Material Loss at the Taper Junction of Retrieved Large Head Metal-on-Metal Total Hip Replacements

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ABSTRACT: It has been speculated that material loss, either as corrosion or wear, at the head–stem taper junction is implicated in the high revision rates reported for metal-on-metal total hip replacements. We measured the volume of material loss from the taper and bearing surfaces of retrieved devices, and investigated the associations with blood metal ion levels and the diagnosis of a cystic or solid pseudotumor. The median volumes of material lost from the female and male taper surfaces were 2.0 and 0.29 mm^3, respectively, while the median volumes of wear from the cup and head bearing surfaces were 1.94 and 3.44 mm^3, respectively. Material loss from the female taper was similar to that from the acetabular bearing surface ($p = 0.55$), but significantly less than that from the femoral bearing surface ($p < 0.001$). Material loss from the male taper was less than that from both bearing surfaces ($p < 0.001$). Multivariable analysis demonstrated no significant correlations between the volume of material lost from the taper surfaces and either blood cobalt or chromium ions, or the presence of pseudotumor. While a substantial volume of material is lost at the taper junction, the clinical significance of this debris remains unclear. J Orthop Res 31:1677–1685, 2013

Keywords: taper; retrievals; metal-on-metal; metal ions; wear

Uncemented stemmed metal-on-metal (MOM) bearings have higher revision rates compared to all other bearing systems used for hip replacement. The National Joint Registry of England and Wales reported a 5-year revision rate of 6.96% for MOM total hip replacements. This compares to <3% for all other conventional hip replacements (MOP, COC, COP), and 4.56% for MOM hip resurfacing.[1] A growing body of evidence shows that large head (>36 mm) MOM total hip replacements (LH-MOM-THR) have higher revision rates than equivalently sized MOM resurfacings with a similar bearing surface design.[1–3] For example the ASR XL THR has a higher revision rate than the ASR hip resurfacing, with reported 5-year revision rates of 21.9% and 13.8%, respectively.[3] Similar results have also been shown for the Birmingham Hip Resurfacing THR.[4] As a result, in February 2012, the British Orthopaedic Association recommended that LH-MOM-THRs no longer be implanted.[5]

It has been speculated that the head–stem taper junction provides an additional source of metal debris either as result of mechanical wear, corrosion, or a combination of both.[1] Higher blood metal ion levels were found in patients with well-performing LH-MOM-THR when compared to hip resurfacing.[6,7] However, the clinical significance of material loss at the taper junction remains unclear, with one previous retrieval study[8] showing no difference in blood metal ion levels between patients with failing LH-MOM-THRs and MOM hip resurfacings.

While numerous qualitative studies of corrosion at the taper junction of many types of total hip replacement exist,[9–11] including one reporting evidence of corrosion at the junction in up to 95% of large head MOM retrievals,[12] only two quantified the volume of material loss from the head–stem taper junction of LH-MOM-THRs.[13,14] We tested three hypotheses: (1) the volume of material loss from the taper junction is greater than that lost from the bearing surfaces; (2) the volume of material loss from the junction is correlated with blood metal ion levels; and (3) the volume of material loss from the junction is higher in cases associated with a diagnosis of pseudotumor. We intended to investigate the clinical relevance of material loss from the junction and not identify the surgical and design factors responsible.

MATERIALS AND METHODS

Patients and Components

This was a retrospective study of prospectively collected data from the first 110 consecutive LH-MOM-THR cases referred to our retrieval laboratory that met our inclusion criteria. To be included, patients must have undergone full pre-clinical assessment, to include Co and Cr blood ion measurement, CT or plain X-ray imaging to measure cup position, and metal artifact reduction sequence (MARS) MRI to assess the soft tissues. Sufficient clinical data were required to diagnose the reason for revision according to categories used by the National Joint Registry of England and Wales.[15] For purposes of blood metal ion analysis, we required that all prostheses be unilateral. To reduce the confounding effect of bedding-in wear at the bearing surfaces, all implants were in situ for ≥12 months.[16,17] Finally, only arthroplasties using a mono-block cup with a large internal surface (>36 mm) were included; all included designs have an equivalent resurfacing prosthesis using identical bearing components.

The laboratory operates with the approval of the Human Tissue Authority and the local institutional ethical committee. Components were collected from 34 surgeons from 24 hospitals in the UK. Patient demographic data and compo-

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Table 1. Overview of the Patient Demographic and Component Details

	Number	Mean	Median	Range
Gender (male:female)	52:68	—	—	—
Age at primary surgery (years)	—	53.5	55.0	36.0–82.0
Time to revision (months)	—	44.2	45.5	12.0–85.0
Femoral head diameter (mm)	—	46.2	47.0	38.0–60.0
Angle of acetbular inclination (°)	—	43.8	43.0	9.0–66.0
Angle of acetbular version (°)	—	12.5	11.0	−29.0 to 57.0
Whole blood cobalt (ppb)	—	19.5	7.6	0.6–237.0
Whole blood chromium (ppb)	—	10.8	3.0	0.4–111.0
Bearing design				
Adept	10	—	—	—
ASR XL	40	—	—	—
Birmingham hip	22	—	—	—
Cormet	8	—	—	—
Durom	12	—	—	—
M2A-Magnum	18	—	—	—
Stem design				
CLS[b]	5	—	—	—
Corail[b]	36	—	—	—
CPCS[a]	7	—	—	—
CPT[a]	6	—	—	—
C-Stem	13	—	—	—
Freeman	6	—	—	—
Taperloc[b]	16	—	—	—
Zweymuller[b]	21	—	—	—

[a]Stem material: cobalt–chrome alloy (Co:Cr:Mo). [b]Stem material: titanium alloy (TiAl6:V4).

nent details for the 110 cases are given in Table 1. The cup and head components were collected in all cases; however, we received only 36 femoral stems: in most cases the surgeon did not remove a well-fixed undamaged femoral stem. Thirty-one stems were titanium alloy and 5 cobalt-chrome alloy.

