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HIP

Explant analysis of the Biomet Magnum/ ReCap metal-on-metal hip joint

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Objectives

The high revision rates of the DePuy Articular Surface Replacement (ASR) and the DePuy ASR XL (the total hip arthroplasty (THA) version) have led to questions over the viability of metal-on-metal (MoM) hip joints. Some designs of MoM hip joint do, however, have reasonable mid-term performance when implanted in appropriate patients. Investigations into the reasons for implant failure are important to offer help with the choice of implants and direction for future implant designs. One way to assess the performance of explanted hip prostheses is to measure the wear (in terms of material loss) on the joint surfaces.

Methods

In this study, a coordinate measuring machine (CMM) was used to measure the wear on five failed cementless Biomet Magnum/ReCap/ Taperloc large head MoM THAs, along with one Biomet ReCap resurfacing joint. Surface roughness measurements were also taken. The reason for revision of these implants was pain and/or adverse reaction to metal debris (ARMD) and/or elevated blood metal ion levels.

Results

The mean wear rate of the articulating surfaces of the heads and acetabular components of all six joints tested was found to be 6.1 mm³/year (4.1 to 7.6). The mean wear rate of the femoral head tapers of the five THAs was 0.054 mm³/year (0.021 to 0.128) with a mean maximum wear depth of 5.7 µm (4.3 to 8.5).

Conclusion

Although the taper wear was relatively low, the wear from the articulating surfaces was sufficient to provide concern and was potentially large enough to have been the cause of failure of these joints. The authors believe that patients implanted with the ReCap system, whether the resurfacing prosthesis or the THA, should be closely monitored.

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Keywords: Hip, Arthroplasty, Wear, Metal-on-Metal, Taper, Film Thickness, Lubrication

Article focus

- How does the *ex vivo* wear of failed Biomet ReCap joints compare with that of similar MoM hip joint designs?

Key messages

- The wear rates of each of these THAs and surface replacement ReCap joints (4.1 to 7.6 mm³/year) were higher than those considered to be able to cause wear-related failures in similar large diameter monoblock MoM hips.
- The wear of the joints measured in this study was mainly found to be from the articulating surfaces.

Strengths and limitations

- The volumetric wear of the ReCap joint has been measured and is reported for the first time using a viable technique for both the articulating surfaces (of the THAs and the resurfacing) and the taper junctions of the THA.
- This paper reports on a relatively low sample size.

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Introduction

In an attempt to minimise the occurrence of failure of hip prostheses due to wear particle-induced osteolysis, there was a resurgence of metal-on-metal (MoM) hip joints between the mid 1990s and mid 2000s.[1-3] These all-metal hip joints had a larger diameter than those that had been available in previous years in an attempt to optimise lubrication and the range of motion available for use, as well as reduce the incidence of dislocation. Larger diameter all-metal hips were often targeted at the younger, more active patient.

There were many designs of these large diameter (⩾ 36 mm) MoM hip joints and there was often the option to have either a surface replacement (hip resurfacing) joint or a total hip prosthesis. Some designs of MoM hip joint, such as the DePuy Articular Surface Replacement (ASR) and the ASR XL total hip arthroplasty (THA), have shown high rates of wear and revision.[4-7] Many failures of these prostheses were attributed to adverse reaction to metal debris (ARMD).[4] It has been suggested that the relatively shallow acetabular component used in both the ASR surface replacement and ASR XL predisposed the implant to edge wear.[4] In addition to this, reports have been published discussing the taper wear of the ASR XL and the possibility of this taper wear being a contributing factor in the failure of MoM THAs.[6,8-10] The high rates of failure of the ASR and ASR XL are not alone among MoM hips. High revision rates have also been reported with the Zimmer Durom,[11] the DePuy Pinnacle,[12] and for the smaller diameter (⩽ 46 mm) Smith & Nephew Birmingham Hip Resurfacing (BHR).[13,14]

This view has led to a reduction in the use of MoM hip prostheses, but there are still a variety of designs available. Some of these had acceptable mid-term performance in appropriate patients.[15,16] Recently, in the United Kingdom, the acceptable survivorship for hip replacements given by the National Institute for Health and Care Excellence (NICE) has been changed from 90% at ten years to 95% at ten years.[17]

It is important to monitor the *in vivo* performance of all hip prostheses in order to protect the patients from further surgery by becoming more knowledgeable regarding those implants that are performing well, and those that are not.

One way to assess the performance of explanted hip prostheses is to measure the material loss from the bearing surfaces.[18] A previous study has shown that wear volumes of a contemporary design of MoM hip joint higher than 2.3 mm^3 per year can result in a wear-related failure of the prosthesis.[6] Another paper stated "Wear rates above 1 mm^3/million cycles were consistent with metal ion levels above 10 ppm (sic), which may produce adverse reactions clinically".[19]

While many MoM hips have high revision rates, one study on the Biomet ReCap resurfacing MoM hip reported that "the Biomet ReCap and Magnum components are not susceptible to the same design problems resulting in implant recall specific to the Durom and ASR prostheses".[20]

Fig. 1a

Fig. 1b

a) Biomet Magnum/ ReCap/ Taperloc large head MoM THA and (b) Biomet ReCap resurfacing hip joint.

The aim of the study reported here was to use a coordinate measuring machine (CMM) to measure the wear (in terms of material loss) on failed Biomet Magnum/ ReCap/ Taperloc large head MoM THAs, along with a Biomet ReCap resurfacing joint. The articulating surface roughness of these explanted prostheses was also measured. The relationship between wear volume, roughness and failure was then explored.

