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Research Paper

In-situ electrochemical study of interaction of tribology and corrosion in artificial hip prosthesis simulators

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ABSTRACT

The second generation Metal-on-Metal (MoM) hip replacements have been considered as an alternative to commonly used Polyethylene-on-Metal (PoM) joint prostheses due to polyethylene wear debris induced osteolysis. However, the role of corrosion and the biofilm formed under tribological contact are still not fully understood. Enhanced metal ion concentrations have been reported widely from hair, blood and urine samples of patients who received metal hip replacements and in isolated cases when abnormally high levels have caused adverse local tissue reactions. An understanding of the origin of metal ions is really important in order to design alloys for reduced ion release. Reciprocating pin-on-plate wear tester is a standard instrument to assess the interaction of corrosion and wear. However, more realistic hip simulator can provide a better understanding of tribocorrosion process for hip implants. It is very important to instrument the conventional hip simulator to enable electrochemical measurements. In this study, simple reciprocating pin-on-plate wear tests and hip simulator tests were compared. It was found that metal ions originated from two sources: (a) a depassivation of the contacting surfaces due to tribology (rubbing) and (b) corrosion of nano-sized wear particles generated from the contacting surfaces.

1. Introduction

The introduction of joint arthroplasty provides a solution for patients to relieve pain and restore the mobility of the joint (Griffith et al., 1978). However, adverse tissue reactions to prosthetic wear particles is believed to be an important factor in the development of osteolysis and a cause of loosening, especially from Polyethylene-on-Metal (PoM) type of joint implants (Amstutz et al., 1984; Semlitsch et al., 1989; Shedel, 2000). Because of the demand of joint replacements (total and resurfacing) in more active and younger patients with life expectancies of these devices after surgery in excess of 25 years, hard-on-hard hip implants have been recommended. This category includes Metal-on-Metal (MoM), Ceramic-on-Metal (CoM) and Ceramic-on-Ceramic (CoC) types of hip replacement, which differ from hard-on-soft types such as MoP variations. Many factors affect the longevity of the service time of these devices, such as the materials, design, manufacturing parameters etc. Research has suggested that by using a larger diameter of femoral hip head (>28 mm) and optimized clearance, reduced total wear (material degradation) can be achieved through the presence of iso-viscoelastic elastohydrodynamic lubrication (Jin et al., 1997)

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It is generally accepted that a lower wear rate equates to an extended implant life. Material loss from MoM articulations has been estimated to be approximately 100 times lower than MoP combinations (Amstutz et al., 1996). Material degradation in metallic joint implants is often thought to be solely induced by mechanical damage due to tribological movements and loading. However, these devices operate in a biological and corrosive environment. The material loss has been shown to be due to much more complicated processes (Isaac et al., 2006; Yan et al., 2006a,2006b,2006c,2006d, 2007a,2007b). For materials used in surgical implants, they are selected due to their very high corrosion resistance. The corrosion resistant alloys have a characteristic passive film on their surface, which acts as a barrier to the release of ions. However, this film can be damaged by relative motion at the surface resulting in an acceleration of corrosion processes (Mischler et al., 1999; Landolt et al., 2001; Garcia and Celis, 2001; Hodgson et al., 2007). Biotribocorrosion is the study of the interactions between tribology (mechanical wear) and electrochemical (corrosion) processes in biological environments and is the focus of this paper.

The spontaneously formed passive film on CoCrMo alloys is a mixture of chromium and cobalt oxides. The film is susceptible to fracture owing to mechanical loading resulting in scratches and dents (Zupanicic et al., 2006). After a metallic material is implanted into a human body, reactions between its surface and surrounding tissues and proteins immediately occur. Few studies have focused on the electrochemical and tribochemical reactions at the interface, which are extremely important in developing an understanding of the system and improving material selection and development. Wimmer et al. (2010), Casaban and Igual Munoz (2011), Myant et al. (2012) and other researchers noticed a thin layer (tribofilm) formed on the bearing surface containing calcium, oxygen, phosphors, *etc*. This tribofilm not only can lubricate the tribological contacts but also can regulate ion release.