Pre-Revision Clinical Assessment

Prior to revision all patients had undergone clinical examination and either CT or plain radiograph assessment of the hip. All had MARS MRI scanning to assess the soft tissues and blood sampling to measure whole blood cobalt and chromium ion levels using inductively coupled plasma mass spectrometry (ICPMS). We defined a pseudotumor as a sterile (non-infected) cystic or solid inflammatory mass in the soft tissues surrounding the joint.[18] If present, the lesion was characterized according to a previously described method.[18]

The reasons for revision were diagnosed using published criteria.[18,19] The presence of a cystic soft tissue mass is not synonymous with revision,[20] and so the presence of pseudotumor was not deemed a "reason for revision." The reasons for revision were: unexplained pain (77), aseptic femoral loosening (12), aseptic acetabular loosening (8), component misalignment (4), infection (4), component mismatch (2), fracture (2), and one case following fracture of the stem–neck trunnion.

Visual Inspection of the Components

All components were visually inspected prior to measurement of material loss from the bearing and taper surfaces. We noted any evidence of surface damage, wear, and corrosion.

Assessment of Corrosion of the Taper Surfaces

Various terms have been used to describe the mating surfaces of the taper junction. We used the terms "female" and "male" to refer to the taper surfaces of the head and stem neck, respectively. In the literature, the term "trunnion" is often used to describe the male taper. Both female and male taper surfaces were inspected macroscopically and then viewed (up to 40×) using a stereomicroscope (Letiz MZ10; Leitz, Wetzlar, Germany) to assess for corrosion. Corrosion was scored using a published method.[9] All taper surfaces were scored by a single author blinded to all other data using a 4-tiered classification (Table 2).

Table 2. Criteria Used to Classify Corrosion of the Taper Surfaces

Severity	Score	Grading Criteria
None	I	No visible evidence of corrosion
Mild	II	<30% taper surface discolored
Moderate	III	>30% taper surface discolored <10% taper surface covered in black corrosive debris
Severe	IV	>10% taper surface covered in black corrosive debris

Measurement of the Bearing Surfaces

The volume of material loss from the bearing surfaces was measured using a Zeiss Prismo (Carl Zeiss, Ltd., Rugby, UK) coordinate measuring machine. Measurements were conducted using a 2 mm ruby stylus moving at 3 mm/s using a previously described protocol optimized for accuracy and measurement certainty.[21] Each surface was digitized using 400 polar scan lines, giving an angular point spacing of 0.9° and a linear point pitch of 0.1 mm. The number of data points obtained for each component was up to 300,000 depending on component diameter and angular coverage.

The data were analyzed using an intelligent iterative least square fitting operation. This involved removal of the worn area from the analysis, and the data refitted using the residual area. The data were segmented so that only the unworn geometry was used, and this was optimized through use of a fitting algorithm such that the surface fitting standard deviation was minimized.[21] This method is robust against phenomena such as edge wear, which can adversely affect the resulting wear measurement,[21] and allows for accurate repeatable determination of unworn geometry, thus allowing direct determination of linear and volumetric wear and accurate mapping of the material loss distribution. A limitation of this method that the femoral heads are assumed spherical, therefore not accounting for any potential manufacturing form errors. Form error is not determinable ex vivo due to component wear.[21]

Measurement of the Taper Surfaces

Taper surfaces were measured using a Talyrond 365 (Taylor Hobson, Leicester, UK) roundness instrument specifically designed for high accuracy measurement of circular and cylindrical components. The components (head or stem) were mounted, using custom fixtures, on a rotating air spindle (maximum run out of 20 nm) and were centered and leveled with respect to the spindle axis, allowing vertical measurement traces coincident to the taper axis. The measurement stylus was a 5 μm conisphere diamond stylus (gauge resolution of 10 nm). A small stylus allows more detailed data collection at a smaller scale than could be achieved with a more commonly used 1 or 2 mm stylus.

The female taper measurement was a series of vertical traces coincident to the taper axis. These were combined into a rectangular surface contour map, and analyzed using a Matlab (Mathworks, Inc., Natick, MA) program to calculate the volume of material loss, accounting for the taper's conical shape. The data were leveled through manual selection of the taper that can be considered to constitute the unworn reference surface (Fig. 1). The surfaces were then digitally regenerated and the volume of material loss calculated using a generated Abbott–Firestone curve.

