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Volumetric assessment of material loss from retrieved cemented metal hip replacement stems

Richard B. Cook [a,*], Natalie R. Shearwood-Porter [b], Jeremy M. Latham [c], Robert J.K. Wood [a]

[a] National Centre for Advanced Tribology at Southampton (nCATS), University of Southampton, Highfield, Southampton SO17 1BJ, UK
[b] Bioengineering Science Research Group, Faculty of Engineering and the Environment, University of Southampton, Southampton SO17 1BJ, UK
[c] Southampton Orthopaedic Centre for Arthroplasty and Revision Surgery (SOCARS), Southampton General Hospital, Tremona Road, Southampton SO16 6YD, UK

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ABSTRACT

The aim of this study was to investigate the scale of metallic wear debris generation at the cement-stem interface of polished cobalt-chrome implants. Thirty-one Zimmer CPT cemented femoral stems were retrieved; mean time *in vivo* was 77.8 months (range 38–97 months), with 70% (n=21) of the stems considered to be well-fixed at the time of revision surgery. Volumetric loss was measured using optical microscopy, with focus variation technology capable of 3D reproduction of the surfaces. The scale of loss was found to be pronounced (mean: 3.1 mm^3, 0.02–11.4 mm^3), with a mean rate of 0.5 mm^3/year (0.003–1.9 mm^3/year). These results demonstrate that material loss from the cement-stem interface is comparable to that of a taper interface, even in apparently well-fixed stems.

1. Introduction

Cemented total hip replacement (THR) accounted for one third (n=25,228) of all primary hip replacements undertaken in the UK in 2012. Damage and material loss from the surfaces of cemented THR stems have been reported in a number of retrieval studies [1–6]. The release of metallic debris and ions from orthopaedic implants and the resultant adverse local tissue reaction (ALTR) seen in patients has become a major concern in the orthopaedic community. The majority of attention has focused on the release of material from the bearing surfaces, the taper interface and the corrosion of wear particles, with the cement stem interface receiving little attention. The origins of the damage at the cement-stem interface has been attributed to a tribocorrosion based process [4,7,8]. The damage originates from a complex interaction of stem micromotion within the cement mantle [9], pores at the cement stem interface [10], the chemistry of the cement [7,11] and the presence of radiopacifier, with different cement compositions and stem designs resulting in different damage mechanisms [12,13]. However, to the authors' knowledge, no study to date has attempted to quantify the scale of the damage to the surfaces of polished stems. This is necessary if the role of stem damage as a source of material release is to be considered alongside that of bearing surfaces and tapers. The aim of this study is to provide a robust estimate of the volume of material loss from a collection of cemented collarless tapered cobalt-chrome stems.

2. Materials and methods

The study assessed 31 hybrid modular total hip replacements. All stems were cemented collarless tapered cobalt-chrome Zimmer CPT stems paired with either a BHR large diameter modular head (LDMH) (Midland Medical technologies; Smith and Nephew) (n=17), Adept LDMH (Finsbury Orthopaedics) (n=13), Versys (Zimmer) (n=3) or Durom LDMH (Zimmer) (n=1); head sizes ranged from 28–50 mm diameter. The LDMH were all large head metal on metal bearings (LHMOM), with the 3 Versys being metal on polymer bearings. Mean time *in vivo* was 77.8 months (38–97 months). Patient and implant characteristics for each retrieved femoral stem are given in Table 1. Ethical approval was granted by the National Research Ethics Service Committee South Central–Southampton A.

2.1. Macroscopic grading

The scale of damage to the stems was graded according to the criteria described by Bryant et al. 2013 [4]. The scale scores stems from one to five based on the area of damage to the stem surface

* Corresponding author. Tel.: +44 2380 593761.
E-mail address: r.b.cook@soton.ac.uk (R.B. Cook).

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Table 1
Patient and implant characteristics.

	Patient age at primary	Patient gender	Time in vivo	Head size	Stem size	Stem loose
1	62	F	72	50+0	2 STD	N
2	64	M	56	50+0	3 EXT	Y
3	70	M	86	46+0	1 EXT	Y
4	44	F	80	46+0	0 STD	N
5	68	F	85	42+4	1 EXT	Y
6	68	M	89	46+0	1 STD	N
7	57	F	52	48+0	1 STD	N
8	60	M	81	50+0	3 EXT	Y
9	74	F	94	46+4	1 STD	N
10	56	F	97	42+4	1 EXT	N
11	59	F	96	50+0	1 EXT	N
12	96	F	88	46+0	? EXT	Y
13	69	F	69	46+0	1 STD	N
14	59	F	99	50+4	2 EXT	N
15	50	M	48	48+3.5	1STD	N
16	71	M	97	46+4	1 EXT	N
17	62	M	93	50+0	3 EXT	N
18	69	F	75	46+0	1 STD	Y
19	71	M	84	46+0	1 STD	N
20	64	F	96	42+0	1 STD	N
21	61	M	65	46+3.5	2 EXT	Y
22	68	M	49	50+0	1EXT	N
23	63	F	96	42+0	N A	N
24	60	F	91	42+3.5	1 STD	N
25	63	F	74	46+3.5	1 EXT	N
26	54	F	93	46+0	1 EXT	NA
27	60	F	82	46+0	0 STD	N
28	72	F	72	46L	3 STD	N
29	65	M	68	36+0	2 STD	Periprosthetic fracture
30	72	F	38	28+0	1 EXT	Periprosthetic fracture
31	57	M	47	36+3.5	4 XEXT	Periprosthetic fracture

from within the cemented region. The categories are 1: $<10\%$, 2: 10–25%, 3: 25–50% 4: 50–75% and 5: $>75\%$ of the surface.