Although reciprocating pin-on-plate wear tests cannot perfectly represent the real tribological contacts of hip implant *in vivo*, it has been recognized as a standard tesing method to characterize the surface performance under simulated conditions. It has been compared to many other methods and it is in an agreement that reciprocating pin-on-plate wear tests is a valid method to study corrosion behavior of materials used for hip bearing applications (Garcia and Celis, 2001; Mathew et al., 2011; Yan et al., 2006a). Hip simulator is the most realistic instrument to simulate hip loading and motion conditions *in vivo*. If the hip simulator can be integrated to study tribocorrosion behavior of given hip implants, it would be very useful to have a closer insight view on the release of metal ions from the hip bearing surfaces. The difficulties have been how to instrument the hip simulator to enable electrochemical measurements to be carried out. However, to gain a more realistic understanding of the material degradation process, integrated hip simulator need to be designed and tested.

The purpose of this study is to compare two apparati for tribocorrosion behavior of CoCrMo alloys used for hip implants. In this paper, both simple reciprocating pin-on-plate wear tests and pendulum hip simulator tests have been carried out to characterize the relationship and interactions between electrochemical reactions (corrosion), mechanical damage (wear) and biological environments. The similarity and difference between a simple reciprocating motion and a more realistic hip friction simulator are discussed.

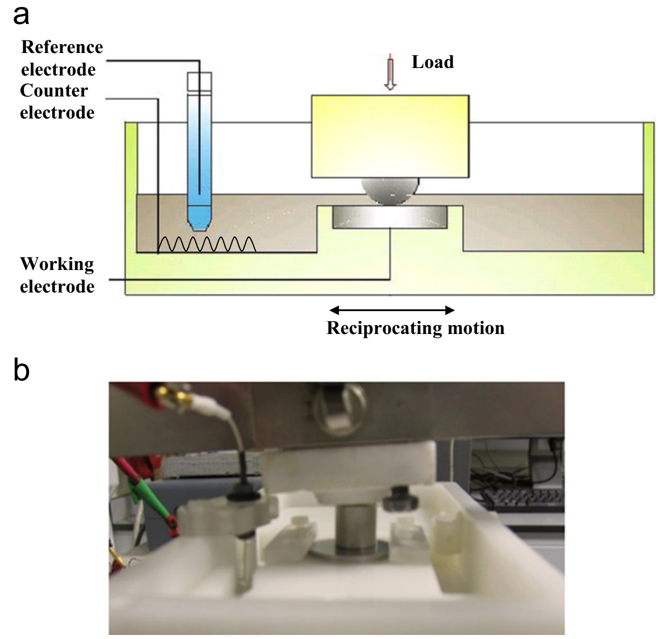

Fig. 1 – (a) Schematic representation of the tribo-electrochemical cell and (b) photograph of the set up.

2. Experimental procedure

Two apparati were used in this study. The main focus is to investigate the tribocorrosion behavior of hip components and wear debris in a relatively simple and realistic simulator. Data also was compared with that from a pin-on-plate tribotester. An integrated tribocorrosion cell (Fig. 1), which comprises a 3-electrode electrochemical cell and the reciprocating tribological tester, was used to perform the tests where tribological and electrochemical damage could be quantified. The 3-electrode cell consists of the specimen as the working electrode (WE), a platinum wire as the counter electrode (CE) and a silver/silver chloride electrode as the reference electrode (RE). The surface area of the CE is 200 mm^2. The distance between the WE and the RE was controlled to 5 mm. A wire was connected from the bottom of the pin to the computer controlled potentiostat (Princeton Applied research VersaSTAT) to perform electrochemical measurements.

Open circuit potential (OCP) measurements: at the open circuit condition, the anodic reaction rate equals the cathodic reaction rate. OCP can give a semi-quantitative assessment of the corrosion regime (active or passive) in which the material resides. It can firstly assess how sliding affects the passivity of a metallic material and how passivity is re-established after the sliding ceases.

Cathodic protection tests (CP): In this study, a potential of −0.8 V (vs. Ag/AgCl) was applied, chosen to be beneath the equilibrium electrode potential for the Co/Co^{2+} reaction yet sufficiently noble enough to prevent hydrogen-evolution at the surface which would inevitably affect the wear processes.