Material loss from the male taper was more difficult to assess. In most cases the entire surface had been engaged with the female taper, and so a true reference surface was unavailable. In such cases, individual areas of material loss were isolated and assessed to give localized volumes of material loss, which were then summed to give the total volume of material loss. A separate Matlab based program was used to calculate the volume of material loss, for which it was required to filter the measured machine-threaded surface texture from the measurement.

Statistical Methods

All univariate distributions were assessed for normality using the Shapiro–Wilk test. Blood metal ion levels and surface measurement data were not normally distributed, so the Wilcoxon signed-rank test was used to compare the median surface measurements and cobalt and chromium ion levels. Spearman's correlation coefficient (ρ) was used to quantify the strength of the relationships between the taper surface and bearing surface measurements.

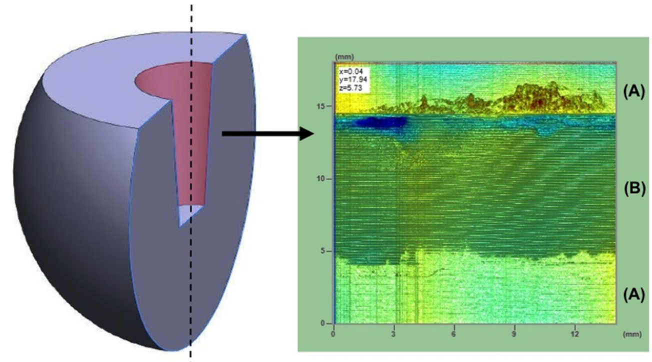


Figure 1. Schematic demonstrating the method and analysis of taper surface measurement. The regions labeled (A) represent unworn areas of the male taper. The worn area of the female taper, labeled (B), represents the area engaged with the male taper.

Multiple linear regression models were used to explore the multivariable associations between metal ion levels and the taper and bearing surface measurements. Tests for interactions between taper and bearing surface measurements were performed to assess whether the relationships with metal ion levels were independent of each other. Similarly, multivariable analysis was used to determine differences in bearing and taper surface material loss according to the presence/absence of pseudotumor. This accounted for interaction between variables. All analyses were performed using Stata/IC version 12.1 (StataCorp, College Station, TX); $p < 0.05$ was considered significant.

RESULTS

Corrosion was found at the female taper surface in 99 out of 110 cases: 29 were classified as mild, 40 as moderate, and 30 as severe. Of the 36 male taper surfaces, 6 demonstrated corrosion, all mild. A strong correlation existed between corrosion score and the volume of material loss at the female taper ($\rho = 0.94$, 95% CI = 0.91–0.96, $p < 0.001$). A similarly strong correlation occurred between corrosion score and the volume of material loss at the male taper ($\rho = 0.72$, 95% CI = 0.44–0.87, $p < 0.001$). Given the strength of these relationships, we report only volumetric data for the remainder of our results. We also noted the presence of significant retrieval damage (deep scratches) on 21 of the 36 male tapers.

A summary of the surface measurement data is given in Table 3. The median volume (2.02 mm^3) of material lost from the female taper surface was significantly less than the median volume of material lost from the femoral head bearing surface (3.44 mm^3, $p < 0.001$), but not different to that from the acetabular bearing surface (1.94 mm^3, $p = 0.55$). For the 36 male tapers, the volume of material loss was negligible (<1 mm^3) in all cases. The median volume (0.29 mm^3)