Patients and Methods

Joints investigated. Between July 2006 and September 2011, 96 patients (110 hips) received the Biomet Magnum/ ReCap/ Taperloc large head MoM THA or the Biomet ReCap resurfacing hip joint as part of the "Magnum Total Hip System International Prospective Data Collection" study at North Bristol NHS Trust (Musculoskeletal Clinical Study 1939). Five patients (six hips) died but the cause of death was unrelated to the hip replacement. Ten patients (11 hips) were lost to follow-up, leaving 93 hips for analysis. A total of 19 patients (20 hips) received the resurfacing joint and 62 patients (73 hips) received the Magnum/ ReCap/ Taperloc THA. There were 38 females (46 hips) and 43 males (47 hips) in the cohort. The mean age at surgery was 57.9 years (26.8 to 73.8) and mean follow-up was 7.1 years (3.7 to 9.2). Eight hips (seven patients) were revised. Two early revisions were performed within the first month, one for a fractured neck of the femur in a resurfacing patient and one for early acetabular component rotation. Six revisions were performed between 31 and 92 months after index surgery; primary diagnosis was osteoarthritis. Written informed consent for retrieval of implants at time of revision was requested from the patient prior to any surgery. This complied with the European Community Regulations. The implant revised at 31 months was not available for investigation in this study.

Five cementless Biomet Magnum/ ReCap/ Taperloc large head MoM THAs and one Biomet ReCap resurfacing hip joint were investigated in this study (examples shown in Fig. 1). The resurfacing joint and four of the five THAs

Table I. Clinical data for the explants measured in this study

Implant	Implant diameter (mm)	Patient age at primary surgery (yrs)	Time *in vivo* (yrs)	Acetabular component inclination angle	Cobalt (µg/l)	Chromium (µg/l)	Histology (Yes/No)
Resurfacing	44	56.2	5.3	NA	NA	NA	No
THA Magnum 1	44	60.3	7.4	43°	4.75	4.57	Yes
THA Magnum 2	46	58.1	7.5	37°	13.8	16.5	Yes
THA Magnum 3	46	59.3	7.6	45°	4.75	4.57	Yes
THA Magnum 4	52	59.8	5.8	42°	1.96	2.48	Yes
THA Magnum 5	48	68.1	6.8	NA	18.1	13.8	No

THA, total hip arthroplasty; NA, data not available

(THA Magnum 1 to 4: Table I) formed part of the prospective Bristol ReCap study. THA Magnum 1 and THA Magnum 3 were sequential bilateral revisions from the same patient. For the resurfacing joint and THA Magnum 1 to 4, index and revision surgeries were performed at the Avon Orthopaedic Centre, North Bristol NHS Trust with revision undertaken between September 2012 and February 2014. For the joint labelled THA Magnum 5 in Table I, both the index and revision surgeries were performed at the Royal United Hospital Bath but by different surgeons. This implant was part of the retrieval study reported here, but is not part of the prospective Bristol ReCap study. Mean time *in vivo* for all of the implants was 6.7 years (5.3 to 7.6) (Table I). The mean age of the patients was 60.3 years (56.2 to 68.1) at primary surgery. The nominal implant diameters ranged from 44 mm to 52 mm. Five of the implants were retrieved from female patients, one was from a male (THA Magnum 4).

All patients were revised for hip pain and/or investigations indicative of an ARMD and/or elevated blood metal ion levels. Prior to retrieval, blood was sampled from four patients (five hips) using a stainless steel 21-gauge needle (Becton Dickinson UK Ltd, Oxford, United Kingdom) and collected in a trace element tube that contained sodium ethylenediaminetetraacetic acid (EDTA). The samples were measured by inductively coupled plasma mass spectrometry (ICPMS) for whole blood. Cobalt (Co) and chromium (Cr) levels are represented in µg/l (Table I) and ranged from 1.96 µg/l to 18.1 µg/l for Co, and 2.48 µg/l to 16.5 µg/l for Cr. In accordance with medicines and healthcare products regulatory agency guidelines, the blood metal ion levels in two patients were higher than 7 µg/l and identified as being at risk for metal-on-metal bearings.[13] Further investigations were performed on three patients (four hips) using metal artefact reduction sequence (MARS) for magnetic resonance imaging (MRI). Evidence of a cystic collection or a soft-tissue mass further supported the presence of an ARMD in all four hips. The MARS MRI was not available in the other two patients. Finally, a positive histological analysis (examination of retrieved cellular tissue) of ARMD was confirmed as the diagnosis in four hips and the reason for failure. Histology was not available in two patients (the resurfacing joint and THA Magnum 5).

The bearing surfaces of the ReCap resurfacing are identical to those of the THA design. Both the resurfacing joint and THA were made from high carbon (> 0.2%) as-cast cobalt-chromium-molybdenum (CoCrMo). The radial clearance is specified as being between 75 µm and 150 µm with sphericity of less than 5 µm. The femoral head extends approximately 23° beyond a full hemisphere. The outside geometry of the acetabular component is hemispherical. The CoCr THA femoral head is designed to accept a tapered titanium (Ti) alloy sleeve. This Ti sleeve has an internal female taper and is used with a forged Ti Taperloc stem to give a Ti/Ti taper/trunnion junction. These data are taken from the ReCap design rationale booklet.[21] The acetabular component internal arc of cover ranges from 154.6° for a 38 mm diameter implant to 163.6° for the 60 mm diameter implant.[20]

All explanted joints were sterilised in 10% formaldehyde solution and cleaned thoroughly before being measured to determine wear volumes.

