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Review Article

On the matter of synovial fluid lubrication: Implications for Metal-on-Metal hip tribology

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ABSTRACT

Artificial articular joints present an interesting, and difficult, tribological problem. These bearing contacts undergo complex transient loading and multi axes kinematic cycles, over extremely long periods of time (>10 years). Despite extensive research, wear of the bearing surfaces, particularly metal–metal hips, remains a major problem. Comparatively little is known about the prevailing lubrication mechanism in artificial joints which is a serious gap in our knowledge as this determines film formation and hence wear. In this paper we review the accepted lubrication models for artificial hips and present a new concept to explain film formation with synovial fluid. This model, recently proposed by the authors, suggests that interfacial film formation is determined by rheological changes local to the contact and is driven by aggregation of synovial fluid proteins. The implications of this new mechanism for the tribological performance of new implant designs and the effect of patient synovial fluid properties are discussed.

Contents

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Nomenclature

BCS	bovine calf serum
CrCoMo	FS75 chromium, cobalt and molybdenum alloy
CoC	ceramic-on-ceramic
EHL	elastohydrodynamic lubrication
LHMoM	large head Metal-on-Metal
MoM	Metal-on-Metal
MoP	Metal-on-Polymer
OA	osteoarthritis
PAL	Protein Aggregation Lubrication
s	inlet reservoir length
SAPL	surface active phospholipid
SF	synovial fluid
Ra	arithmetic mean surface roughness
R'	reduced radius
U	entrainment speed
W	applied load
η	dynamic viscosity

1. Introduction

Prosthetic implants restore joint function which has been impaired due to disease, trauma or genetic condition. Due to an ageing population this is a rapidly growing sector; National Joint Registry (2012) figures for England and Wales reported 88,984 total hip and 93,080 knee replacement procedures in 2012. However, there are significant clinical concerns over the use of 2nd generation Metal-on-Metal (MoM) hip joints as these have been associated with the development of periprosthetic tissue lesions (Revell et al., 1997). These concerns resulted in the issue of a medical device alerts by the UK MHRA (2010) for MoM implants and the withdrawal of some designs from the market.

MoM hips are not a recent concept; they were first introduced in the early 1960s with the McKee-Farrar cemented joint, which used a CoCrMo alloy for the head and articular cup. Although these were widely implanted, early failures did occur due to asceptic loosening and poor manufacturing quality. As a result the implant was discontinued in favour of the Charnley Metal-on-Polymer (MoP) hip. However, for some patients the McKee-Farrar joint had good survivorship (>20 years) with no apparent attendant problems (Isaac et al., 2006). In the late 1980s attention turned again to the MoM design as a replacement for MoP hips, which were found unsuitable as a long term solution for younger patients. The 2nd generation MoM designs, which included resurfacing, larger head diameters (LHMoM) and modular hips, were driven partly by clinical requirements of reduced risk of dislocation, ease of implantation, conservation of bone stock and greater degree of movement. Although the hip simulator studies indicated reduced wear with the large head MoM designs (Dowson et al., 2004; Isaac et al., 2006) the *in vivo* experience has been less positive. The UK NJR (2012) reports higher than expected revision rates for LHMoM joints, >5%, compared to 2% for conventional MoM hips. Implant failure can be due to a number of reasons (NJR, 2012), including aseptic loosening, infection and breakage; however a significant number of patients experience “unexplained pain” and this is often linked to high levels of metal ions in the blood. Explant analysis has shown these hips often have high levels of wear, often due to edge-wear of the cup (Underwood et al., 2012). The reasons for increased wear and failure are complex and include design, metallurgy, implantation (particularly cup position) and patient factors. The patient factors include gait (Bowsher et al., 2006), lifestyle (Brown and Clarke, 2006; Shetty and Villar, 2006) and synovial fluid (SF) composition (Klein, 2006; Liao, et al., 1999; Maskiewicz, et al., 2010). Excessive implant wear is essentially due to the breakdown of the lubricating film which separates the surfaces; the formation mechanisms and properties of the lubricating films are the focus of this paper.

2. Why is the lubrication mechanism important?

In many cases both short and long term failure of artificial joints is due to wear of the articulating surfaces. Material loss and damage of the surfaces may originate in physical (abrasion or adherence) or chemical (corrosion) mechanisms. These result in the formation of micron (polymer) or nanometre (metal) sized wear debris which is biologically active and often provokes an adverse cellular response (Wroblewski and Siney, 1993; Hart et al., 2006; Revell et al., 1997). The development of wear-resistant materials, including cross-linked polyethylene (Wang et al., 1998), metal treatment (Varano et al., 2006) and ceramics (Essner et al., 2005) has been the focus of much research over the years (Katti, 2004). However the range of materials available to the implant designer is limited as these must be low wearing, biocompatible; both in bulk and particulate and easy to manufacture to a reliable standard (Katti, 2004).

The other approach to improving wear performance is to optimise the lubrication function of the joint, to exploit this we need to understand the film formation mechanisms occurring during articulation. Currently there are two general theories; fluid film EHL (Dowson, 2006) and boundary lubrication (Hills, 2000) mechanisms. Although these theories are often treated separately it is highly likely, depending on the implant operating conditions, both will contribute to lubricant film formation during articulation.

Most tribology studies of implants have focused on the measurement of wear; either in simple pin-on-disc devices to study fundamental material properties (Tipper et al., 1999; Yao et al., 2003) or in more complex hip simulators where the effect of additional implant parameters (design, gait, and position) can be assessed (Bowsher et al., 2009; Fisher et al., 2004; Medley et al., 1997). Wear is essentially determined by the lubricant film and material properties. It is, therefore, important to understand lubricant behaviour over the entire gait cycle, including film thickness and distribution in the loaded-contact zone. Artificial joints undergo a range of