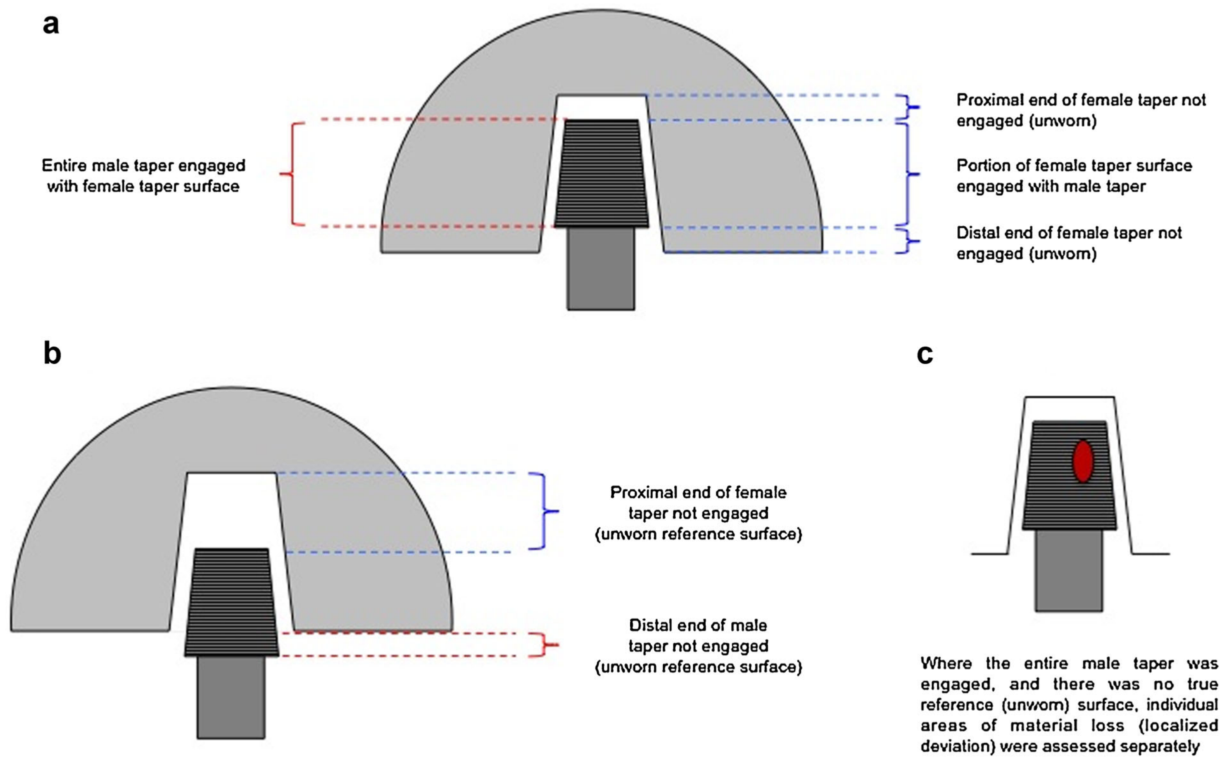


Figure 2. Schematic diagram of the taper junction. (a): The most common situation in which the entire male taper is engaged with the female taper. While unworn regions of the female taper could be we used as a reference surface, the entire male taper is engaged with no unworn regions. In this case, areas of material loss (deviations) were assessed individually (c). In some cases, the most proximal portion of the male taper was not engaged and could be used as an unworn reference surface (b).

was significantly less than that lost from the female taper and the head and acetabular bearing surfaces (all $p < 0.001$). Comparison of the taper and bearing surface data is shown in Figure 3. Material loss from the female taper was greater than that from the combined bearing surfaces in only 23% of the cases.

A weak but significant positive correlation existed between the volume of material loss from the female taper and that from the head-bearing surface ($\rho = 0.25$, 95% CI = 0.05–0.44, $p = 0.017$). The correlation between volume loss from the female taper and that from the acetabular bearing surface ($\rho = 0.17$, 95% CI = −0.04–0.36, $p = 0.12$) was not significant (Fig. 4).

A moderate significant correlation existed between the volume of material loss from the male and female tapers ($\rho = 0.42$, 95% CI = 0.01–0.72, $p = 0.04$). No significant correlations existed between the volume of material loss from the male taper and that from the femoral ($\rho = 0.03$, 95% CI = −0.45 to 0.40, $p = 0.90$) and acetabular bearing surfaces ($\rho = 0.17$, 95% CI = −0.27 to 0.55, $p = 0.43$).

The median Co level of 7.6 ppb was significantly higher than the median Cr level of 3.0 ppb ($p < 0.0001$; Fig. 5).

Univariable analysis showed that a weak but significant positive correlation existed between the volume of material loss from the female taper and Co levels ($\rho = 0.29$, 95% CI = 0.09–0.47, $p = 0.01$); however, no significant correlation was found with Cr levels ($\rho = 0.19$, 95% CI = −0.02 to 0.38, $p = 0.08$). No significant correlations existed between the male taper volume loss and either Co ($\rho = 0.41$, 95% CI = −0.10 to 0.75, $p = 0.10$), or Cr ($\rho = 0.47$, 95% CI = −0.03 to

Table 3. Summary of the Volumetric Material Loss From the Bearing and Taper Surfaces

	Cup Bearing Surface ($n = 110$)		Head Bearing Surface ($n = 110$)		Female Taper Surface ($n = 110$)		Male Taper Surface ($n = 36$)	
	Volume (mm^3)	Rate (mm^3/year)	Volume (mm^3)	Rate (mm^3/year)	Volume (mm^3)	Rate (mm^3/year)	Volume (mm^3)	Rate (mm^3/year)
Mean	9.04	2.56	11.62	3.10	3.60	0.85	0.34	0.12
Median	1.94	0.62	3.44	1.31	2.02	0.54	0.29	0.08
Range	0.06–194.80	0.04–39.62	0.11–228.30	0.06–45.66	0.00–25.19	0.00–4.29	0.00–0.83	0.00–0.36

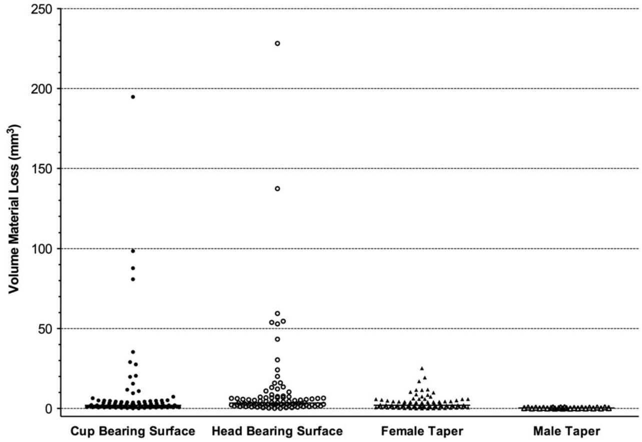


Figure 3. Graph comparing volumetric material loss of the bearing and taper surfaces.

