 (0.9)         10 (0.8)         4         0.200         0.00           Incorrect implant size         9 (0.4)         8 (0.4)         0 (0)         100         100           Incorrect implant size         9 (0.4)         102 (40.8)         68 (41.4)         0 (41 (3.5)         0 (7)         100           Actabular component (-/- head + liner +-/- taper adaptor)         178 (3.1)         73 (3.1)         4         100         100         100         100         100	Femoral loosening	125 (4.9) 112 (4.4)	105 (4.5)	7 (3.7) 7 (3.7)	0.392
Acatabular osteolysis         101 (4.3)         104 (4.4)         6 (3.1)         0.330           Femoral osteolysis         101 (4.0)         85 (4.1)         6 (3.1)         0.527           Other abnormal findings         85 (3.4)         81 (3.5)         #         0.405           Inplant mallingingment         43 (1.7)         40 (1.7)         #         0.0278           Acatabular component wear         43 (1.7)         39 (1.7)         8 (4.2)         0.563           Dislocation/subluxation         21 (0.9)         19 (0.8)         #         0.200           Infection         22 (0.9)         19 (0.4)         8 (0.2)         0.001         0.503           Infection         6 (0.2)         6 (0.3)         0 (0/0         1.00         5.00           Revisence revised         6 (0.2)         0 (0/1         0.001         1.00         5.00           Retabular component (+- head +- liner +- taper adapter)         138 (40.0)         1071 (45.8)         22 (40.2)         0.001         1.00           Retabular component (+- head +- liner +- taper adapter)         138 (40.0)         1071 (45.8)         22 (40.4)         0.101         1.00           Retabular component (+- head +- liner +- taper adapter)         138 (40.0)         101 (45.7)         22 (30.0)	Osteolysis (any)	177 (6.9)	166 (7.1)	11 (5.7)	0.479
remoral osteolysis         In (4.0)         56 (4.7)         6 (4.7)         6 (4.7)         0.22/           Implant milalignment         79 (3.1)         76 (3.2)         4         0.273           Acetabular component wear         31 (1.7)         40 (1.7)         4         0.005           Fracture         31 (1.7)         39 (1.7)         8 (4.2)         0.6563           Dislocation/subluxation         22 (0.9)         19 (0.8)         4         0.200           Infection         22 (0.9)         19 (0.8)         4         0.200         0.230           Incorrect implant size         9 (0.4)         8 (0.3)         4         0.508         0.200         0.00         1.00           Indention/subluxation         9 (0.4)         9 (0.4)         10.40         0 (0)         1.00         1.00           Inter dissociation         9 (0.4)         10.41         1.02         0.005         1.00           Revision procenders, 'NS         -         -         1.00         1.00         1.00           Revision formoral bed size (mm), 'n (S)         -         27 (1.7.2         27 (1.7.2         0.015           Revision formoral bed size (mm), 'n (S)         -         2.2.5 to 48         2.2.5 to 48         2.2.5 to 48	Acetabular osteolysis	110 (4.3)	104 (4.4)	6 (3.1)	0.390
minipant malalignment         79 (3.1)         76 (3.2)         ‡         0.278           Acetabular component wear         43 (1.7)         40 (1.7)         ‡         0.00           Fracture         43 (1.7)         39 (1.7)         ‡         0.00           Dislocation/subluxation         37 (1.5)         29 (1.2)         8 (4.2)         0.006           Infection         20 (0.9)         19 (0.8)         ‡         0.508           Incorrect implant size         9 (0.4)         8 (0.3)         ‡         0.508           Inipend fissociation         9 (0.4)         8 (0.3)         ‡         0.508           Raispont procedure, n (%)         6 (0.2)         6 (0.3)         0 (0)         100           Raispont procedure, n (%)         102 (40.8)         968 (41.4)         64 (33.5)         0 (0)         0.031           Acetabular component (+/- head +/- liner +/- taper adapter)         163 (46.0)         1071 (45.8)         92 (48.2)         100         100           Femoral loomponent (+/- head +/- liner +/- taper adapter)         163 (46.0)         1071 (45.8)         92 (48.2)         116           Mochalar component (+/- head +/- liner +/- taper adapter)         163 (46.0)         1071 (45.8)         22 (48.2)         12         100         12	Pemoral osteolysis Other abnormal findings	101 (4.0) 85 (3.4)	95 (4.7) 81 (3.5)	6 (3.7) ±	0.527
Acetabular component wear         \$1,7,7         \$0,7,7         \$1,0,0         \$1,5,7         \$1,0,0	Implant malalignment	79 (3.1)	76 (3.2)	÷	0.278
Fracture         43 (1.7)         39 (1.7)         ‡         0.563           Dislocation/subluxation         37 (1.5)         29 (1.2)         8 (4.2)         0.053           Infection         20 (0.9)         19 (0.8)         ‡         0.230           Incorrect implant size         9 (0.4)         8 (0.3)         ‡         0.563           Liner dissociation         9 (0.4)         8 (0.3)         0 (0)         1.00           Implant fracture         0 (0.2)         0 (0.3)         0 (0)         1.00           Rowino procedure, *n (%)	Acetabular component wear	43 (1.7)	40 (1.7)	<b>‡</b>	1.00
Displantion         Displant         Displant <thdisplant< th="">         Displant         Displant</thdisplant<>	Fracture Dislocation/subluyation	43 (1.7) 37 (1.5)	39 (1.7) 29 (1.2)	‡ 8 (4 2)	0.563
Incorrect inplant size         9 (0,4)         8 (0,3)         ‡         0.508           Liner dissociation         9 (0,4)         9 (0,4)         0 (0)         1,00           Inplant facture         6 (0.2)         6 (0.3)         0 (0)         1,00           Rotizen procedure, r (%)          6 (0.2)         6 (0.3)         0 (0)         1,00           Rotizen procedure, r (%)          58 (41.4)         64 (33.5)         0 (3)         1           Acetabular component (+/- head +/- liner +/- taper adapter)         180 (30.0)         101 (45.8)         22 (48.2)         0 (3)           Rotizen termoral near size (mm), r (%)         251 (10.2)         227 (37.7)         30 (15.7)         1           Roundponents only *         251 (10.2)         221 (3.2)         34.4 (3.4)         0.418           Range         22.5 to 48         22.5 to 44         22.2 to 48         0.418           Range         22.5 to 48         22.5 to 44         22.5 to 48         23.3 (2)         36         15.9 (3.1)         15.9 (3.1)         15.9 (3.1)         15.9 (3.1)         35.9 (3.1)         5.9 (3.1)         5.9 (3.1)         5.9 (3.1)	Infection	22 (0.9)	19 (0.8)	‡	0.230
Liner dissociation         9 (0.4)         9 (0.4)         0 (0)         1.00           Implant fracture         6 (0.2)         6 (0.3)         0 (0)         1.00           Revision procedures, n (\$5)         .	Incorrect implant size	9 (0.4)	8 (0.3)	<b>‡</b>	0.508
Industry	Liner dissociation	9 (0.4) 6 (0.2)	9 (0.4)	0 (0)	1.00