Equipment. The volumetric wear from the articulating surfaces (femoral head and acetabular component) of the six retrieved implants was measured on a CMM (Legex 322; Mitutoyo UK Ltd, Andover, United Kingdom) with an accuracy of 0.8 µm.[8,18] The volumetric wear of the tapers of the five femoral heads from the Magnum/ReCap/ Taperloc THAs was also measured on this CMM. No femoral stems were available for analysis. The CMM is a contacting instrument where a stylus is used to map the geometrical profile of the specimen surface.[8,18] A custom-designed Matlab programme was used to provide the volumetric wear of the surfaces. The CMM and Matlab method have been shown to have an accuracy of approximately 0.5 mm^3 [18,22] for the wear measurements of the articulating surfaces, and 0.2 mm^3 for the wear measurements of the tapers.[8]

In addition to the wear measurements, surface roughness measurements were taken on the articulating surfaces using a Zygo NewView 5000 non-contacting white light interferometric profilometer (Zygo Corporation, Middlefield, Connecticut). This has previously been used to measure the roughness of explanted MoM hips.[23-25] The ×10 lens was used with a x2 zoom, giving an area of view of 317 x 238 µm. The manufacturers of the NewView 5000 state that the vertical resolution of this profilometer

is better than 1 nm with a 0.99 μm lateral (x, y) resolution for the magnification used. Measurements of S_a (mean surface roughness over the 3D area of view), S_q (root mean square surface roughness over the 3D area of view), and S_{sk} (surface skewness over the 3D area of view) were taken. The skewness of a surface is a measure of symmetry of the profile about the mean line. A positively skewed surface has a predominance of peaks, and a negatively skewed surface has more pronounced valleys. All six heads and all six acetabular components were measured in the unworn region and the worn region. In order to determine the areas of the surfaces that were unworn and worn, the surfaces of these joints were visually inspected – this was then confirmed by images taken using the CMM. Ten measurements were taken within each region and the mean calculated.

Surface roughness measurements were also taken on the five femoral head tapers using a Mitutoyo Surftest SJ-210 (Mitutoyo Corporation, Kanagawa, Japan). Four 5 mm line profiles were taken at 90° angles to each other. These profiles were taken in the region where the taper was engaged with the trunnion (as shown by the CMM measurements). The mean R_a (mean surface roughness of the 2D line profile) and R_q (root mean square surface roughness of the 2D line profile) values of these four roughness profiles were calculated for each of the five tapers.

Theoretical analysis. Theoretical studies were also performed. The predicted minimum film thickness using the theory by Hamrock and Dowson,[26] along with the surface roughness measurements of the articulating surfaces, was used to calculate the theoretical lubrication regimes acting within the joints.[27] These equations have been used previously in the calculation of the theoretical lubrication regimes of MoM joints,[28] and the equations are given below.

The minimum film thickness equation:[26]

$$\frac{h_{min}}{R_x} = 2.798\left(\frac{\eta u}{E' R_x}\right)^{0.65}\left(\frac{L}{E' R_x^2}\right)^{-0.21}$$

h_{min} is the minimum film thickness, R_x is the equivalent radius for a ball on plane model (equation shown below), η is the viscosity of the lubricant (taken as 0.010 Pa s, a similar viscosity to pathological synovial fluid under the shear-thinning encountered during the stance phase of the walking cycle[29]), u is the entraining velocity (0.012 ms^{-1}, again, during the stance phase of walking), E' is the equivalent elastic modulus of the material pairing (equation shown below; 2.3×10^{11} Pa for CoCrMo) and L is the applied load (taken as 2000 N).

The equivalent radius equation:

$$\frac{1}{R_x} = \frac{1}{R_h} - \frac{1}{R_c}$$

R_x is the equivalent radius, R_h is the radius of the femoral head and R_c is the radius of the acetabular component.

The equation for the equivalent elastic modulus:

$$\frac{1}{E'} = 0.5\left\{\left(\frac{1-\upsilon_1^2}{E_1}\right) + \left(\frac{1-\upsilon_2^2}{E_2}\right)\right\}$$

υ_1 and E_1 are the Poisson's ratio and elastic modulus of the head (0.3 and 2.1×10^{11} Pa) and υ_2 and E_2 are the Poisson's ratio and elastic modulus of the component (0.3 and 2.1×10^{11} Pa).

