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Original Article

Damage Patterns at the Head-Stem Taper Junction Helps Understand the Mechanisms of Material Loss

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ABSTRACT

Background: Material loss at the taper junction of metal-on-metal total hip arthroplasties has been implicated in their early failure. The mechanisms of material loss are not fully understood; analysis of the patterns of damage at the taper can help us better understand why material loss occurs at this junction.
Methods: We mapped the patterns of material loss in a series of 155 metal-on-metal total hip arthroplasties received at our center by scanning the taper surface using a roundness-measuring machine. We examined these material loss maps to develop a 5-tier classification system based on visual differences between different patterns. We correlated these patterns to surgical, implant, and patient factors known to be important for head-stem taper damage.
Results: We found that 63 implants had “minimal damage” at the taper (material loss <1 mm^3), and the remaining 92 implants could be categorized by 4 distinct patterns of taper material loss. We found that (1) head diameter and (2) time to revision were key significant variables separating the groups.
Conclusion: These material loss maps allow us to suggest different mechanisms that dominate the cause of the material loss in each pattern: (1) corrosion, (2) mechanically assisted corrosion, or (3) intraoperative damage or poor size tolerances leading to toggling of trunnion in taper.
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Material loss at the taper junction of stemmed metal-on-metal total hip arthroplasties (MOM-THAs) has been implicated in the early failure of these implants [1,2]. It is speculated that the mechanism of material loss at this junction involves either corrosion [3-6], mechanical wear (fretting), or a combination of the 2 [7].

Previous retrieval work has reported volumetric material loss from the head-stem taper junction as high as 25 mm^3 [8], which accounts for a third of the total material loss in contemporary MOM-THAs. However, few studies have specifically looked at explaining the mechanisms [1-6] behind this material loss, and therefore, this remains an area of uncertainty.

Analysis of the patterns of taper surface damage can help us to understand material loss mechanisms. Bishop et al [1] analyzed retrieved components from 5 patients and identified 2 patterns of material loss: axisymmetric and asymmetric. They attributed the asymmetric pattern to toggling of the head on the stem trunnion while the axisymmetric pattern was attributed to a uniform seating of the head taper onto the stem trunnion. The numbers of hips investigated in this study are, however, low and the mechanisms of material loss remain unclear.

At our retrieval center we noticed patterns of taper material loss that did not fit into the 2 patterns suggested by Bishop et al [1]. Consequently, we set out to (1) identify the patterns of material loss at the head-stem taper junction in a series of 155 retrieved MOM-THAs at our center and (2) relate these patterns to associated surgical, implant, and patient factors.

Materials and Methods

This retrieval study involved a consecutive series of 155 failed MOM-THAs that had been received at our center. The hips were

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retrieved from 66 male and 89 female patients with a median age of 61 years (26-83) and a median time to revision of 40 months (12-89); the reasons for revision, as reported by the revising surgeon, were given unexplained pain (n = 148) and implant loosening (n = 7). The median head size was 46 mm (36-58), and the median prerevision whole-blood cobalt (Co) and chromium (Cr) levels were 7.4 (0.6-212.4) and 3.5 (0.2-111), respectively; the median Co/Cr ratio was 1.45 (0.03-17.70). Prerevision plain radiographs were obtained for each implant to determine the median acetabular inclination and the median horizontal and vertical femoral offsets; these were 42° (12-68), 37 mm (6-66), and 79 mm (10-145), respectively. The implants consisted of over 10 different contemporary bearing designs together with over 9 stem designs, Table 1.

Head Taper Corrosion Assessment

A single examiner inspected all 155 head taper surfaces for evidence of corrosion using macroscopic analysis and also light microscopy (maximum magnification × 40, Leica Microsystems, Germany). Corrosion severity was graded using a well-published 4-tier classification system [6], which has previously been shown to be both reproducible and repeatable [9] using a published method of assessing observer agreement [10].

Taper Material Loss Pattern Mapping

The volume of material loss at the head taper surfaces was measured using a Talyrond 365 (Taylor Hobson, Leicester, United Kingdom), roundness measurement machine. We did not include analysis of the stem trunnion in this study as the surgeon had opted to retain the stem in the majority of cases. Furthermore, it has previously been shown that in hips with CoCr tapers and titanium stem trunnions, material is often lost preferentially from the head taper due to a mechanism of galvanic corrosion [8]; stem trunnions that macroscopically appear undamaged have been shown to exhibit minimal material loss.