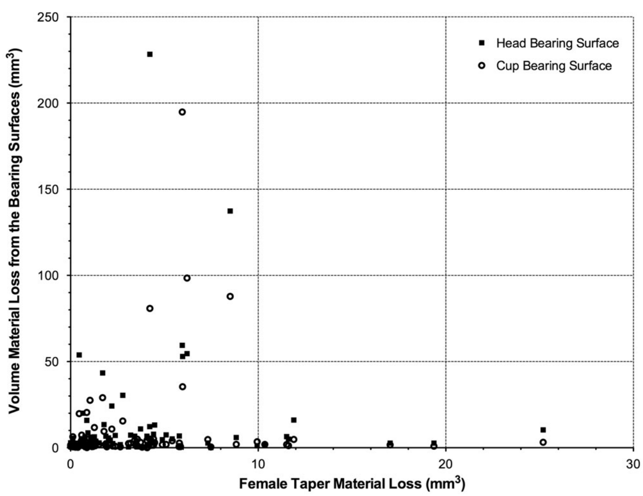


Figure 4. Scatter plot showing the correlations between the volume of material loss from the female taper and the bearing surfaces.

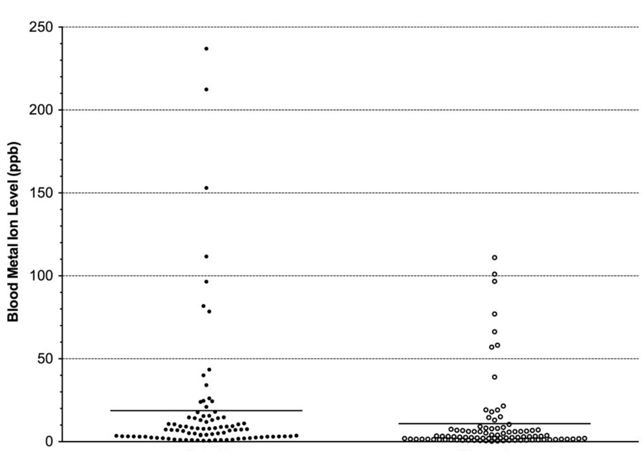


Figure 5. Comparison of whole blood Co and Cr ion levels.

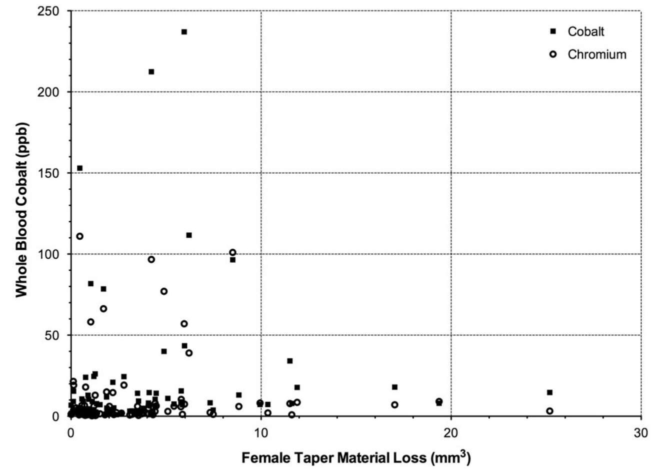


Figure 6. Scatter plot showing the correlation between whole blood metal ion levels and the volume of material loss from the female taper.

0.78, $p = 0.06$) levels. Conversely, univariable analysis showed that the volume of material loss from the femoral bearing was significantly correlated with both Co ($\rho = 0.40$, 95% CI = 0.21–0.56, $p < 0.001$) and Cr levels ($\rho = 0.41$, 95% CI = 0.22–0.57, $p < 0.001$). Similarly, the acetabular bearing volume loss was significantly correlated with Co ($\rho = 0.39$, 95% CI = 0.20–0.55, $p < 0.001$), and Cr ($\rho = 0.37$, 95% CI = 0.18–0.54, $p < 0.001$) levels (Figs. 6 and 7).

Further multiple linear regression analysis, adjusted for both femoral and acetbular bearing surface wear, confirmed the absence of any significant correlations between the volume of material lost at the female taper and either Co ($p = 0.18$) or Cr ($p = 0.60$) levels. Furthermore, there was no evidence of any significant interactions between the volumes of material lost at the female taper and bearing surfaces. Full results of the multiple regression analyses are given in Tables 4 and 5, showing bearing surface material loss as the only independent predictor of blood metal ion levels.

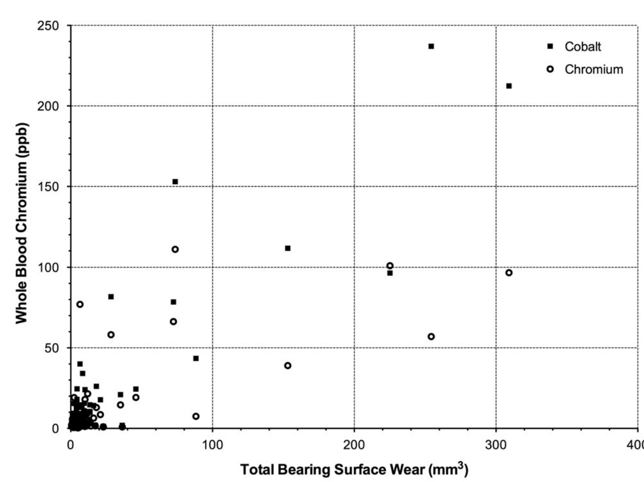


Figure 7. Scatter plot showing the correlation between whole blood metal ion levels and bearing surface wear volumes.

