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Research Paper

Effect of head size on wear properties of metal-on-metal bearings of hip prostheses, and comparison with wear properties of metal-on-polyethylene bearings using hip simulator

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ABSTRACT

The effects of articular head size on the wear losses of the metal insert and articular head for a metal-on-metal bearing were examined using a hip simulator manufactured to satisfy ISO 14242-1. The wear properties of metal-on-metal and metal-on-polyethylene bearings were also compared under the same conditions. The total wear losses of the metal insert and articular head decreased with increasing diameter of the metal insert in the range from 28 to 44 mm. The total wear loss was greater for a diameter of 48 mm than for a diameter of 44 mm. When the articular metal insert diameter was smaller than 44 mm, the wear loss was reduced because the contact surface pressure increased with increasing metal insert diameter. However, the increase in wear loss observed for the 48-mm-diameter insert might have been due to the considerable increase in the rotation moment with increasing insert diameter. The tendency of decreasing contact pressure calculated using the Hertzian contact stress equation nearly conformed to the change in wear loss. On the other hand, the wear loss of an artificial hip joint consisting of a cross-linked ultrahigh-molecular-weight polyethylene insert (UHMWPE) and a Co–Cr–Mo articular head was small.

1. Introduction

For the hard-on-soft and hard-on-hard bearings of artificial hip joints, metal-on-polyethylene and ceramic-on-polyethylene bearings, and ceramic-on-ceramic and metal-on-metal bearings are in worldwide use, respectively. Recently, many adverse clinical experiences regarding metal-on-metal bearing devices have been reported (National Joint Replacement Registry, 2012; National Joint Registry for England and Wales, 2012; Catelas et al., 2006, 2011; Lu et al., 2012; Doorn et al., 1998, Urban et al., 2000; Davies et al., 2005; Kostensalo et al., 2012; Malek et al., 2012; Langton et al., 2011; Hart et al., 2012, 2011; Willert et al., 2005; Park et al., 2005; Browne et al., 2010; Grammatopoulos et al., 2010; Kwon et al., 2011; Williams et al., 2011; Campbell et al., 2010; Freemont, 2012; Watters et al., 2010; Counsell et al., 2008; Nich and Hamadouche, 2011; Khair et al., 2013). In

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particular, the high revision rate for metal-on-metal hip bearings in comparison with other bearings was reported in the 2012 annual reports of the Australian National Joint Replacement Registry and the England and Wales National Joint Registry. According to the analysis of the Australian National Joint Replacement Registry (2012), the revision rate markedly increases with increasing articular head diameter. From these clinical findings, it is necessary to investigate the effect of articular head size on the wear properties of metal-on-metal bearing devices.

The wear particles released from metal-on-metal bearings are extremely small, ranging in diameter from 6 to 830 nm (Catelas et al., 2006; Lu et al., 2012; Doorn et al., 1998). Such wear particles are associated with joint pain, implant loosening, device failure, and the need for revision. Moreover, it has been found to accumulate in the liver, spleen, lymph nodes, and bone marrow (Urban et al., 2000). Consideration of the reactive chemical nature of these metallic particles has led to concerns about their potential to cause hypersensitivity and osteolysis (Davies et al., 2005; Kostensalo et al., 2012; Malek et al., 2012; Langton et al., 2011; Hart et al., 2012, 2011; Catelas et al., 2011; Willert et al., 2005; Park et al., 2005; Browne et al., 2010). Moreover, the wear particles can damage bone and/or tissue surrounding the implant and joint. This is referred to as adverse local tissue reaction (ALTR) or adverse reaction to metal debris (ARMD). Recently, the presence of pseudotumors has attracted attention and caused concern (Grammatopoulos et al., 2010; Kwon et al., 2011; Williams et al., 2011; Campbell et al., 2010; Freemont, 2012; Watters et al., 2010; Counsell et al., 2008; Nich and Hamadouche, 2011; Khair et al., 2013). Aseptic lymphocytic vasculitis-associated lesions (ALVALs) are a typical example of pseudotumors and the number of reports on them has been increasing rapidly (Kwon et al., 2011; Williams et al., 2011; Campbell et al., 2010; Freemont, 2012; Watters et al., 2010; Counsell et al., 2008; Nich and Hamadouche, 2011; Khair et al., 2013). It is important to develop a test method to evaluate the wear properties of metal-on-metal bearings in detail.