All components revised     1032 (40.8)     968 (41.4)     64 (33.5)     0.031       Actabular component (+/ head +/ liner +/ taper adapter)     163 (60.0)     1071 (45.8)     92 (48.2)       Femoral component (+/ head +/ liner +/ taper adapter)     73 (3.1)     4       Modular component (+/ head +/ liner +/ taper adapter)     73 (3.1)     4       Revision femoral based isse (mm), n (%)     22 (9.7)     30 (15.7)       Revision femoral based isse (mm), n (%)     34.3 (3.2)     94.2 (3.2)     30 (15.7)       Range     22.25 to 48     22.25 to 48     22.55 to 48       < 36	Revision procedure," n (%)	0 (0.2)	0 (0.3)	0 (0)	1.00
Acetabular component (+/- hage +/- taper adapter)         1163 (46.0)         1071 (45.8)         92 (48.2)           Femoral component (+/- hage +/- taper adapter)         78 (3.1)         73 (3.1)         4           Modular component (+/- hage +/- taper adapter)         78 (3.1)         73 (3.1)         4           Modular component (+/- hage +/- taper adapter)         78 (3.1)         73 (3.1)         30 (15.7)           Revision femoral head size (mm), 'n (%)         257 (10.2)         227 (9.7)         30 (15.7)           Revision femoral head size (mm), 'n (%)         44.3 (3.4)         0.418           Range         34.3 (3.2)         34.2 (3.2)         34.4 (3.4)         0.418           Range         22.5 to 48         22.5 to 48         22.5 to 48         23.6           São         82 (55.3)         820 (55.6)         62 (33.0)         0.751           São         1486 (59.5)         1371 (59.4)         115 (61.2)         15           São         1486 (59.5)         1371 (59.4)         115 (61.2)         10.751           CoP         1486 (59.7)         1040 (46.5)         64 (35.4)         0.017           CoC         765 (31.7)         693 (31.0)         72 (39.8)         0.017           CoD         765 (31.2)         488 (21.8)	All components revised	1032 (40.8)	968 (41.4)	64 (33.5)	0.031
Cancel of an instruction profession of a star of a st	Acetabular component (+/- head +/- liner +/- taper adapter)	1163 ( <i>46.0</i> ) 78 (2.1)	1071 ( <i>45.8)</i>	92 (48.2)	
Revision femoral head size (mm)," n (%)         Valuation femoral head size (mm)," n (%)           Valuation femoral head size (mm), n (%)         Valuation femoral head size (mm), n (%)           Valuation figure (mm), n (%)         Valuation femoral head size (mm), n (%)           Valuation figure (mm), n (%)         Valuation figure (mm), n (%)           Valuation figur	Modular components only <sup>†</sup>	257 (10.2)	227 (9.7)	+ 30 <i>(15.7)</i>	
Meen (sD)         34.3 (3.2)         34.2 (3.2)         34.4 (3.4)         0.118           Range         22.5 to 48         22.25 to 48         22.55 to 48         22.55 to 48           < 36	Revision femoral head size (mm), <sup>°</sup> n (%)				
Number         22,20 0.94         22,20 0.94         22,20 0.94           >36         22,00 0.94         22,00 0.94         0.751           >36         882 (35.3)         820 (35.5)         62 (33.0)         0.751           >36         130 (5.2)         1371 (59.4)         115 (61.2)         15           >36         30 (5.2)         19 (5.2)         11 (5.9)         100 (5.2)         100 (5.2)           Revision bearing surface, *n (%)         50 (35.10)         72 (39.8)         0.017           CoC         765 (31.7)         693 (37.0)         72 (39.8)         0.01           MoP         533 (22.1)         488 (21.8)         45 (24.9)         0.02           CoM, Mor MoC         14 (6.6)         100 (87.3)         139 (80.1)         0.52           Comentless         1919 (87.5)         120 (87.5)         129 (80.71)         0.522	Mean (SD) Bange	34.3 (3.2) 22 25 to 48	34.2 (3.2) 22 25 to 44	34.4 (3.4) 22.25 to 48	0.418
36         1486 (59.5)         1371 (59.4)         115 (61.2)           > 36         130 (5.2)         119 (5.2)         116 (5.2)           Revision bearing surface, 'n (%)         1         104 (45.7)         1040 (46.5)         64 (35.4)         0.017           CoC         765 (31.7)         693 (31.0)         72 (39.8)         0.017           MoP         533 (22.1)         488 (21.8)         45 (24.9)         0.001           CoM, Mod r MoC         14 (0.6)         14 (0.6)         0.001         0.202           Careentless         139 (87.5)         139 (87.5)         139 (80.7.1)         0.522	< 36	882 (35.3)	820 (35.5)	62 (33.0)	0.751
> 36 19 (5.2) 19 (5.2) 19 (5.2) 11 (5.9) Revision Bearing surface," n (%) CoP 104 (45.7) 1040 (46.5) 64 (35.4) 0.017 CoC 765 (31.7) 693 (31.0) 72 (39.8) MoP 533 (32.7) 488 (21.8) 45 (24.9) CoM, MoM or MoC 14 (0.6) 10 (0 Apertabular component fixation, n (%) Camentiless 199 (97.5) 1190 (97.5) 129 (80.7.1) 129 (80.7.1) 0.522	36	1486 (59.5)	1371 (59.4)	115 ( <i>61.2</i> )	
Normal searing surface, in (%)         0.014 (45.7)         1040 (46.5)         64 (35.4)         0.017           CoP         104 (45.7)         693 (31.0)         72 (39.8)         72 (39.8)           MoP         533 (22.7)         488 (27.8)         45 (24.9)         600           CoM, MoM or MoC         14 (0.6)         14 (0.6)         0.00         600           Apertabular component fixation, n (%)         2         2         7         70.00 (97.8)         129 (89.7)         0.522	> 36 Revision bearing surface <sup>9</sup> n (9/)	130 (5.2)	119 (5.2)	11 (5.9)	
CoC         765 (31.7)         693 (31.0)         72 (39.8)           MoP         533 (22.1)         488 (21.8)         45 (24.9)           CoM, MoM or MoC         14 (0.6)         0 (0)           Asstabular component fixation, n (%)         2         29.8           Cementless         1919 (87.5)         1780 (87.3)         139 (89.1)         0.522	CoP	1104 (45.7)	1040 (46.5)	64 (35.4)	0.017
MoP         533 (22.1)         488 (21.8)         45 (24.9)           CoM, Mo or MoC         14 (0.6)         0 (0)           Assaultar component fixation, n (%)         2         2           Cementiles         1919 (87.5)         1780 (87.3)         139 (89.1)         0.522	CoC	765 (31.7)	693 (31.0)	72 (39.8)	
Component fixation, n (%)         14 (0.0)         0 (0/)           Cementless         1919 (87.5)         1780 (87.3)         139 (88.1)         0.522	MoP CoM MoM or MoC	533 (22.1) 14 (0.6)	488 (21.8) 14 (0.6)	45 (24.9)	
Cementless 109 (87.5) 1780 (87.3) 139 (89.1) 0.522	Acetabular component fixation. n (%)	i⇔ (0.0)	14 (0.0)	0.07	
	Cementless	1919 (87.5)	1780 ( <i>87.3</i> )	139 (89.1)	0.522
Jementea 2/b (12.b) 258 (12.7) 17 (10.9)	Cemented	275 (12.5)	258 (12.7)	17 (10.9)	
remoral component fixedon, n (%) Cementies 723 (65.3) 674 (64.9) 49 (71.0) 0.299	remoral component fixation, n (%) Cementless	723 (65.3)	674 (64.9)	49 (71.0)	0.299
Cemented 385 (3.8.9) 365 (35.1) 20 (29.0)	Cemented	385 (34.8)	365 (35.1)	20 (29.0)	
Bone graft (femoral), n (%) 76 (3.0) 71 (3.0) ‡ 0.739	Bone graft (femoral), n (%)	76 (3.0)	71 (3.0)	‡	0.739
$\frac{1}{2} \frac{1}{2} \frac{1}$	pone gram (acetabular), n (%) missing data for stated number of bine: BMI (n = 682); rouisio	203 (20.1)	407 (19.0) (n = 29): revision bearing surface (n = 119)	52 (271)	0.012