Table 4. Results of the Multiple Linear Regressions Model Describing the Relationship Between Material Loss and Whole Blood Cobalt Ion Levels

	95% Confidence Interval	p-Value
Cup bearing surface material loss	0.27 to 0.76	<0.001
Head bearing surface material loss	−0.04 to 0.46	0.098
Female taper surface material loss	−0.07 to 0.36	0.177

When adjusted for the other sources of material loss, wear of the cup bearing surface was the only significant predictor of blood cobalt ion levels.

Table 5. Results of the Multiple Linear Regression Model Describing the Relationship Between Material Loss and Whole Blood Chromium Ion Levels

	95% Confidence Interval	p-Value
Cup bearing surface material loss	0.16 to 0.68	0.002
Head bearing surface material loss	0.01 to 0.53	0.042
Female taper surface material loss	−0.17 to .29	0.598

When adjusted for the other sources of material loss, wear of the cup and head bearing surfaces were the only significant predictor of blood chromium ion levels.

Too few cases of male tapers existed to perform meaningful multivariable statistics.

Pseudotumors were found in 69 out of 110 cases (62.7%); 68 were cystic and 1 solid. Univariable analysis showed that cases with pseudotumor were associated with significantly higher median volumes of material loss at the cup and head bearing surfaces and the female taper surface, but not the male taper (Table 6). However, after adjustment for the volume of material loss at each of the other surfaces (accounting for possible interactions), neither the material losses at either bearing surface or at the female taper were significantly associated with the presence of pseudotumor. Increased total bearing surface material loss was associated with increased odds of pseudotumor presence, but when adjusted for female taper material loss this relationship became insignificant ($p = 0.142$). Full results of the multiple linear regression analysis for pseudotumor are given in Table 7. Again, too few cases of male tapers existed to perform meaningful multivariable statistics.

None of the clinical and design variables (Table 1) were significantly associated with higher taper material loss. There were no differences between prosthesis design (manufacturer) and no difference between similar- and mixed-alloy head–stem combinations.

DISCUSSION

Our study provides clinically relevant findings and contributes to the understanding of the failure mechanisms of LH-MOM-THRs. First, material loss from the female taper is of a similar magnitude to the bearing surfaces, although the predominant source of implant-derived metal debris in less than a third of failed LH-MOM-THR cases. Second, in patients with failing LH-MOM-THRs, high taper material loss is difficult to detect using blood metal ion levels. Third, pseudotumors are not more likely to occur in cases with higher volumes of taper material loss.

While the head–stem taper junction is clearly an important source of implant-derived material in LH-MOM-THR, it is difficult to explain the higher revision

Table 6. Comparison of material loss according to the presence or absence of pseudotumor on MARS-MRI scans

	Bearing Surface Material Loss (mm^3)				Taper Surface Material Loss (mm^3)			
	Cup ($n = 110$)		Head ($n = 110$)		Female Taper ($n = 110$)		Male Taper ($n = 36$)	
	Pseudotumor	No Pseudotumor	Pseudotumor	No Pseudotumor	Pseudotumor	No Pseudotumor	Pseudotumor	No Pseudotumor
Median	2.55	1.13	4.49	2.20	3.15	1.20	0.35	0.34
Mean	12.18	3.17	14.90	5.50	4.18	2.51	0.32	0.36
Range	0.11–194.80	0.06–20.46	0.11–228.30	0.12–53.85	0.00–25.19	0.00–10.36	0.00–0.62	0.00–0.83

Univariable analysis showed that head and cup bearing surface material loss and female taper surface material loss were significantly higher in cases associated with pseudotumor (all $p < 0.05$). Increased material loss at the male taper surface was not significantly associated pseudotumor ($p = 0.446$).

Table 7. Results of the Multiple Linear Regression Model Describing the Relationship Between Material Loss and the Presence/Absence of Pseudotumor

	95% Confidence Interval	p-Value
Cup bearing surface material loss	−0.13 to 1.32	0.109
Head bearing surface material loss	−1.90 to 0.14	0.092
Female taper surface material loss	−1.59 to 0.51	0.315

When adjusted for other sources of material loss, neither increased material loss from the cup or head bearing surfaces or increased material loss from the female taper surface was significantly associated with the presence of pseudotumor.

