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ORIGINAL ARTICLE

# MOM Failure Modes: An In-Depth Look at Metal Ions and Implant Wear

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## Introduction

Contemporary MOM bearings (large-diameter heads) offered the perceived benefits of much greater range of motion and greater stability with reduced risk of impingement and dislocation. A variety of design and Both positive [1-3] and negative reports [4-8] have now emerged with regard to total hip arthroplasty (THA) and resurfacing arthroplasty. As a result, there has been an avalanche of studies focused on critical issues such as: surgical positioning, shallow cups (face angles 144-170°) [9-11] and "edge loading". [5,7,12-17] However, there are several, possibly synergistic, risk scenarios that could trigger adverse MOM wear and very little progress has been made in understanding such interacting parameters. In an effort to understand the role of metal ion analysis and how it relates to revision surgery and implant wear, selected MOM revised cases were reviewed [28]. Retrieval data was included in conjunction with metal ion analyses and intraoperative observations to determine various failure modes. We suggest MOM devices that are well fixed but fail after 2 years can be classified into one of six modes: (i) normal, (ii) allergic reaction, (iii) 3rd body wear, (iv) repetitive subluxation with metal impingement, (v) multi-directional subluxation with soft tissue impingement, and (vi) repetitive subluxation with soft tissue impingement.

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## Methods

Six cases were selected based on their clinical history, imaging and retrieval analyses (Table 1). Times to revision varied from 3 to 8 years for cases with MOM diameters 28-55mm and listed causes for revision included: pain, high concentrations of metal ions, and cystic images viewed by MRI. X-ray imaging showed 3 cases with cup orientations in the so-called "safe zone" and three outside this zone (Fig. 1).

***Table 1:*** *Patient demographics, implant sizes, and clinical findings.*

| Mode | Age | Sex | Years in vivo | Size | | Clinical Findings |
|---|---|---|---|---|---|---|
| | | | | Ball | Cup | |
| 1 | 76 | F | 7.8 | 38 | NA | Infection |
| 2 | 45 | F | 5.7 | 55 | NA | Pain, effusion, ions |
| 3 | 55 | F | 3.25 | 38 | 50 | Pain, snapping, catching |
| 4 | 63 | F | 3.5 | 28 | | Pain, clicking, ions |
| 5 | 33 | M | 8.3 | 38 | 50 | Pain, ions, lytic cyst, squeaking |
| 6 | 77 | F | 6 | 42 | 48 | Pain, lytic cysts, ions |

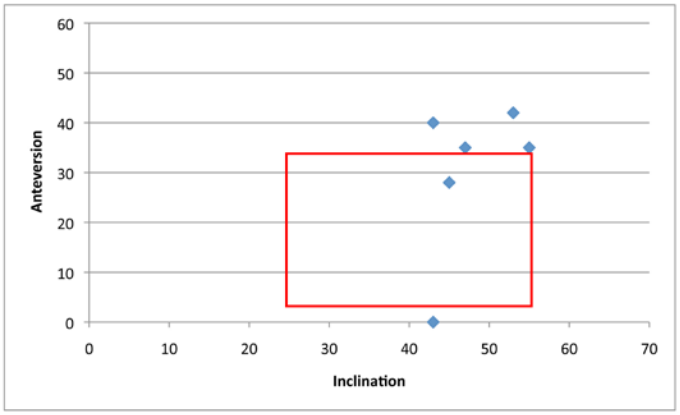


***Figure 1:*** *Scatter plot of inclination and anteversion angles for all 6 THA cases.*

All MOM bearings were cleaned using a standard mild alkaline detergent and ultrasonic bath with ethyl alcohol. Strongly adherent protein films and rainbow colored hues were frequently evident [18] on retrieved bearings. The retrieved MOM bearings were then analyzed microscopically and by laser interferometry to document wear patterns. [19] Measurements of sphericity (form factor) and diameter-mismatch were included.

All implants were studied by the contour measurement method (CMM: Legex 322, Mitotoyo Inc., NJ) to provide an indication of wear magnitudes. Out of round measurements < 20$\mu$m were considered within the range of manufacturing tolerances (grade-1). Form factors were graded as; minimal wear (grade-2 =20-50$\mu$m), mild wear (grade-3 =50-100$\mu$m), moderate wear (grade-4 =100-250$\mu$m), and severe wear (grade-5 > 250$\mu$m).

The femoral stripe patterns were identified and being very difficult to photograph were first marked with ink. [20-23] Each femoral neck and cup rim was inspected for signs of impingement. In each case, the cup was positioned to check alignment with stripe wear patterns on femoral heads. Surface damage was imaged by scanning electron microscopy (SEM: MA 13, Zeiss, Cambridge UK) and by energy dispersive spectroscopy (EDS: Bruker Inc.). Variations in surface roughness were analyzed both by SEM (magnifications x100-1,000) and white-light interferometry (WLI: NewView 600, lens x5 and x25, Zygo, AZ).

