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Research Paper

Galvanically enhanced fretting-crevice corrosion of cemented femoral stems

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ABSTRACT

The Ultima TPS MoM THR was designed and developed as a 2nd generation MoM THR specifically aimed at younger more active patients due to the anticipated low wear rates and increased longevity of MoM THRs. In 2010, published clinical data highlighted the early failure of the Ultima TPS MoM due to fretting-crevice corrosion at the stem–cement interface. Since 2010 similar observations have been reported by other clinical centres implicating competitor products as well as the Ultima TPS MoM THR. In an attempt to replicate the electrochemical reaction and interactions established across MoM THR systems, fretting-crevice corrosion tests subjected to galvanic coupling were conducted. Galvanic coupling was seen to significantly increase the rates of corrosion under static and dynamic conditions. This was due to the large potential differences developed across the system between active and passive areas, increasing the rates of corrosion and metallic ion release from the stem–cement interface.

1. Introduction

Joint replacements have been a medical intervention practised since the late nineteenth century (Reynolds and Tansey, 2006). However it has only been since the 1950s that it has become a long-term solution to arthritic and congenital diseased joints due to the advances in both fixation techniques and implant design made by Sir John Charnley. The orthopaedic industries have made many advances since, and Total Hip Arthroplasty (THA) is now widely accepted as being a successful surgical procedure with results from the National Joint Registry supporting this (National Joint Registry, 2012). THAs are commonly used to treat arthritis or severe joint damage. Osteoarthritis of the hip joint is a painful and debilitating condition, estimated to affect 8 million people in the United Kingdom and 27 million in the United States (National Joint Registry, 2012; World Health Organisation, 2014). Different treatments exist to treat the condition but to date the most effective method of alleviating pain and restoring motion is THA.

MoM Total Hip Replacements (THRs) have the longest clinical history of any of the bearing combinations with the

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Table 1 – Chemical composition of alloys tested in this study. † Chemical composition of Ultima TPS™ femoral stem.

	Chemical composition (wt%)										
	C	Si	Mn	P	S	Cr	Fe	Mo	N	Ni	Co
LC CoCrMo	0.04	0.21	0.69	<0.005	0.0008	27.65	0.41	5.40	0.17	0.48	Bal.
LC CoCrMo†	0.05	0.19	0.67	0.005	0.0010	27.65	0.30	5.48	0.18	0.24	Bal.

first generation of MoM THR being designed and developed by Philip Wiles in 1938 (Santavirta et al., 2003). However these implants were largely unsuccessful due to the poor quality of material which was primarily stainless steel, poor manufacture and lack of inadequate fixation within the body (Reynolds and Tansey, 2006). MoM THR's regained popularity in the last 10 years due to improved manufacturing methods and decreased wear rates (Fisher et al., 2006). Retrieval studies indicate that well-functioning MoM THRs produce minimal wear debris and the surrounding tissues appear to have less inflammation compared with typical histiocyte-dominated tissue response to polyethylene debris (Jacobs et al., 1998). However in the recent years the amount of revisions has increased due to the Adverse Reaction to Metal Debris (ARMD).

The Ultima TPS™ was introduced in 1997 as triple tapered, highly polished cemented femoral stem. The Ultima TPS™ was primarily used with an MoM bearing typically coupled with a 28 mm 10/12 taper low CoCrMo Ultima femoral head, 28 mm high CoCrMo Ultima acetabular liner and a Ti–6Al–4V cementless acetabular shell that ranged from 48 mm to 68 mm in size. Polished tapered femoral stems generally have a good survivorship with revision rates of 2.8% at 7 years after operation being seen for commonly cemented stainless steel devices (Purbach et al., 2009). Similar figures have been presented for CoCrMo polished demonstrating revision rates of 4.1% 10 years postoperative (Burston et al., 2012). However recent studies have highlighted the importance of wear and corrosion, known as *tribocorrosion*, at the stem–cement interface with clinical studies implicating the interface with high failure rates due to ARMD (Bolland et al., 2011; Donell et al., 2010).

Of the tribocorrosion tests of components for THR all are primarily concerned with one part of the entire THR system; the bearing surfaces the taper and the stem–cement interface. Therefore this study considers the role of electrochemical coupling between the stem–cement interfaces and the assumed to be passive Ti–6Al-4V cementless acetabular shell in an attempt to simplify and understand how the system variables interact when subjected to both wear and corrosion. To the authors' knowledge this study is the first to introduce other interfaces/metals in order understand the role galvanic coupling plays on the corrosion of cemented MoM devices.

2. Experimental materials and method

2.1. Test specimens

In order to gain a full and comprehensive understanding of the role fretting-corrosion and galvanically-enhanced fretting

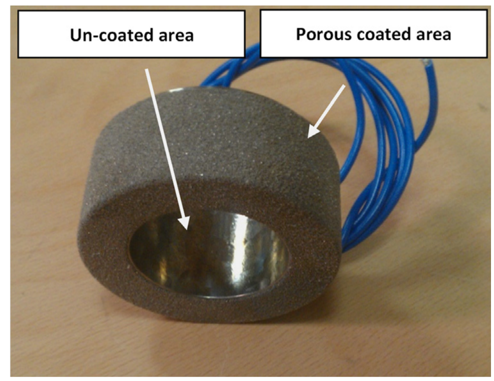

Fig. 1 – Ti ring manufactured to represent the acetabular components.

corrosion play in the overall degradation of cemented femoral stems low carbon (LC) (CoCrMo) Ultima TPS™ (DePuy International, Leeds, United Kingdom) femoral stems were utilised in this study as the working electrodes (WE). Table 1 gives results from analysis of the Ultima TPS femoral stems along with the ISO 5832-12:2007 standard for the LC alloy.

In order to replicate the galvanic interaction between the CoCrMo and Ti-6Al-V acetabular components, Ti–6Al–4V rings with the same surface area of the 68 mm Ti alloy acetabular component[1] were manufactured. Because it is difficult to estimate the exact surface area of the Ti alloy acetabular component due to the presence of a porous coating, a CAD package (SolidWorks, USA) was utilised to calculate the coated and uncoated area of the acetabular component. A total surface area of 140 cm^2 and 75 cm^2 for the total Ti alloy acetabular cup and porous coated surface area, respectively, was calculated and re-created with the Ti alloy rings (Fig. 1). This yields an approximate area ratio of 3:1 for the Ti alloy ring and CoCrMo femoral stem (surface area $\approx$ 58 cm^2), respectively. Once Ti alloy rings had been manufactured and the Ti–6Al–4V Porocoat© (DePuy International, United Kingdom) porous coating applied, each ring was cleaned and passivated, which consisted of ultrasonic cleaning and chemical passivation processes. To facilitate electrochemical measurements a plastic coated Cu wire was glued to the surface of the Ti alloy ring and CoCrMo femoral stem using conductive epoxy glue.

[1](Ø68 mm was the largest Ti–6Al–4V acetabular available on the market at the time and considered to be the worst case scenario with respect to surface area ratios. The entire area of the acetabular cup was assumed to be exposed to the electrolyte. This was informed from clinical retrieval analysis of this particular cohort due to the level of bone in-growth into the acetabular shell.)