2.2. *Volume loss assessment*

2.2.1. *Stems*

Each femoral stem was photographed with a digital single lens reflex (DSLR) camera in four orientations, providing medial, lateral, anterior and posterior views. A photographic scale bar was imaged alongside the stem. Analysis of the area of damage on the stem surface was conducted using ImageJ 1.47 software (National Institutes of Health, Maryland, USA).

The regions of damage on the femoral stems were imaged using an Alicona InfiniteFocus microscope (Alicona Imaging GmbH, Graz, Austria). This optical microscopy technique uses focus variation technology to extract 3D morphology and depth information from the surface. Images of the damaged surface (Fig. 1a) were taken using either $10\times$ lens or $20\times$ lenses depending on the nature of the surface, with the vertical resolution of the system set to 100 nm for the $10\times$ lens and 70 nm for the $20\times$ objective. A series of images were taken to provide a mean value of material loss across each region of damage.

The volumetric material loss from the stem surface was determined using Alicona IFM 4.2 software. The orientation of the reference plane of each 3D surface was adjusted to best fit the measured surface and then the area of the surface for investigation was selected. Using the top-cover mode an ISO-surface was applied to the area of interest (Fig. 1b). The top cover mode generates the ISO-surface *via* an iterative procedure. Starting at the boundary of the selected area of investigation, the original values obtained in the *z*-axis (vertical axis) are assigned. The

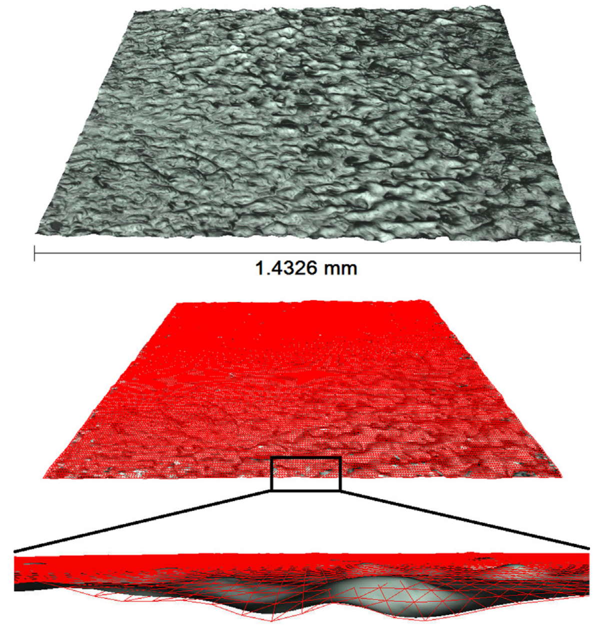

Fig. 1. a) Alicona 3D optical microscope area of damage, b) Alicona 3D optical microscope area of damage with top-cover ISO surface fitted.

neighbouring points are examined and their *z*-values are adapted with respect to a minimum curvature constraint. This procedure is repeated until all points within the area of interest fulfil a minimum curvature constraint with respect to the neighbouring points and the original surface. This surface is taken to represent the original implant surface and the volume of material lost within that unit area was computed from beneath this surface.

By combining the area measured from the different regions of damage and the results of the volumetric assessment, a robust estimate of the volume of material loss was generated. Assessment and combination of the errors within the two measures provided an error of $+/-16.3\%$ of the measured value.

2.2.2. *Femoral head, acetabular cup and taper assessment*

The bearing surfaces of the femoral heads and acetabular cups were directly assessed using a RedLux artificial hip joint profiler (RedLux, Southampton, UK). Information on the technique has been published previously by Tuke et al. (2010). The technique uses a chromatically encoded confocal measurement method to provide ultra-precision three-dimensional (3D) form metrology with a resolution of 20 nm. The taper assessments were performed on a casting of the female taper surface made from a high-resolution (0.05 μm) replication polymer (Microset Products, Leicestershire, UK).

3. Results

Table 2 shows the volume and rates of material loss from the 4 sites assessed. Damage was observed on the surface of all stems, although the extent and severity varied. The mean volumetric material loss from the entire data set was 3.1 mm^3 (ranging from 0.02–11.4 mm^3), with a mean rate of 0.5 mm^3/year (ranging from 0.003–1.9 mm^3/year) (Fig. 2). While this volume and rate is below that of the bearing surfaces, it is approximately twice that of the loss from the female taper surfaces.

During retrieval of the implants, the retrieving surgeon noted if the stem was well-fixed or loose in the cement mantle. Comparison of the measured volumetric material loss for the well-fixed and loose stems (Table 2) highlights that high levels of volume loss