missing data for stated number of hips: BMI (n = 682); revision procedure (n = 5); revision femoral head size (n = 29); revision bearing surface (n = 119) finvolves revision of the femoral head and liner, with or without the use of a taper adapter data suppressed due to small count within the cell. The actual number was between 1 and 5 Statistically significant differences between the re-revised and non-re-revised hips (p < 0.05) are highlighted in bold text All numerical data were compared using unpaired / tests, apart from the number of ARMD hip revision procedures performed by each centre, which was compared using the Wilcoxon rank-sum test. All categorical data were compared using the chi-squared test, apart from the following covariates, which were compared using Fisher's exact test: certain revision indications (other abnormal findings; implant malalignment; acetabular com-ponent wear; fracture; infection; incorrect implant size; liner dissociation; implant fracture], revision procedure, revision bearing surface, and bone graft (femoral) So, standard deviation; BMI, body mass index; THA, tota hip arthroplasty; IRA, hip resurfacing; ASA, American Society of Anesthresiologist; VTE, venous thromboembolism; LMWH, low molecular weight heparin; CoP, ceramic-on-polyethylene; CoC, ceramic-on-ceramic; NoP, metal-on-polyethylene; CoM, ceramic-on-metal; MoM, metal-on-ceramic; NA, not applicable

Multiple imputation is an accepted statistical method for managing missing data.<sup>15</sup> In total, 50 complete datasets were imputed, with data assumed to be missing at random. Imputation models included all other covariates from the regression analyses with complete data available and the study outcome (Nelson-Aalen estimate, and