## Results

### *NORMAL*

a. No measurable wear/minimal wear (CMM)
b. Defined MWZ, possible stripe wear
c. Low metal ion concentrations
d. No stained tissue

CASE-1 (R611)
A 76 y/o female with bilateral MOM replacements was revised at approximately 8 years due to infection (only the femoral head was retrieved). This patient had moderately elevated ions at the time of revision (Co=5, Cr=2.3). Retrieval analysis identified a well-defined main-wear zone with one polar stripe (Fig. 2). The CMM study indicated there was minimal wear overall (form factor = 11$\mu$m; grade 1).

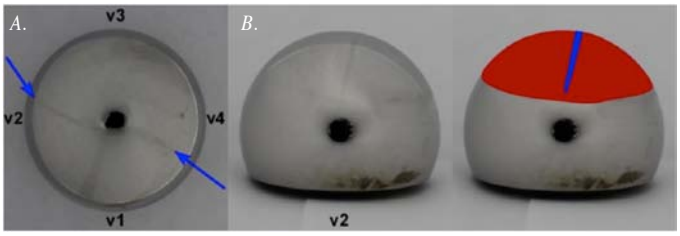


***Figure 2:*** *Views of head showing main-wear zone (MWZ) with arrows indicating stripe wear*
*A) Aerial view with arrows indicating the long polar stripe*
*B) Side view of femoral head showing MWZ (colored red) and polar stripe (colored blue).*

### *ALLERGIC REACTION*

a. Minimal wear (CMM)
b. Defined MWZ, possible stripe wear
c. Low-mild metal ion concentrations
d. Possible effusion, but no stained tissue

CASE-2 (R789)
This 45 y/o female was revised at approximately 6 years due to pain, reactive response effusion, and moderately elevated ions (Co=5, Cr=6). Retrieval analysis identified a well defined main-wear zone and one polar stripe (Fig. 3: only head retrieved). Minimal wear was indicated by CMM (form factor = 21, grade-2).

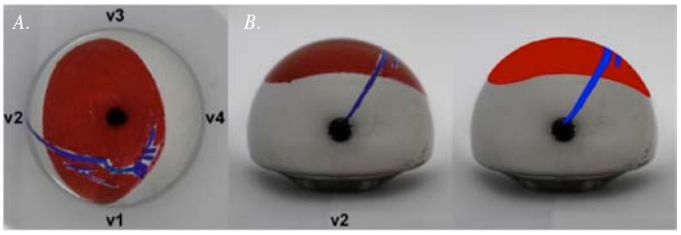


***Figure 3:*** *Views of head showing MWZ with arrows indicating stripe wear:*
*A) Aerial view of head with arrows indicating the long polar stripe*
*B) Side view of head showing MWZ (colored red) and long polar stripe (colored blue).*

### *3RD BODY WEAR*

a. Minimal-moderate wear (CMM)
b. Defined MWZ, multi-directional stripe wear
c. Mild-moderate metal ion concentrations
d. Frequently presents with stained tissue

CASE-3 (Sorim)
This 55 y/o female was revised at approximately 3 years due to a hip "snapping" pain during flexion. CT scan showed that the antero-inferior aspect of the cup rim was uncovered 1.5cm and exposed to the illiopsoas tendon. Intraoperatively, there was evidence of wear represented by the darkly stained tissue. Retrieval analysis identified wear on the antero-inferior cup rim (Fig. 4). Both bearing surfaces had evidence of 3rd body wear seen as deep multidirectional scratching and measuring

3$\mu$m wide and 0.4$\mu$m deep (Fig. 5). Two novel features point to the 'snapping' illiopsoas tendon as the wear trigger; a) abrasion of the Ti6Al4V cup rim by the illiopsoas and b) accelerated 3rd-body wear of the bearings surfaces by titanium oxide particles released from the cup. Note: This case pre-dated metal ion studies and was returned to the referring center before CMM analysis was performed.

