



# The effect of lubrication on the friction and wear of Biolo<sup>®</sup>x<sup>®</sup>delta

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## ARTICLE INFO

### Article history:

Received 16 May 2011

Received in revised form 12 December 2011

Accepted 16 December 2011

Available online 13 February 2012

### Keywords:

Ceramic hip joints

In vitro testing

Lubrication effects

Wear mechanisms

## ABSTRACT

The performance of total hip-joint replacements depends strongly on the state of lubrication in vivo. In order to test candidate prosthetic materials, in vitro wear testing requires a lubricant that behaves in the same manner as synovial fluid. The current study investigated three lubricants and looked in detail at the lubrication conditions and the consequent effect on ball-on-flat reciprocating wear mechanisms of Biolo<sup>®</sup>x<sup>®</sup>delta against alumina. Biolo<sup>®</sup>x<sup>®</sup>delta, the latest commercial material for artificial hip-joint replacements, is an alumina-matrix composite with improved mechanical properties through the addition of zirconia and other mixed oxides. Three commonly used laboratory lubricants, ultra pure water, 25 vol.% new-born calf serum solution and 1 wt.% carboxymethyl cellulose sodium salt (CMC-Na) solution, were used for the investigation. The lubrication regimes were defined by constructing Stribeck curves. Full fluid-film lubrication was observed for the serum solution whereas full fluid-film and mixed lubrications were observed in both water and the CMC-Na solution. The wear rates in the CMC-Na and new-born calf serum were similar, but were an order of magnitude higher in water. The worn surfaces all exhibited pitting, which is consistent with the transition from mild wear to severe or “stripe” wear. The extent of pitting was greatest in the serum solution, but least in the water. On all worn surfaces, the zirconia appeared to have fully transformed from tetragonal to monoclinic symmetry. However, there was no evidence of microcracking associated with the transformed zirconia. Nevertheless, AFM indicated that zirconia was lost preferentially to the alumina grains during sliding. Thus, the current study has shown conclusively that the wear mechanisms for Biolo<sup>®</sup>x<sup>®</sup>delta clearly depend on the lubricant used, even where wear rates were similar.

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## 1. Introduction

Total hip-joint replacements (THRs) account for the largest proportion of orthopaedic surgery. Since their introduction, the lifetime of THRs has been greatly improved with time, and can now commonly last over 10–15 years [1,2]. However, the increasing number of younger and more active patients and the small but still significant occurrence of clinical failure (such as fracture and aseptic loosening) means that there is still a challenge to develop new biomaterials that are more damage-tolerant than the existing materials.

Modern commercial artificial hip-joint ball-in-socket combinations usually comprise metal (such as Co–Cr–Mo alloy), polymer (such as ultrahigh-molecular-weight polyethylene, UHMWPE) and ceramic (such as alumina) combinations. Since the first introduction of alumina-on-alumina THR was made in the 1970s, its high wear resistance and excellent biocompatibility make it an ideal material for THRs. Although some other ceramics (such as zirconia) were developed as alternative bearing materials, alumina

THR has been the most widely used over the last 30 years. First introduced in the 1970s, more than 3.5 million alumina components have been implanted worldwide. However, poor performance of alumina-on-alumina THRs was observed early on, in particular a high fracture rate in vivo, which restricted its development worldwide. With the concerns related to fracture in ceramics, substantial improvements in microstructure have been made by controlling the processing to achieve medical-grade THR products according to ISO 6474. A major step forward was the use of hot isostatic pressing (HIP), which substantially increases the density of the component. In addition, small additions of MgO led to a smaller and more uniform grain size. This led to the so-called third generation of commercial alumina products, introduced in 1994, e.g. Biolo<sup>®</sup>x<sup>®</sup>forte produced by CeramTec AG, Germany. These have become increasingly popular THRs.

The lifespan of a ceramic-on-ceramic THR offers substantial improvements over other THRs, although concerns over component fracture led to a delay in the introduction of alumina-on-alumina THRs in the USA until recently. Retrieved implants from aseptic loosening reveal a distinctive localized region of high wear, known as “stripe wear” [3–7], associated with surface intergranular fracture. While the mechanisms leading to stripe wear are still a

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