whether the hip was re-revised), given that all of these factors carried information about the missing values.

# **Results**

Intra-operative complications. Of the 2535 MoMHAs revised for ARMD (Table I), intra-operative complications

Re-revision indications and intra-operative findings	Events, n (%)			
Overall	291 causes in 192 re-revised hips			
Hips with one indication	121 ( <i>63.0</i> )			
Hips with two to four indications	71 ( <i>37.0</i> )			
Specific indications				
Pain	52 ( <i>27.1</i> )			
Adverse reactions to metal debris	48 ( <i>25.0</i> )			
Dislocation/subluxation	43 (22.4)			
Deep infection	31 ( <i>16.1</i> )			
Aseptic loosening – acetabular	29 (15.1)			
Aseptic loosening – femoral	15 ( <i>7.8</i> )			
Implant malalignment – acetabular	15 ( <i>7.8</i> )			
Osteolysis – femoral	10 ( <i>5.2</i> )			
Other indication	10 ( <i>5.2</i> )			
Periprosthetic fracture – femoral	8 (4.2)			
Periprosthetic fracture – acetabular	8 (4.2)			
Acetabular component wear	8 (4.2)			
Other (including femoral malalignment, implant fracture, and liner dissociation)	8 (4.2)			
Osteolysis – acetabular	6 (3.1)			

 Table II. Indications for metal-on-metal hip arthroplasties undergoing re-revision surgery following revision surgery performed for adverse reactions to metal debris (n = 192)



Fig. 1

Kaplan-Meier cumulative implant survival rate following revision surgery performed for adverse reactions to metal debris at up to five years. The shaded area represents the respective upper and lower limits of the 95% confidence intervals (Cls). Risk table indicates the number of hips at risk at one-year intervals, with the corresponding number in brackets detailing the number of hips undergoing rerevision surgery during each one-year interval. The one re-revision which was performed more than five years following revision surgery is not included in the risk table. The cumulative five-year implant rate of survival was 89.5% (J 87.3 to 91.3).

occurred in 40 hips (1.6%). The most common complications were fractures of the calcar (n = 11, 27.5%) and greater trochanter (n = 8, 20.0%).