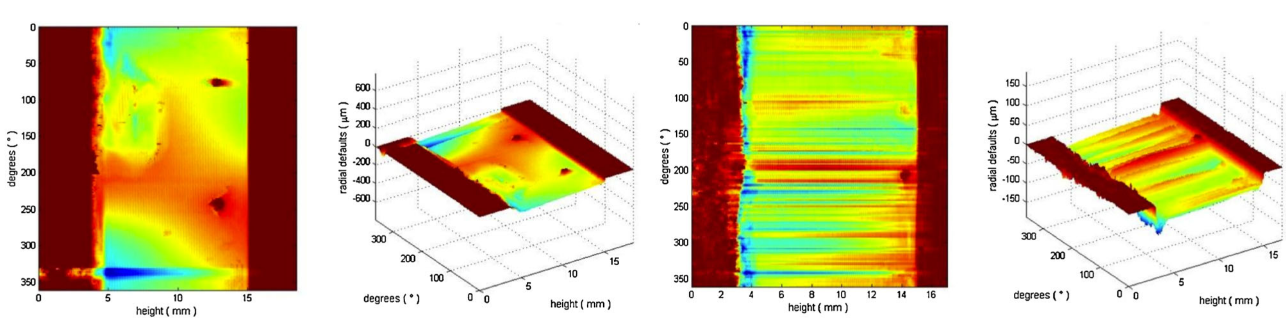
rates of these devices compared to MOM hip resurfacing through a dose-response reaction alone. However, it might be that additional material from the stem (either cobalt-chrome or titanium) may contribute to failure or the material lost from the taper junction may be more potent than the particulate debris released from the bearing surfaces.

We have reported data for a large series of explanted LH-MOM-THRs of several designs, and shown a wide variation in the volume of taper material loss. A previous study of only one design, the ASR XL proposed a predominantly mechanical mechanism to explain the variation in taper material loss,[13] in which the combination of a large head, short taper length and a low stem-shaft angle provide a lever-arm sufficient to cause high volumes of localized wear at the taper junction. The authors suggest that corrosion occurs secondary to this primarily mechanical process.[13] Whilst it is likely that material loss at the taper junction is multi-modal and in some cases mechanical wear maybe the dominant process, our results suggest that corrosion is likely to be the principle source of implant-derived material. Corrosion of the female taper was virtually universal (99 of 110 cases), and the presence of "imprinting" of the stem–neck thread onto the female taper surface is highly suggestive of galvanic corrosion, a process by which material is lost preferentially from one surface (in this case the female taper). This is supported by data from the 36 retrieved stems in our study; the male tapers all had negligible material loss (<1 mm^3) and only six of the taper surfaces demonstrated any evidence of corrosion (and all only mild). Furthermore, the morphology of the taper surface measurement profiles was rarely consistent with a mechanical process. In most cases we observed an axisymmetric pattern of material loss (Fig. 8), where material was lost uniformly over the male taper surface. This likely represents uniform loss or transfer of material, supporting a mechanism involving corrosion rather than wear. In contrast, increased local contact pressures would result in localized areas of increased material loss.

Our data support a mechanism whereby the volume of material loss at the taper junction is only weakly associated with elevated metal ion levels and soft tissue reactions. This may be explained if we consider the ionic (corrosive) taper material to be a considerably more potent stimulator of inflammation than particulate debris from the bearing surfaces. This may then help explain the higher revision rates of LH-MOM-THR compared to MOM hip resurfacing.

Our results compare well with those reported by Langton et al.[13] for the ASR XL; they reported rates of material loss at the taper junction from 0.46 to 82.5 mm^3 per year. The slightly higher volumes may be explained by the inclusion of only one design that is recognized to have the poorest performance.[2,15] Differences in measurement technique and analysis may also account for some variation and is likely to provide ongoing problems comparing data between studies.

Our findings provide important information for clinical surveillance of patients with LH-MOM-THRs. We showed that the volume of material loss from the female taper is of a similar magnitude to the loss from each of the bearing surfaces. However, this was not reflected in the blood Co and Cr ion levels measured



(a) Asymmetrical pattern of material loss (a) Aximmetrical pattern of material loss

Figure 8. Typical taper surface measurements demonstrating (a) asymmetrical (19.4 mm^3), and (b) axisymmetrical (17.0 mm^3) patterns of material loss.

prior to revision surgery. Similar to the trend observed for MOM hip resurfacing, in our group of retrieved MOM total hip replacements, bearing surface wear volumes were strongly correlated with blood metal ion levels. In contrast, the volumes lost from the Co–Cr tapers were only weakly correlated with ion levels. This supports our theory that material loss from the taper junction is the predominant source of implant derived debris in few cases (less than a third), and in the majority of cases an increased potency of a low volume of ionic material is likely to be responsible for failure. Another explanation for the higher revision rates of LH-MOM-THR is that these implants are subject to a higher total volume of material loss; a combination of material loss from the bearing and taper surfaces. However, the evidence is unclear given that previous studies showed an equally high occurrence of pseudotumors (and revisions) in both low-wearing and high-wearing MOM hip replacements,[18,19] and in our study a substantial number of cases with pseudotumor had low volumes of material loss at the bearing and taper surfaces. While the role of taper material loss remains unclear, high taper material loss is likely to present clinically in a variety of ways, not merely adverse soft tissue reactions.

As with all work on retrievals, there are several limitations. We were able to analyze only 36 male tapers, as in the majority of cases the revising surgeon did not remove a well-fixed femoral stem. Also, we did not assess the stem itself as a potential source of material loss. Data for the male tapers were excluded from multivariable regression analyses. However, we emphasize that in the available cases material loss from the male taper was negligible and therefore omission is unlikely to have affected our results. Another limitation is the lack of Ti ion measurement. Titanium ion release from mixed-alloy MOM total hip replacements is of unknown clinical significance; future studies and follow-up of these patients may incorporate this measurement.