Finally, the calculated minimum film thicknesses, together with the recorded mean values of average root mean square S_q for the femoral head and acetabular component (S_{qh} and S_{qc}) for each joint, were used to determine the dimensionless parameter λ and therefore the theoretical lubrication regimes acting within the joints.[27]

$$\lambda = \frac{h_{min}}{\left(S_{qh}^2 + S_{qc}^2\right)^{0.5}}$$

Previous work has shown that if the ratio of the minimum film thickness to the combined surface roughness is greater than one but less than three, mixed lubrication is likely.[27] If $\lambda > 3$ then a full-fluid film-lubricating regime is predicted,[27] i.e. the asperities of the bearing surfaces are completely separated by the lubricant film. A λ value of less than one indicates boundary lubrication.[27]

Results

Wear of the articulating surfaces. Wear data for the articulating surfaces of the femoral head and acetabular component of each joint are shown in Table II, along with the radial clearances of the unworn sections (as measured on the CMM). These wear values are given as means because the data were found to be normally distributed using the Anderson-Darling test for normality ($p = 0.918$). The total wear volume for the head and the acetabular component of the THAs and resurfacing joint was between 30.0 mm^3 and 57.3 mm^3, and the volumetric wear rate was between 4.1 mm^3/year and 7.6 mm^3/year (mean: 6.1 mm^3/year). The mean volumetric wear rate measured for the five THAs was also 6.1 mm^3/year, with a range of 4.1 to 7.6 mm^3/year. The ReCap resurfacing hip joint provided a wear rate of 5.9 mm^3/year. In all cases, the femoral head wear volume was larger than the wear volume from the acetabular component. The mean femoral head:acetabular component wear ratio was 62:38 (54:46 to 69:31). Examples of the images obtained showing the wear profiles for the articulating surfaces of the femoral head and acetabular component are shown in Figure 2. The femoral head wear can be seen as being located close to the pole and the acetabular component

Table II. Wear data for each hip joint

Joint	Radial clearance (μm)	Wear (mm³)		Total wear (mm³)	Wear rate (mm³/yr)
		Femoral head	Acetabular component		
Resurfacing	84	21.1	10.0	31.1	5.9
THA Magnum 1	92	17.7	12.3	30.0	4.1
THA Magnum 2	120	31.0	26.3	57.3	7.6
THA Magnum 3	108	25.0	15.6	40.6	5.3
THA Magnum 4	98	26.3	14.6	40.9	7.1
THA Magnum 5	110	29.8	13.3	43.1	6.3

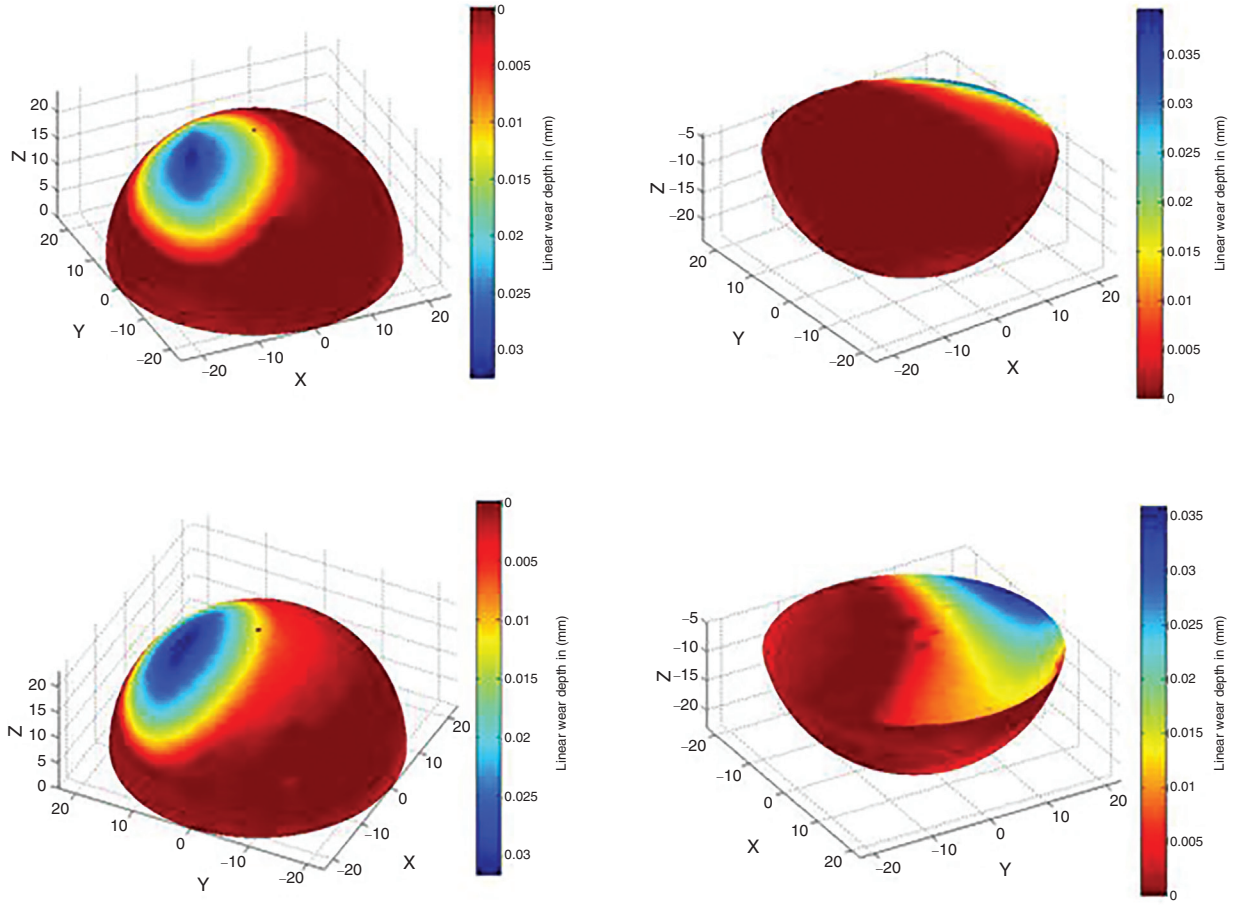

Fig. 2

Examples of worn images (blue/green) of areas on femoral head (left) and acetabular component (right) indicative of all joints measured in this study.

wear was mainly at the rim. The measured radial clearances were within the range given in the manufacturer's specifications.[21]

Surface roughness measurements of the articulating surfaces. The surface roughness measurements performed on the unworn and worn regions of the femoral heads and acetabular components are shown in Tables III and IV. It was not possible to distinguish an unworn area on the acetabular component of THA Magnum 3, therefore, no unworn measurements were available for this acetabular component. Figures 3 and 4 show examples of images acquired by the non-contacting profilometer on the unworn (a) and worn (b) regions of the femoral heads and acetabular components, respectively.