**Patient mortality**. Overall mortality following revision surgery was 1.6% (n = 41). The mean time from ARMD revision to death was 1.9 years (0.1 to 5.9); no patient who died during the follow-up period had undergone re-revision. The cumulative one-year and five-year patient survival rate following ARMD revision was 99.4% (95% CI 99.1 to 99.7) and 95.9% (95% CI 92.3 to 97.8) respectively.

**Re-revision surgery**. Following ARMD revision, re-revision was performed in 192 hips (7.6%) at a mean of 1.2 years

(one day to 5.7 years). In re-revised hips, 71 (37.0%) had more than one indication for failure. The most common rerevision indications were pain (n = 52, 27.1%), ARMD (n = 48, 25.0%), dislocation or subluxation (n = 43, 22.4%), infection (n = 31, 16.1%) and acetabular loosening (n = 29, 15.1%) (Table II).

The mean follow-up time for hips not undergoing rerevision was 2.9 years (1.0 to 6.6). The cumulative five-year implant survival rate following ARMD revision was 89.5% (95% CI 87.3 to 91.3) (Fig. 1).

**Predictors of re-revision surgery: univariable analysis.** Univariable analysis identified six predictors of re-revision (Table III): high BMI at revision; primary THA (compared with HR); shorter interval between primary and revision surgery; modular component only revisions (femoral head and liner with or without taper adapter); ceramic-onceramic revision bearings and acetabular bone grafting.

Predictors of re-revision surgery: multivariable analysis. The final multivariable model included 1766 hips (70% of the cohort) with data available for all variables, including BMI. Four predictors from the univariable analysis remained significant predictors of re-revision in the multivariable model (Table III): high BMI at revision (subhazard ratio (SHR) 1.06 per kg/m<sup>2</sup> increase; 95% CI 1.02 to 1.09; p = 0.001); modular component only revisions (SHR 2.01; 95% CI 1.19 to 3.38; p = 0.009); ceramic-on-ceramic revision bearings (SHR 1.86; 95% CI 1.23 to 2.80; p = 0.003); acetabular bone grafting (SHR 2.10; 95% CI 1.43 to 3.07; p < 0.001). Type of primary joint arthroplasty (THA versus HR) was not eligible for final model inclusion (p = 0.670). Time between primary and revision surgery was included in the final model, but did not reach statistical significance (p = 0.067). The final multivariable model had a reasonable discriminatory ability for distinguishing between hips undergoing and not undergoing re-revision

Table III. Univariable and multivariable Fine and Gray <sup>1</sup>	<sup>2</sup> competing-risk (mortality)	regression analysis to ider	ntify predictors of re-revision	on surgery
following revision surgery performed for adverse react	ions to metal debris (ARMD)			

Covariate	Univariable subhazard ratio (95% Cl)	p-value	Multivariable subhazard ratio (95% CI)	p-value
Gender				
Female vs male	1.14 (0.85 to 1.55)	0.382	t	
Age at revision (per yr)	0.99 (0.98 to 1.01)	0.455	t	
BMI (per kg/m <sup>2</sup> )	1.05 (1.02 to 1.08)	0.003	1.06 (1.02 to 1.09)	0.001
Bilateral revisions for ARMD	1.03 (0.63 to 1.70)	0.901	t	
Primary hip arthroplasty				
HR	1.00	Ref	t	
ТНА	1.47 (1.05 to 2.06)	0.023		
Time from primary to revision (per yr)	0.87 (0.79 to 0.95)	0.002	0.91 (0.81 to 1.01)	0.067
ASA grade at revision				
1	1.00	Ref	1.00	Ref
2	1.00 (0.69 to 1.45)	0.989	*	0.946
3 or above	0.92 (0.50 to 1.70)	0.798	0.58 (0.28 to 1.21)	0.147
VTE – chemical				
None	1.00	Ref	t	
LMWH (+/-other)	0.66 (0.42 to 1.04)	0.074		
Aspirin only	0.87 (0.35 to 2.12)	0.753		
Other	0.72 (0.45 to 1.15)	0.173		
VTE - mechanical		0.170		
	0.79 (0.39 to 1.60)	0 509	t	
Number of ARMD hip revision procedures performed by each centr (oer 10 cases)	<b>1</b> 02 (0.99 to 1.05)	0.118	1.03 (0.99 to 1.06)	0.056
Revision surgeon grade				
Consultant vs other	0.83 (0.42 to 1.62)	0.583	t	
Surgical approach				
Posterior vs other	0.91 (0.63 to 1.32)	0.624	t	
Revision indications		0.024		
ABMD only	100	Ref	t	
2 to 6 indications	0.80 (0.58 to 1.09)	0.156		
Revision details				
Acetabular component (+/- head +/- liner +/- taper adapter)	1.00	Ref	1.00	Ref
All components revised	0.78 (0.56 to 1.07)	0.126	×	0.878
Femoral component (+/- head +/- liner +/- taper adapter)	0.22 (0.30 to 1.59)	0.133	±	<b>‡</b>
Modular components only <sup>5</sup>	1.59 (1.04 to 2.43)	0.032	2.01 (1.19 to 3.38)	0.009
Revision femoral head size				
< 36 mm	1.00	Ref	t	
36 mm	1.12 (0.82 to 1.53)	0.491		
> 36 mm	1.04 (0.53 to 2.02)	0.915		
Revision bearing surface				
CoP	1.00	Ref	1.00	Ref
CoC	1.54 (1.10 to 2.16)	0.013	1.86 (1.23 to 2.80)	0.003
MoP	1.44 (0.98 to 2.10)	0.062	1.45 (0.88 to 2.39)	0.141
CoM, MoM or MoC	±	+	±	ŧ
Acetabular component fixation				
Cementless	1.00	Ref	t	
Cemented	0.89 (0.54 to 1.47)	0.656		
Femoral component fixation				
Cementless	1.00	Ref	t	
Cemented	0.76 (0.44 to 1.30)	0.316		
Bone graft (femoral)	0.74 (0.28 to 1.96)	0.541	t	
Bone graft (acetabular)	1.52 (1.10 to 2.11)	0.011	2.10 (1.43 to 3.07)	< 0.001
*specific subgroup did not meet inclusion criteria for final multivari	sable model ( $n > 0.200$ )			