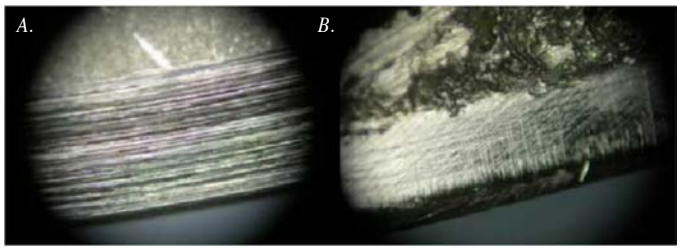


***Figure 4:*** *Comparison of new and worn cup rims:*
*A) Normal cup rim with manufacturing grooves evident.*
*B) Worn cup rim showing wear tracks perpendicular to the manufacturing grooves and loss of some titanium backing.*

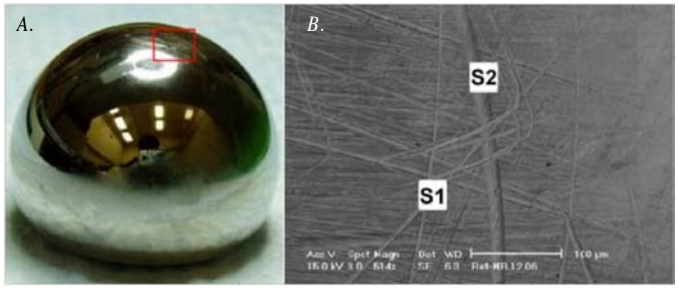


***Figure 5:*** *Severely abraded head:*
*A) Side view of head with square marked to indicate area examined by SEM*
*B) SEM image of microgrooves formed via 3rd body wear.*

## *REPETITIVE SUBLUXATION WITH METAL IMPINGEMENT (ANTERIOR, POSTERIOR)*

a. Moderate-high wear (CMM)
b. Defined MWZ, two polar stripes with offset, one or two notches on femoral stem
c. Moderate-high metal ion concentrations
d. Frequently presents with stained tissue

CASE-4 (R879)

This 63 y/o female was revised at approximately 3.5 years due to pain, clicking sensations and elevated ions (Co=47, Cr=41). Intraoperatively, there was evidence of femoral neck impingement on the posterior cup rim and stained tissue. The femoral head, acetabular cup and stem were retrieved, the latter featuring two notches on its postero-inferior aspect. Retrieval analysis identified a well defined main-wear zone and several polar stripes. One pronounced stripe traversed the MWZ, while several shorter stripes rand the length of the MWZ and corresponded to the cup rim-stem impingement (Fig. 6). CMM indicated moderate wear of the bearing couple (head form factor > 30$\mu$m grade-2, cup form factor >70$\mu$m grade-3).

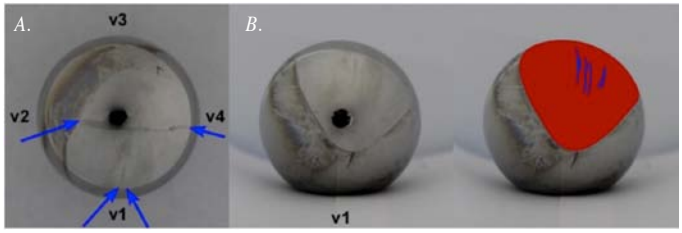


***Figure 6:*** *Femoral head with multiple stripe wear:*
*A) Aerial view of femoral head with arrows indicating polar stripe wear*
*B) Side view of femoral head and cartoon showing MWZ and polar stripes.*

## *MULTI-DIRECTIONAL SUBLUXATION WITH SOFT TISSUE IMPINGEMENT (ANTERIOR OR POSTERIOR)*

a. Moderate-severe wear (CMM)
b. Defined MWZ, multi-directional stripes
c. Moderate-high metal ion concentrations
d. Frequently presents with stained tissue

CASE-5 (R770)

This 33 y/o male (bilateral MOM hip replacements) had a left THA revision at approximately 8 years due to pain, popping/catching sensations, and elevated ions (Co=33, Cr=17). At surgery the implant was observed subluxing superiorly from the acetabular cup with anterior rotation of the leg. Both the femoral head and acetabular cup were retrieved. Retrieval analysis identified a well defined main-wear zone and multi-directional polar stripe formations (Fig. 7) similar to those reported on dislocated implants. CMM indicated severe wear of the bearing couple (head and cup form factor > 120$\mu$m, grade-4).

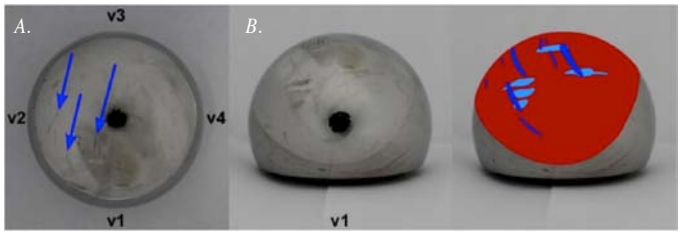


***Figure 7:*** *Femoral head with multiple stripe wear:*
*A) Aerial view of femoral head with arrows indicating polar stripe wear.*
*B) Side view of femoral head and cartoon showing MWZ and polar stripes.*