Theoretical lubrication regimes. Using the equations for predicted minimum film thickness, h_{min}, and the dimensionless parameter, λ, the theoretical lubrication regime acting within each joint during the stance phase of the walking cycle was calculated. Table V shows the predicted lubrication regimes for each joint using the surface roughness values obtained in the unworn region and the worn region of each component.

Table III. Surface roughness (S_a, S_{qh} and S_{sk}) results for the six femoral heads in the unworn and worn regions

Joint	S_a (µm)		S_{qh} (µm)		S_{sk}	
	Unworn	Worn	Unworn	Worn	Unworn	Worn
Resurfacing	0.048 (0.006)	0.022 (0.011)	0.064 (0.007)	0.043 (0.022)	1.112 (0.613)	0.277 (1.411)
THA Magnum 1	0.006 (0.000)	0.019 (0.010)	0.011 (0.003)	0.037 (0.021)	1.231 (6.205)	-0.326 (5.741)
THA Magnum 2	0.007 (0.001)	0.046 (0.026)	0.012 (0.002)	0.070 (0.036)	2.776 (4.635)	0.128 (2.342)
THA Magnum 3	0.019 (0.003)	0.025 (0.032)	0.027 (0.004)	0.045 (0.040)	1.321 (0.359)	3.225 (4.458)
THA Magnum 4	0.008 (0.002)	0.068 (0.102)	0.011 (0.003)	0.092 (0.117)	0.719 (1.681)	-2.305 (2.537)
THA Magnum 5	0.033 (0.003)	0.038 (0.051)	0.047 (0.005)	0.062 (0.066)	1.655 (1.066)	0.382 (2.343)

Mean values with standard deviations shown in brackets

Table IV. Surface roughness (S_a, S_{qc} and S_{sk}) results for the six acetabular components in the unworn and worn regions

Joint	S_a (µm)		S_{qc} (µm)		S_{sk}	
	Unworn	Worn	Unworn	Worn	Unworn	Worn
Resurfacing	0.026 (0.003)	0.028 (0.010)	0.037 (0.004)	0.049 (0.028)	1.361 (0.955)	-0.712 (2.080)
THA Magnum 1	0.016 (0.002)	0.021 (0.005)	0.021 (0.003)	0.040 (0.012)	0.691 (0.301)	-3.642 (1.418)
THA Magnum 2	0.024 (0.004)	0.034 (0.017)	0.030 (0.005)	0.061 (0.031)	0.539 (0.316)	0.629 (2.789)
THA Magnum 3	NA	0.034 (0.014)	NA	0.059 (0.021)	NA	-1.257 (2.160)
THA Magnum 4	0.007 (0.001)	0.036 (0.021)	0.013 (0.004)	0.065 (0.031)	3.035 (8.560)	-2.416 (2.240)
THA Magnum 5	0.008 (0.001)	0.049 (0.032)	0.013 (0.003)	0.087 (0.054)	1.456 (4.308)	-0.466 (1.276)

THA, total hip arthroplasty; NA, data not available
Mean values with standard deviations shown in brackets