tovariate was not eligible for inclusion in the final multivariable model

Toovanate was not eligible for inclusion in the final multivariable model trunable to calculate value as no hips in this subgroup underwent re-revision surgery Sinvolves revision of the femoral head and liner, with or without the use of a taper adapter All univariable analyses were based on a cohort of 2416 hips with complete data available for all variables, excluding BMI (181 hips undergoing re-revision surgery and 39 deaths) Multivariable analysis, and the univariable analysis for BMI were based on a cohort of 1766 hips with data available for all variables, including BMI (181 hips undergoing re-revision surgery and 39 deaths) Multivariable analysis, and the univariable analysis for BMI were based on a cohort of 1766 hips with data available for all variables, including BMI (182 hips undergoing re-revision surgery and 28 deaths) Statistically significant differences between the re-revised and no re-revised hips (p < 0.05) are highlighted in bold text C1, confidence interval; BMI, body mass index; THA, tota Hip arthroplasty; HR, hip resurdariang; SAS, American Society of Anesthesiologists; VTE, venous thrombo-embolism; LMWH, low molecular weight heparin; CoP, ceramic-on-polyethylene; CoC, ceramic-on-ceramic; MoP, metal-on-polyethylene; CoM, ceramic-on-metal; MoM, metal-on-metal; MoC, metal-on-ceramic; Ref, reference group

surgery (c statistic = 0.66). When using the imputed dataset, high BMI at revision, modular component only revisions. ceramic-on-ceramic revision bearings and acetabular bone grafting were also identified as significant predictors of re-revision (supplementary table available online).

Modular component only revisions had an increased risk of re-revision compared with hips undergoing all component revisions (SHR 2.03; 95% CI 1.17 to 3.54; p = 0.012), and compared with hips undergoing acetabular component revisions (with or without head, liner, taper adapter revision) (SHR 2.01; 95% CI 1.19 to 3.38; p = 0.009). Rerevisions following modular component only revisions (n = 30) were most frequently for dislocation or subluxation (n = 10, 33.3%) and infection (n = 8, 26.7%).

Ceramic-on-ceramic revision bearings had an increased risk of re-revision compared with hips revised with ceramic-onpolyethylene bearings (SHR 1.86; 95% CI 1.23 to 2.80; p = 0.003), but not compared with hips revised with metalon-polyethylene bearings (SHR 1.27; 95% CI 0.80 to 2.02; p = 0.308). Re-revisions following the use of ceramic-onceramic revision bearings (n = 74) were most frequently for pain (n = 25, 33.8%), ARMD (n = 20, 27.0%) and acetabular loosening (n = 16, 21.6%).