***REPETITIVE SUBLUXATION WITH SOFT TISSUE IMPINGEMENT (ANTERIOR OR POSTERIOR)***

a. Moderate-severe wear (CMM)
b. Defined MWZ, one broad polar stripe
c. Moderate-high metal ion concentrations
d. Frequently presents with stained tissue

CASE-6 (R751)

This 77 y/o female was revised at approximately 6 years due to pain, suspected implant loosening, osteolytic cysts determined by CT, and highly elevated ions (Co=164, Cr=45). Intraoperatively, there was evidence of wear including darkly stained tissue and osteolytic cysts. Both the femoral head and acetabular cup were retrieved. Retrieval analysis identified a well defined main-wear zone and one polar stripe (Fig. 8). CMM indicated severe wear of the bearing couple (head form factor > 200 grade-4, cup form factor >300 grade-5).

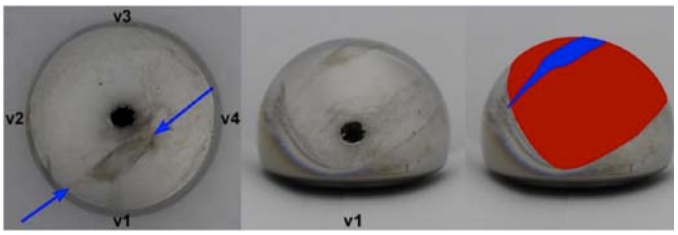


***Figure 8:*** *Femoral head with multiple stripe wear*
*A) Aerial view of femoral head with arrows indicating polar stripe wear*
*B) Side view of femoral head and cartoon showing MWZ and polar stripe.*

## Discussion

This study reviewed several unique failure modes using patient complaints, metal ion analysis, intraoperative findings, and retrieval analysis. It can be appreciated that descriptive studies such as this have multiple limitations. First, this study analyzed failed implants and these results may not reflect the overall population of MOM implants. Secondly, in the first two cases the stem and cups were found to be stable with good bony in-growth and therefore were left in the patient during revision surgery. Thus the wear in those two cases was based on data obtained from the femoral head only. Thirdly, some cases used to highlight unique modes of failure were (a) revised prior to our metal-ion studies and (b) no longer available for CMM measurements. Lastly, the pathways by which each case has come to failure classifications are based on the opinion of one experienced hip surgeon and may be considered subjective and speculative.

CMM measurements of sphericity and diameter-mismatch provided some clues about the overall volumetric wear of the MOM bearings. As the form factor (asphericty measurement) increased in most cases, so did the metal ion levels and the degree of stained tissue (Table 2). This suggested that CMM indicated the degree of material lost from the MOM bearing, which then goes on to stain local tissues and seep into the blood as metal ions.

It is the understanding of this group that MWZ areas and stripe wear may be a normal component of MOM bearing wear. However, dramatic changes in MWZ area and multiple or significantly larger stripe wear may warrant a closer scrutiny. The MWZ area appears to be consistent across multiple bearing types and patients and appears to increase with respect to diameter but maintains approximately 55% hemisphere. [24] Stripe wear is consistently observed as well, with the polar stripe being the most prominent but having the lowest surface roughness due to polishing effects in the MWZ. It is considered that polar stripes form at the terminal point in a patient's ROM and as the patient pushes beyond that point, subluxation may occur and form a larger polar stripe or additional polar stripes.

Given that 5 of 6 cases were greater than 38mm diameter, such large heads were expected to be stable and have a high range of motion and be free of impingement problems seen in 28mm MOM. [19] However, we concluded that this is not the case. Despite the use of large diameter implants, most of the cases showed evidence of patients exceeding their 'design' range of motion leading to stripe wear during either subluxation or impingement. [19,24-27]

| Mode | F/U (y) | Metal Ion Analysis | | Stained Tissue | IntraOperative Observations | Ball FF ($\mu$m) | Cup FF ($\mu$m) | MWZ | Stripes |
|---|---|---|---|---|---|---|---|---|---|
| | | Co | Cr | | | | | | |
| 1 | 7.8 | 5 | 2 | N | | 11 | NA | Y | Y |
| 2 | 5.7 | 5 | 6 | N | Discoloration | 21 | NA | Y | Y |
| 3 | 3.25 | NA | NA | Y | | NA | NA | Y | Y |
| 4 | 3.5 | 47 | 21 | Y | Stem impingement | 31 | 71 | Y | Y |
| 5 | 8.3 | 34 | 17 | Y | Superior subluxation | 158 | 127 | Y | Y |
| 6 | 6 | 164 | 45 | Y | Osteolytic cysts | 214 | 324 | Y | Y |

***Table 2:*** *Summary of results including: metal ion analysis, intraoperative observation, and retrieval analysis.*

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