The purpose of this study was not to identify surgical and design factors responsible for increased taper material loss. There are likely to be many variables including horizontal femoral offset, taper length, material combination, and surface finish that affect the rate of material loss from the taper junction. Future work investigating a number of taper designs may focus on establishing these factors.

In conclusion, though a significant volume of material is released at the taper junction, the failure mechanism of these implants remains unclear. It appears unlikely to be a simple dose-response relationship. We suggest the mechanism of material loss is predominantly corrosion. Ionic debris is likely to be a more potent inflammatory stimulator compared to particulate debris released from the bearing surface, and this may explain the differences in revision rates between resurfacing and LH-MOM-THRs. Of clinical importance is the lack of a significant correlation between taper material loss and either blood metal ion levels or the incidence of pseudotumors. This has implications for the clinical surveillance of all patients with LH-MOM-THRs.

REFERENCES

1. Smith AJ, Dieppe P, Vernon K, et al. 2012. Failure rates of stemmed metal-on-metal hip replacements: analysis of data from the National Joint Registry of England and Wales. Lancet 379:1199–1204.
2. Australian Orthopaedic Association National Joint Replacement Registry. 2012 Annual Report. 2012.
3. Langton DJ, Jameson SS, Joyce TJ, et al. 2011. Accelerating failure rate of the ASR total hip replacement. J Bone Joint Surg [Br] 93:1011–1016.
4. Malviya A, Ramaskandhan JR, Bowman R, et al. 2011. What advantage is there to be gained using large modular metal-on-metal bearings in routine primary hip replacement? A preliminary report of a prospective randomised controlled trial. J Bone Joint Surg [Br] 93:1602–1609.
5. Skinner J, Gie G, Kay P. 2012. (British Orthopaedic Association). Metal on Metal Hip Replacement and Hip Resurfacing Arthroplasty: what does the MHRA Medical Device Alert mean? http://www.britishhipsociety.com/pdfs/BHS_MOM_THR.pdf
6. Beaule PE, Kim PR, Hamdi A, et al. 2011. A prospective metal ion study of large-head metal-on-metal bearings: a matched-pair analysis of hip resurfacing versus total hip replacement. Orthop Clin North Am 42:251–257.
7. Garbuz DS, Tanzer M, Greidanus NV, et al. 2010. The John Charnley award: metal-on-metal hip resurfacing versus large diameter head metal-on-metal total hip arthroplasty: a randomized clinical trial. Clin Orthop Relat Res 468:318–325.
8. Matthies A, Underwood R, Cann P, et al. 2011. Retrieval analysis of 240 metal-on-metal hip components, comparing modular total hip replacement with hip resurfacing. J Bone Joint Surg [Br] 93:307–314.
9. Goldberg JR, Gilbert JL, Jacobs JJ, et al. 2002. A multicenter retrieval study of the taper interfaces of modular hip prostheses. Clin Orthop Relat Res 401:149–161.
10. Lindgreen JU, Brismar BH, Wikstrom AC. 2011. Adverse reaction to metal release from a modular metal-on-polyethylene hip prosthesis. J Bone Joint Surg [Br] 93:1427–1430.
11. Huber M, Reinisch G, Trettenham G. 2009. Presence of corrosion products and hypersensitivity associated reactions in periprosthetic tissue after aseptic loosening of total hip replacements with metal bearing surfaces. Acta Biomater 5:172.
12. Fricka KB, Ho H, Peace WJ, et al. 2012. Metal-on-metal local tissue reaction is associated with corrosion of the head taper junction. J Arthoplasty 27:26–31 (e1).
13. Langton DJ, Sidaginamale R, Lord JK, et al. 2012. Taper junction failure in large-diameter metal-on-metal bearings. Bone Joint Res 1:56–63.
14. Bolland BJ, Culliford DJ, Langton DJ, et al. 2011. High failure rates with a large-diameter hybrid metal-on-metal total hip replacement: clinical, radiological and retrieval analysis. J Bone Joint Surg [Br] 93:608–615.
15. National Joint Registry for England and Wales. Ninth Annual Report. 2012.
16. Dowson D, Hardaker C, Flett M, et al. 2004. A hip joint simulator study of the performance of metal-on-metal joints. Part III: design. J Arthoplasty 19:124–130.
17. Heisel C, Kleinhans JA, Menge M, et al. 2009. Ten different hip resurfacing systems: biomechanical analysis of design and material properties. Int Orthop 33:939–943.

18. Matthies AK, Skinner JA, Osmani H, et al. 2012. Pseudotumors are common in well-positioned low-wearing metal-on-metal hips. Clin Orthop Relat Res 470:1895–1906.
19. Hart AJ, Matthies A, Henckel J, et al. 2012. Understanding why metal-on-metal hip arthroplasties fail: a comparison between patients with well-functioning and revised Birmingham hip arthroplasties. AAOS exhibit selection. J Bone Joint Surg [Am] 94:e22.
20. Kwon YM, Ostlere SJ, McLardy-Smith P, et al. 2011. Asymptomatic pseudotumors after metal-on-metal hip resurfacing arthroplasty: prevalence and metal ion study. J Arthroplasty 26:511–518.
21. Bills PJ, Racasan R, Underwood RJ, et al. 2012. Volumetric wear assessment of retrieved metal-on-metal hip prostheses and the impact of measurement uncertainty. Wear 274:212–219.