# Discussion

We observed few intra-operative complications during revision surgery for ARMD (1.6%). Similar to previous studies, fractures of the femur represented the most common complication.<sup>16</sup> Mortality rates following ARMD revision were also low (4.1% at five years), which is lower than for primary THA according to NJR data (9.5% at five years).<sup>9</sup> However, this is likely to be related to the younger age of MoMHA patients undergoing revision surgery compared with the full population of primary THA patients (mean age 63.6 years *versus* 69 years, respectively).<sup>9</sup>

Early studies reported catastrophic short-term outcomes following ARMD revision, with one-third of patients requiring re-operations.<sup>1,2,17</sup> Recent studies have observed better outcomes with increased surgical experience,<sup>8</sup> with a reported five-year implant rate of survival of 87.9% following ARMD revision.<sup>7</sup> Although the five-year implant rate of survival was similar in our study (89.5%) to recent studies, 7.8these outcomes appear inferior compared with the implant survival following revision of conventional THA performed at specialist centres.<sup>18,19</sup> However, registries may under report arthroplasty failures,<sup>20,21</sup> which makes comparison with single-centre cohorts problematic. Perhaps the fairest comparison of our results would be with registry outcomes following non-MoMHA revision. Although the lack of a comparator group undergoing non-MoMHA revision surgery is a significant limitation of our study, the NJR does report implant survival following such procedures.<sup>9</sup> The fiveyear implant survival rates following all-cause non-MoMHA revision surgery (with linked primary procedures) recorded in the NJR are 87.8% to 89.1% for primary metal-onpolyethylene THAs (depending on the method of fixation), and 88.2% for primary uncemented ceramic-on-ceramic THAs.9 Therefore implant survival rates following MoMHA revision for ARMD appear similar to those in non-MoMHA patients revised for all indications. However it was not possible to adjust for potential confounding factors, given the non-MoMHA revision outcome data were obtained from the latest NJR report.9 Furthermore, as most patients who underwent MoMHA were young and active,<sup>22</sup> consideration should be given to patient-reported outcome measures following revision but these were not available. Registries do not collect data on patient-reported outcomes following revision, or on non-revision procedures.<sup>9</sup>

Re-revisions following ARMD surgery occurred early, with the indications for re-revision similar to previous reports.<sup>3</sup> Dislocation can occur as the soft-tissue destruction of ARMD may require extensive debridement, and the diameter of the femoral head is commonly reduced.<sup>2,8</sup> The risk of infection is increased by repeat surgery and incomplete excision of metal debris and necrotic tissue, whilst ARMD-induced osteolysis may lead to loosening of the ace-tabular component.<sup>2,3</sup> Recurrence of ARMD has been reported following revision,<sup>3</sup> and in this series ARMD was recorded in 25% of all re-revision cases. This is concerning given the short-term follow-up and exchange to non-MoM bearings in all hips.

The final multivariable model was only reasonable for distinguishing between those hips which either did or did not undergo re-revision surgery. Registry based models are unlikely to have much better discriminatory ability given they do not collect data on variables such as blood metal ion levels and the findings from imaging. However, our final model did provide four predictors of re-revision with large effect sizes.

High BMI at revision and acetabular bone grafting were both associated with an increased risk of future re-revision. We consider these to be largely non-modifiable risk factors. High BMI also predicts re-revision following revision THA performed for non-ARMD indications.<sup>23,24</sup> Patients who required acetabular bone grafting had twice the risk of rerevision. Bone grafting suggests a more complex reconstruction, which may be required because of ARMDinduced osteolysis and/or iatrogenic bone loss from the removal of well-fixed components.5,7,8 Alternatively acetabular bone grafting may represent a modifiable risk factor if the reasons for the higher re-revision rates are related to this strategy being ineffective for managing ARMDinduced osteolysis compared with other reconstructive methods. Complications associated with bone grafts include infection, component migration and loosening, which can all require further surgery.<sup>25</sup>

Modular component only revisions and ceramic-onceramic revision bearings both predicted future rerevision, and represent modifiable surgical risk factors. Some surgeons advise retaining well-fixed and wellpositioned components at revision for ARMD, with exchange of the modular components to non-MoM bearings.<sup>2,26</sup> Taper adapters are also recommended if tapers are not severely damaged.<sup>2,27</sup> Modular exchange is attractive, to prevent the morbidity associated with the removal of well-fixed components.<sup>16,28</sup> However, there is little evidence to support this approach.<sup>2,27</sup> We observed that modular component-only revisions had twice the risk of re-revision compared with all component revisions and acetabular component-only revisions. Failures following modular revision were commonly due to dislocation. This supports the evidence from previous studies employing this strategy,<sup>2,27</sup> suggesting hip stability is difficult to control after ARMD revision with modular component exchange alone. As component malposition represents an important risk factor for subsequent revision of THAs,<sup>29,30</sup> the failure to correct any component malposition would be expected to increase the risk of future revision. However, the NJR does not collect information on component positioning. It is hoped that future studies with detailed radiographic data available could investigate this further.

