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Research Paper

Characterization of the fretting corrosion behavior, surface and debris from head-taper interface of two different modular hip prostheses

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ABSTRACT

Modular hip prostheses are flexible to match anatomical variations and to optimize mechanical and tribological properties of each part by using different materials. However, micromotions associated with the modular components can lead to fretting corrosion and, consequently, to release of debris which can cause adverse local tissue reactions in human body. In the present study, the surface damage and residues released during *in vitro* fretting corrosion tests were characterized by stereomicroscope, SEM and EDS. Two models of modular hip prosthesis were studied: Model SS/Ti Cementless whose stem was made of ASTM F136 Ti-6Al-4V alloy and whose metallic head was made of ASTM F138 austenitic stainless steel, and Model SS/SS Cemented with both components made of ASTM F138 stainless steel. The fretting corrosion tests were evaluated according to the criteria of ASTM F1875 standard. Micromotions during the test caused mechanical wear and material loss in the head-taper interface, resulting in fretting-corrosion. Model SS/SS showed higher grade of corrosion. Different morphologies of debris predominated in each model studied. Small and agglomerated particles were observed in the Model SS/Ti and irregular particles in the Model SS/SS. After 10 million cycles, the Model SS/Ti was more resistant to fretting corrosion than the Model SS/SS.

1. Introduction

Over the last 35 years significant progress has occurred in the design and development of modular hip prostheses. This type of implant involves at least one male-female junction between components, such as the connection between tapered stem and spherical head. The attachment method is designed to self lock and withstand large compressive, tensile and rotational loads (Hallab et al., 2004). The use of modular hip prostheses present many advantages, such as

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various geometries allowing the surgeon to select the most appropriated prosthesis to the anatomy of each patient (Triantafyllidis et al., 2007). In addition, modular components permit the use of heads and stems of different materials, so as to optimize the properties of each component. However, the modular interfaces are subjected to small oscillatory motion (below 100 μm) and body fluids can penetrate into the junction, favoring the occurrence of fretting corrosion (Triantafyllidis et al., 2007), which is a synergistic combination of electrochemical dissolution and mechanical wear (Geringer et al., 2012; Urban et al., 1997). Fretting corrosion is considered the most important mechanism of corrosion at the head–taper interface of hip prosthesis (Brown et al., 2014; Hoeppner and Chandrasekaran, 1994).

Most alloys used for orthopedic appliances rely on the formation of a passive film to prevent oxidation from taking place. These films consist of metal oxides, which form spontaneously on the surface of the metal in such a way that they prevent transport of metal ions and electrons across the film (Cohen, 1998). The periodical removal (depassivation) and growth (repassivation) of this protective oxide layer in the fretted zone cause variation on the free corrosion potential of the material used in the implant, increasing the corrosion susceptibility in the saline environment of human body (Kumar et al., 2010).

The extent of damage on the fretting zone is also restricted, while in the remaining area the passive film is preserved, thus leading to the formation of a galvanic cell between the active fretted zone and the passive intact oxide area (Kumar et al., 2010).

The degradation of metallic implants into the body is undesirable for two main reasons: the process can reduce the structural integrity of the implant and the release of corrosion products can cause adverse biological reactions (Cohen, 1998).

The total area surface of contact between implant material and the biologic environment is considerably increased by fragmentation, thus accelerating wear and the dissemination of potentially toxic elements at the interface. Particles with suitable sizes can be phagocytosed by cells, which may induce changes in intracellular processes. In addition, these phagocytosed particles can be transported to regions which are very distant to the implant site, such as lymph nodes, lungs and spleen (DiCarlo and Bullough, 1992). These biological responses to metal debris depends on particle size, morphology, chemical composition, concentration and capability to form agglomerates (Kranz et al., 2009; Topolovec et al., 2013).

In spite of the increasing use of titanium and its alloys in the last decades, stainless steel is still extensively used in Brazil for total hip arthroplasty due to its lower cost associated with good mechanical properties and satisfactory corrosion resistance. In this country the main customer is the Health Ministry which supplies the demands of public hospitals through the Unified Health System (SUS – Sistema Único de Saúde). In some cases a stainless steel head is used together with titanium alloys stem (Azevedo and Hippert, 2001, 2002).

Both stainless steel and commercially pure titanium (cp Ti) are widely used as dental and internal fixation implants. Krischak et al. (2004) reported that stainless steel is more likely to corrode with a markedly higher amount of potentially toxic metallic particles release in the soft tissues compared with cp Ti implants. Implants made of stainless steel have shown higher grades of corrosion and considerably larger uptake of the metallic elements representing the main components of the material (Fe, Cr, Ni, Mo) compared with implants made of cp Ti.

Although it is generally good practice to avoid contact between dissimilar metals or similar metals in different conditions, the presence of a passivating film alters the kinetics of the corrosion reaction so that certain combinations of metals or conditions are not accompanied by galvanic corrosion (Cohen, 1998).

In vitro studies on fretting corrosion are very important to understand the mode of corrosive attack and the generation of the particulate debris during fretting of a modular interface (Kumar et al., 2010). This knowledge about the mechanism and its residues is mainly important in the design stage of hip prosthesis, aiming to minimize the amount of tissue exposed to corrosion products.

The objective of this study was to evaluate the fretting corrosion behavior and release of debris of two models of modular hip prostheses (head-stem) manufactured by the same company, considering their differences in materials, surface finishes, designs and geometries.

2. Materials and methods

In the present study two different models of modular hip prostheses were analyzed. Model SS/SS Cemented (Fig. 1, bottom): prosthesis of long term use with the femoral head and stem made of austenitic stainless steel (ASTM F138-13a, *Standard Specification for Wrought 18Chromium-14Nickel-2.5Molybdenum Stainless Steel Bar and Wire for Surgical Implants*) and polished surface finish (body of the stem), indicated to arthroplasty procedure using bone cement. Model SS/Ti Cementless (Fig. 1, top): prosthesis of long term use with the femoral head made of ASTM F138 stainless steel and stem made of Ti-6Al-4V alloy (ASTM F136-13, *Standard Specification for Wrought Titanium-6Aluminum-4Vanadium ELI (Extra Low Interstitial) Alloy for Surgical Implant Applications*) and rough surface finish obtained by blasting (body of the stem), indicated to cementless arthroplasty

Fig. 1 – Modular hip prostheses: Model SS/Ti Cemented (top) – head made of ASTM F138 stainless steel and stem made of ASTM F136 Ti-6Al-4V alloy; Model SS/SS Cementless (bottom) – head and stem made of ASTM F138 stainless steel.