A hip simulator has become an efficient tool for preclinical tests to minimize patient risk. The history of simulator development, mainly driven by research, has led to the development of many diverse designs (Kaddick and Wimmer, 2001; Affatato et al., 2008). The loading waves and angle of flexion or extension, angle of adduction or abduction, and angle of inward or outward rotation for hip simulator wear testing are specified in ISO 14242-1 (2002). It is reported that the metal insert of metal-on-metal hip bearings shows low volumetric wear rates between 0.1 and 6 mm^3 per million cycles (Goldsmith et al., 2000; Scholes et al., 2001; Firkins et al., 2001; Essner et al., 2005). The measurement of wear loss of only the insert has been frequently reported, but there are few reports on the measurement of the wear loss of the articular head. Therefore, these reported results are different from the recent tendency that has been observed in clinical cases. There are also few reports on the wear properties of metal-on-metal bearings examined using a hip simulator fabricated in accordance with ISO 14242-1.

In this study, the effects of articular head size on both the liner and articular head wear properties of a metal-on-metal bearing were examined using a hip simulator in accordance with ISO 14242-1. The findings are discussed in relation to the results of the Hertzian contact stress equation. Moreover, the wear properties of metal-on-metal and metal-on-polyethylene bearings under the same conditions were compared. To investigate the cause of adverse clinical experience, the metal concentration in the wear solution was measured.

2. Test and samples

2.1. *Test samples*

Table 1 shows the test samples used in the simulator test. Four types of metal-on-metal bearing made of Co–28Cr–6Mo alloy were used. Bearing A was made by Zimmer Inc. and consisted of a Metasul articular head (28 mm), an acetabular shell (multihole; inner diameter, 51 mm), and a Metasul insert (inner diameter, 28 mm; outer diameter, 51 mm; diametral clearance between metal head and metal insert, 100 μm). Bearing B was made by Biomet Inc. and consisted of articular heads (M2A taper; inner diameters, 28 and 32 mm), metal shells (M2A taper; universal two-hole; inner diameters, 50 and 52 mm), and metal inserts (M2A41 taper liner HC; inner diameters, 28 and 32 mm; diametral clearance, 50–150 μm). Bearing C was made by Depuy Corporation and consisted of Ultamet articular heads (28 and 36 mm), metal shells (HA coating; inner diameters, 50 and 52 mm), and metal inserts (Pinnacle; inner diameter, 28 mm; diametral clearance, 40–80 μm; outer diameter, 50 mm, and; inner diameter, 36 mm; diametral clearance, 80–120 μm; outer diameter, 52 mm). Bearing D was made by MMT Co., Ltd., and consisted of metal heads (Adept metal-on-metal modular; diameters, 44 and 48 mm) and metal shells (Adept metal-on-metal; inner diameter, 44 mm; outer diameter, 50 mm, and inner diameter, 48 mm; outer diameter, 54 mm; diametral clearance, 150–240 μm).

For comparison of wear properties between hard-on-hard and hard-on-soft bearings under the same condition, bearings consisting of the following four types of UHMWPE insert and an articular head of Co–28Cr–6Mo alloy (head diameters, all 26 mm) were used (Table 1(b)). Bearing E was made by Zimmer Inc. and consisted of an articular head (VerSys6°), a metal shell (HA/TCP Trilogy acetabular shell; multihole; inner diameter, 50 mm), and polyethylene (Longevity; elevation, 10°; liner thickness, 8.3 mm) that was cross-linked by electron beam irradiation at a dose of 100 kGy. After cross-linking, the polyethylene liner was remelted at 150 °C for 6 h and then sterilized using gas plasma. Bearing F was made by Stryker Corporation and consisted of an articular head (Osteonics Supersecure Fit head component V40), a metal shell (acetabular component multihole; outer diameter, 50 mm), and polyethylene (Crossfire; elevation, 10°; liner thickness, 8.9 mm) that was cross-linked by γ-ray irradiation with a total dose of 105 kGy (initial γ-ray radiation dose of 75 kGy followed by 30 kGy γ-ray sterilization in nitrogen). After initial cross-linking, the polyethylene liner was annealed at 120 °C. Bearing G was made by Smith & Nephew Ltd. and consisted of an articular head (universal modular head), a metal shell (Reflection Interfit multihole, eight holes; outer diameter, 52 mm), and polyethylene (Reflection XLPE; elevation, 20°;