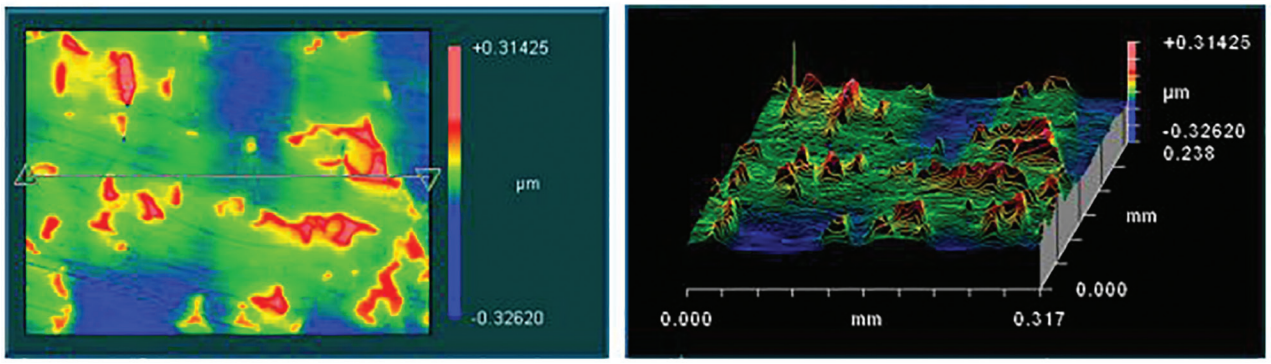

Fig. 3a

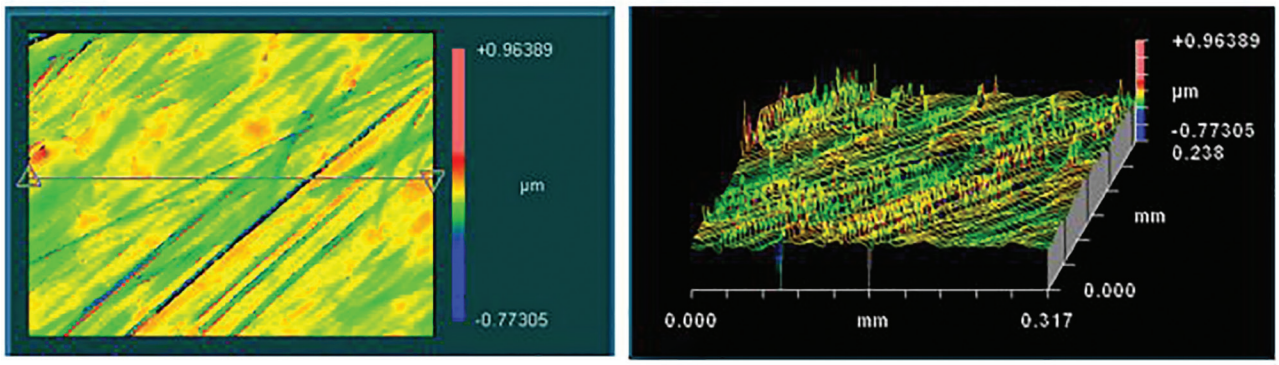

Fig. 3b

Surface profilometry images of a femoral head (a) unworn region showing carbides (S_{qh}: 0.047 µm; S_{sk}: 0.929), and (b) worn region showing scratching (S_{qh}: 0.075 µm; S_{sk}: 0.473).

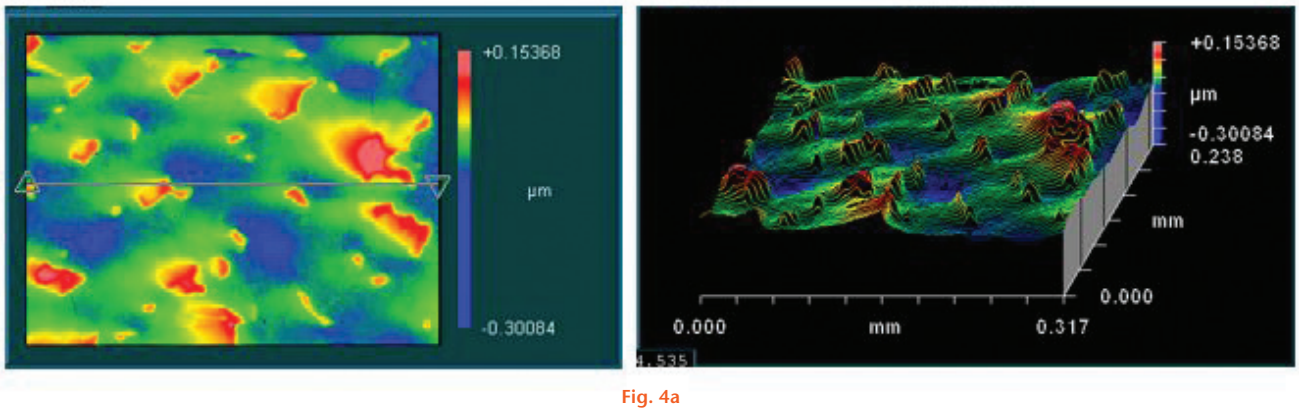

Fig. 4a

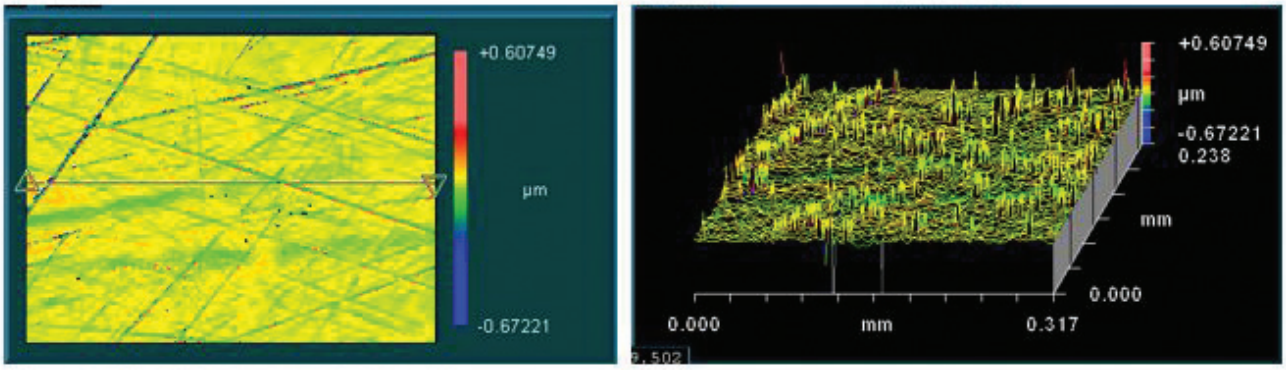

Fig. 4b

Surface profilometry images of an acetabular component (a) unworn region showing carbides (S_{qc}: 0.035 µm; S_{sk}: 1.032) and (b) worn region showing scratching (S_{qc}: 0.054 µm; S_{sk}: -0.112).