A series of 180 vertical traces were taken along the axis of the taper surface using a 5-μm diamond styles. These traces were combined to form a rectangular surface depicting both undamaged regions and regions of material loss (hereafter referred to as material loss maps); these maps visually depict the distribution and severity of surface damage using a color scale; this ranges from dark red regions representing the unworn regions of the taper surface while the transition from yellow, to green, to blue indicates regions of increasing material loss from the surface, Figure 1. Therefore, each material loss map creates a recognizable pattern which can be categorized by an examiner. The subtraction of undamaged surface areas from damaged areas also allows for an estimation of material loss volume.

Classification of Taper Damage Patterns

In this study we considered tapers that had lost less than 1 mm^3 of material from their surfaces as having "minimal damage". All tapers with less than 1 mm^3 of material loss were, therefore, categorized as being in the minimal damage group.

A committee consisting of 2 examiners experienced in retrieval analysis examined each of the remaining taper material loss maps to jointly agree how these should be categorized according to their visual appearance. The examiners were blind to all material loss data for the hips.

Bearing Surface Material Loss Measurement

In order to assess the role of bearing surface wear on taper damage, we also measured the volume of material loss of the cups and heads. Measurements were carried out using a Zeiss Prismo (Carl Zeiss, Ltd, Rugby, United Kingdom) coordinate measuring machine with a 2-mm ruby stylus. The protocol acquired up to 30,000 data points along 400 polar scan lines, and data analysis was performed using an iterative least-square fitting operation (Matlab, Mathworks, Inc, Natick, MA). We utilized the unworn geometry and fitting algorithms to determine the shape of the original surfaces, thus enabling us to calculate volumetric material loss. The generated wear maps were also used to determine of the implant had been edge wearing.

Analysis of Clinical and Implant Variables

We performed nonparametric analysis to determine the significance of differences between the different damage pattern

Table 1
Patient and Implant Data for the MOM-THAs.

	Number	Median	Range
Gender (male:female)	66:89	—	—
Age at primary surgery (y)	—	61	26-83
Time to revision (mo)	—	40	12-89
Femoral head diameter (mm)	—	46	36-58
Inclination°	—	42	12-68
Horizontal offset (mm)	—	37	6-66
Vertical offset (mm)	—	79	10-145
Whole-blood cobalt (ppb)	—	7.4	0.6-212.4
Whole-blood chromium (ppb)	—	3.5	0.2-111
Cobalt/chromium ratio	—	1.45	0.03-17.70
Bearing design			
Biomet Magnum	32	—	—
Corin Cormet	10	—	—
DePuy ASR XL	26	—	—
DePuy Pinnacle	18	—	—
Finsbury Adept	14	—	—
S&N BHR	27	—	—
Wright Conserve	6	—	—
Zimmer Metasul	4	—	—
Zimmer Durom	8	—	—
Others	10	—	—
Stem design			
CLS	6	—	—
Corail	35	—	—
CPCS	4	—	—
CPT	11	—	—
S-ROM	7	—	—
Synergy	7	—	—
Taperloc	24	—	—
Zweymuller	12	—	—
Others	49	—	—

MOM-THAs, metal-on-metal total hip arthroplasties.

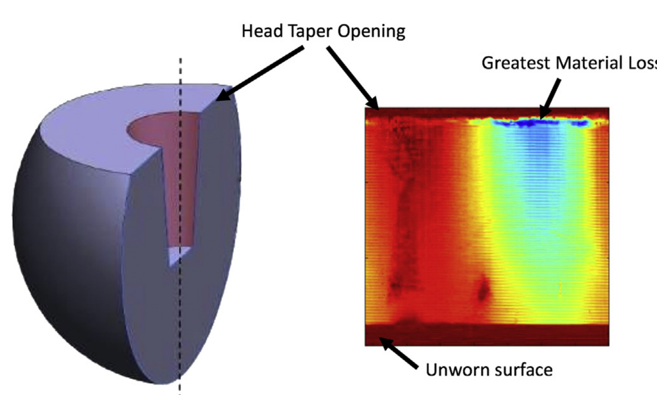

Fig. 1. Example of material loss map generated. Red regions represent unworn surfaces while blue regions represent areas with the greatest material loss.

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