There is no consensus on which non-MoM bearing surface should be used when revising for ARMD. Ceramic bearings are popular because MoMHA revision patients are generally young and active.<sup>2,5,6,8</sup> However, we observed that ceramic-on-ceramic bearings have an 86% increased risk of re-revision compared with ceramic-on-polyethylene bearings. It is unclear why hard-on-hard ceramic bearings have inferior outcomes, with re-revision indications in this subgroup being consistent with the whole cohort. However, our analysis is limited as we do not know the specific type of ceramic head implanted. Our findings that ceramic-onpolyethylene bearings have the lowest re-revision risk following ARMD revision complement the registry observations of a lower failure rate for this bearing surface in primary THA.9,31

Primary MoM THA has an inferior survivorship compared with HR, even when bearing surfaces from the same manufacturer are implanted.9,32,33 We observed that in MoMHAs undergoing ARMD revision, the primary implant (THA versus HR) did not influence the future re-revision risk. Although limited evidence is available, previous studies have also not identified any difference in outcome following ARMD revision between THAs and HRs.<sup>3,7</sup>

The strengths of our study include the use of linked data from the largest arthroplasty registry in the world, which provides details of the primary MoMHA and all subsequent procedures. Furthermore, the assessment of an unselected population will reduce the likelihood of sampling bias. Therefore, we suspect our findings have good external validity and generalisability. Given the large number of rerevisions, our regression models were not over-fitted.

Nevertheless, registries have numerous potential limitations, which could affect our findings. The use of observational data means we cannot infer causality. Non-registry validation is therefore recommended. However, it would be difficult to achieve this with adequate statistical power as specialist centres perform relatively few ARMD revisions.<sup>1-3,5,7,8,26</sup> Another important limitation is that no large scale validation of the NJR has been performed. Recent studies to validate MoMHA retrievals using NJR data concluded that although revision rates may be underestimated, the completeness of data and accuracy of procedures which were recorded within the NJR were excellent.<sup>20,21</sup> Therefore we assume our study only involves a sample of all ARMD revisions actually performed, and the subsequent rate of failure may also be underestimated. However, details of the cases included are likely to be accurate.

A further limitation is that MoMHA revision rates vary both regionally and between surgeons.<sup>9,31,34,35</sup> Various centres and surgeons may have used different criteria for both diagnosing ARMD and performing revisions. The ARMD revisions analysed here are suspected to comprise a heterogeneous group, ranging from small collections around the arthroplasty and/or metallosis to large invasive and destructive lesions.<sup>1,5,7,8</sup> Furthermore, as the NJR does not collect histopathological data, it is possible that some MoMHAs truly revised for ARMD have been missed as they may have been recorded with different indications in the NJR. Conversely some ARMD revisions in this study may have been misdiagnosed intra-operatively and were revised for non-ARMD indications, such as infection.

Although our findings have been compared with data on all primary hips from the NJR report,<sup>9</sup> the lack of raw data means that we cannot determine how the predictors identified here (such as high BMI and acetabular bone

grafting) influence outcomes following non-MoMHA revisions. Although missing data for some variables (namely BMI) could potentially affect the final model, our findings were confirmed when missing data were imputed (supplementary table available online). Further surgery represents an important outcome measure, but some procedures will not have been captured by the NJR, such as closed reductions of dislocations, debridement and washouts for infection and internal fixation for periprosthetic fractures. Finally, although we assessed the effect of primary MoM implant (THA versus HR) on re-revision rates, it was not possible to stratify the analysis further by implant manufacturer as we were not allowed access to this sensitive data by the registry and manufacturers.

Data from the largest arthroplasty registry in the world have demonstrated that the short-term risk of re-revision following MoMHA revision surgery performed for ARMD was comparable with that reported within the NJR following allcause non-MoMHA revision.9 However predictors of rerevision included factors that the surgeon can modify intraoperatively (type of revision procedure and bearing surface). Surgeons may therefore be able to reduce the rate of failure further following ARMD revision. Our findings may be useful when advising MoMHA patients about the risks associated with revision surgery for ARMD, and for making decisions regarding the type of hip reconstruction to perform.

Take home message:



- Factors predictive of re-revision following ARMD revision surgery included modifiable factors (type of revision procedure and bearing surface), which suggests that surgeons may reduce fail-

#### Supplementary material

ure rates further following ARMD revision.

A table showing the competing risk regression analysis in a complete dataset, where missing data were imputed, is available alongside the online version of this article at www.bjj.boneandjoint.org.uk

#### Author contributions:

G. S. Matharu: Study design, Data analysis and interpretation, Manuscript draft, revision and approval.

A. Judge: Study design, Data analysis and interpretation, Manuscript revision and approval.

H. G. Pandit: Study design, Data interpretation, Manuscript revision and approval.

D. W. Murray: Study design, Data interpretation, Manuscript revision and approval

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1027

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