Table V. Predicted minimum film thicknesses (h_{min}) and lubrication regimes

Joint	Implant diameter (mm)	h_{min} (µm)	λ	
			Unworn	**Worn**
Resurfacing	44	0.05	0.68 Boundary	0.78 Boundary
THA Magnum 1	44	0.06	2.61 Mixed	1.14 Mixed
THA Magnum 2	46	0.06	1.91 Mixed	0.67 Boundary
THA Magnum 3	46	0.05	NA	0.68 Boundary
THA Magnum 4	52	0.07	3.89 Full-fluid film	0.59 Boundary
THA Magnum 5	48	0.06	1.29 Mixed	0.59 Boundary

THA, total hip arthroplasty; NA, data not available

Taper wear. The taper angles and wear volumes measured on the female tapers of the five THA femoral heads are shown in Table VI. The volumetric wear for each of the five Biomet Magnum THA tapers ranged from 0.16 to 0.96 mm^3, with a mean total volumetric wear of 0.38 mm^3 and a mean wear rate of 0.054 mm^3/year. The maximum wear depths ranged from 4.6 µm to 8.5 µm, with a mean of 5.7 µm. Indicative images displaying the positioning of the wear on the tapers are shown in Figure 5.

Table VII provides the surface roughness results for the tapers of each THA Magnum femoral head. These were measured in the regions that were engaged with the trunnion when implanted.

Discussion

For all six explants, wear on the femoral head was localised in a region towards the pole (as illustrated in Fig. 2). The wear area of the acetabular component was positioned mainly at the rim. Variable magnitudes of this edge wear was found on all of the acetabular components measured. The acetabular component inclination angles ranged from 37° to 45° (Table I). Surgical

Table VI. Taper angle and wear data for each femoral head taper

Joint	Taper angle	Wear (mm³)	Wear rate (mm³/yr)	Maximum wear depth (μm)
THA Magnum 1	4.06°	0.19	0.026	4.6
THA Magnum 2	4.09°	0.96	0.128	8.5
THA Magnum 3	4.00°	0.16	0.021	4.3
THA Magnum 4	4.01°	0.24	0.041	6.6
THA Magnum 5	4.02°	0.36	0.053	4.7

THA, total hip arthroplasty

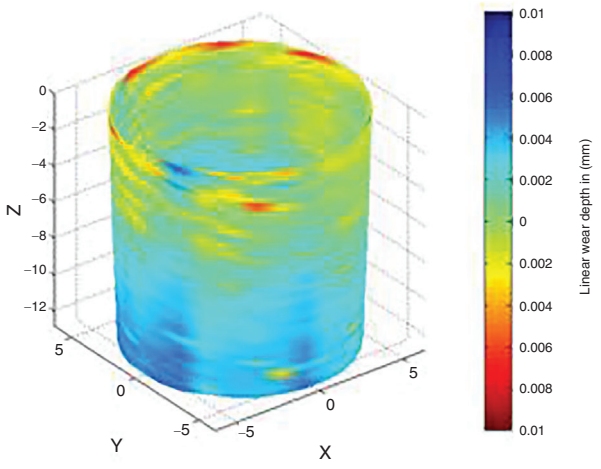

Fig. 5a

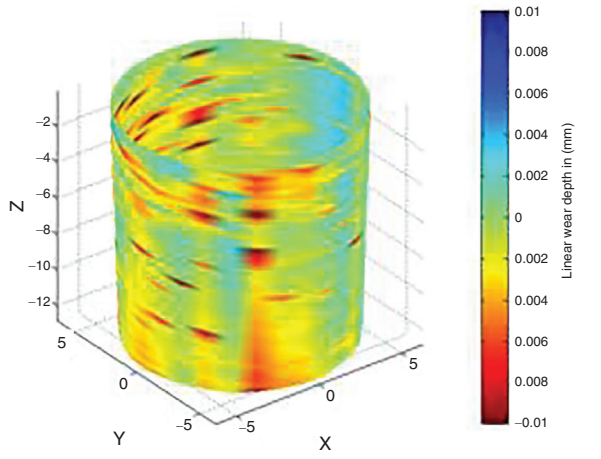

Fig. 5b

Images of worn (blue/green) areas on the femoral head tapers of the THAs.

positioning has, therefore, been excluded as the reason for this edge wear. It must be noted, however, that the explant with the lowest acetabular component inclination angle (37°) gave the highest wear, along with high blood metal ion levels; this explant also had the highest radial clearance. Acetabular component edge wear is a common feature with failed MoM hip joints.[4,30]

Previous work performed on 57 failed DePuy ASR MoM hip joints[6] reported that a volumetric wear rate of 2.3 mm³/year from the articulating surfaces was sufficient to

Table VII. Taper surface roughness measurements (R_a and R_q) (mean values with standard deviations shown in brackets below)

Joint	R_a (μm)	R_q (μm)
THA Magnum 1	0.286 (0.016)	0.349 (0.019)
THA Magnum 2	0.707 (0.124)	0.868 (0.138)
THA Magnum 3	1.177 (0.129)	1.331 (0.136)
THA Magnum 4	0.803 (0.087)	0.957 (0.090)
THA Magnum 5	0.319 (0.063)	0.398 (0.094)

THA, total hip arthroplasty

Table VIII. Revision rates for metal-on-metal total hip arthroplastys[32]

Manufacturer	Femoral component	Acetabular component	Cumulative percentage revision at 7 yrs
Smith & Nephew	Synergy	BHR	7.4
Biomet	Taperloc	ReCap	8.6
Zimmer	Alloclassic	Durom	10.4
DePuy	Summit	ASR	32.4
DePuy	Corail	ASR	38.7

BHR, Birmingham Hip Resurfacing; ASR, articular surface replacement

cause revision due to ARMD (the range of wear rates was 2.3 mm³/year to 95.5 mm³/year). The wear rates of each of these THA and surface replacement ReCap joints (4.1 to 7.6 mm³/year) fall within this range. Published work posing a view on wear rates of MoM hips sufficient to lead to revision has been available for many years. In 2003, 22 explanted MoM hips of 28 mm diameter were measured to have a mean wear rate of 2.02 mm³/year (0.55 to 3.74).[31] It was reported that these joints were revised for early aseptic loosening. Therefore, it could have been argued in 2003 that a wear rate of more than 0.55 mm³/year was sufficient to cause failure of a MoM hip.

The cumulative percentage probability of revision for the Biomet ReCap resurfacing replacement joint is shown in the 2016 National Joint Registry (NJR) as 7.79% at seven years. This compares with 5.47% for the BHR and 20.88% for the ASR.[7] In the Australian Orthopaedic Association (AOA) National Joint Registry Annual Report 2015, the Biomet ReCap resurfacing has a revision rate of 12.2% at seven years.[32] It is clear that the Biomet ReCap resurfacing replacement has a lower revision rate than the DePuy ASR, and this may be because they are 'not susceptible to the same design problems' as the ASR.[20] This may be due to the larger arc of cover provided by the

acetabular components. It has been shown[4,8] that the ASR has a lower arc of cover (151° for a 52 mm diameter joint) than the BHR (162° for a 52 mm joint). The arc of cover of the Biomet ReCap resurfacing joint ranges from 154.6° for a 38 mm diameter implant to 163.6° for the 60 mm diameter implant.[20]

With regard to the Magnum/ ReCap/ Taperloc THA, the AOA Registry showed the cumulative percentage revision as 8.6% at seven years.[32] No data were available on the Magnum/ ReCap/ Taperloc THA in the NJR.[7] Table VIII shows the cumulative percentage revision of MoM primary THAs at seven years from the Australian Joint Registry. It can be seen that, in comparison with alternative designs, the Magnum/ ReCap/ Taperloc produced only slightly higher cumulative percentage rates of revision at seven years than the BHR.

The revision rates stated in the NJR for MoM THAs are higher than those for the MoM hip resurfacings.[7] The reasons for this were investigated[6,8] and it was concluded that wear at the modular junction between the head taper and trunnion of the stem in the DePuy ASR and the DePuy 36 mm diameter MoM Pinnacle Articuleze joints can result in ARMD. Any taper wear will add to the wear produced at the articulating surfaces and lead to greater failure rates of THA.[6]

The taper wear measurements for the Ti taper of the Biomet Magnum THAs (mean: 0.05 mm^3/year) were low compared with those measured for the CoCr tapers of the DePuy ASR XL (mean: 2.60 mm^3/year) and DePuy Pinnacle Articuleze prostheses (mean 2.80 mm^3/year).[8] The wear results displayed in Table V show the low taper wear for this Ti/Ti taper junction in this study. In fact, the wear measurements on the tapers of three of the joints (THA Magnum 1, 3 and 5) were close to or below the 0.2 mm^3 accuracy limit of the CMM used for these taper wear measurements. So why did these Biomet joints provide such low taper wear? This may be due to the material combination used at the taper junction; Ti/Ti junctions used with the THA Magnums have been shown to provide lower wear than the Ti stem/CoCr head taper used with the ASR XL and Pinnacle.[33] However, this should not be seen as a panacea as similar materials can 'cold weld' and show adhesive wear. Other factors may also be involved. It appears that the taper design used with the Biomet Magnum joints has reduced the wear at the taper junction compared with other designs. It is appreciated that any material released at this Ti/Ti taper junction will not have contributed to the Co and Cr metal ion levels measured. Thus, for the Biomet ReCap explants analysed in this study, failure was due to ARMD likely caused by wear from the articulating surfaces, not the femoral head tapers.

In summary, the wear rates for the five retrieved Biomet Magnum/ ReCap/ Taperloc THAs and one Biomet ReCap resurfacing hip joint were higher than those considered to be able to cause wear-related failures in similar large diameter monoblock MoM hips (2.3 mm^3/year). The wear of the joints measured in this study was mainly found to be from the articulating surfaces. The authors believe that patients implanted with the Biomet ReCap system should be monitored.

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Author Contribution

- S. C. Scholes: Preparation of study plan, Testing, Data collection, Data analysis, Writing the paper.
- B. J. Hunt: Surface roughness testing on the tapers
- V. M. Richardson: Composition of manuscript and management of data.
- D. J. Langton: Assistance with experimental technique, Writing the paper.
- E. Smith: Data analysis and composition of paper.
- T. J. Joyce: Preparation of study plan, Data analysis, Writing the paper.

ICMJE Conflicts of Interest

- D. J. Langton states that he is currently involved in "Personal litigation against Depuy in the United States. Possible financial reward. I do not believe this has any relevance to this manuscript however."
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