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Metal-on-metal vs. metal-on-polyethylene total hip arthroplasty tribological evaluation of retrieved components and periprosthetic tissue

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ABSTRACT

Background and purpose: Metal-on-metal (MoM) bearings were introduced as an alternative to conventional metal-on-polyethylene (MoP) bearings to reduce the wear and to increase the survival of hip prostheses. The goal of the present study was to compare tribological properties and to evaluate periprosthetic tissue reaction in two identical groups of prostheses differing only in the type of bearings.

Patients and methods: At revision operations 26 MoM and 12 MoP bearing components and perisprosthetic tissue samples were collected. Prosthetic components were used to assess wear damage, linear and volumetric wear and roughness. Periprosthetic tissue samples were used for histological as well as immunohistochemical analysis and isolation and characterization of wear particles.

Results: The mean linear wear rate in the MoM group was 2.34 (SD 1.93) μm/year, significantly lower than the value in the MoP group, 11.52 (SD 7.82) μm/year. Significantly lower was also the volumetric wear, 0.19 (SD 0.32) mm^3/year for MoM compared to 0.98 (SD 0.78) mm^3/year for MoP. In both groups the main wear mode was abrasive wear. Histological results for MoM group indicate more lymphocyte dominated periprosthetic tissue reaction compared to MoP group. The mean size of polyethylene particles in the MoP group was 0.21 (SD 0.44) μm. In the MoM nanosized CoCrMo particles were identified. The characterization of metal particles was complex and required special attention in terms of instrumentation (field emission scanning electron microscopy in back-scattered mode); otherwise it was difficult to distinguish metal particles from other particles in the tissue.

Conclusions: Despite a significantly lower wear and, consequently, smaller load of periprosthetic tissue with wear particles in the MoM group, the tissue reaction was similar, if not more intense than in the MoP group.

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1. Introduction

Aseptic loosening resulting from polyethylene (PE) wear particles has been identified as the main reason for implant failure with conventional metal-on-polyethylene (MoP) hip arthroplasty bearings (Revell, 2008). In an attempt to address this problem, alternatives were developed. Newer generations of hard-on-hard bearings, metal-on-metal (MoM) and ceramic-on-ceramic (CoC), were evolved aiming to prolong the long-term survival of prostheses by eliminating polyethylene wear and thus lowering the volumetric wear rate (Ingham and Fisher, 2005; Zywiel et al., 2011). By the use of alternative bearings, the amount of volumetric wear was reduced; but the number of particles produced increased 100-fold (Tipper et al., 1999; Silva et al., 2005). The aseptic loosening due to wear particles was not eliminated (Goodman, 2007; Ollivere et al., 2012; Gallo et al., 2013). Moreover, these new bearings have raised new problems in foreground associated with small metal particles and their relationship to local and systemic environment. Furthermore, with increasing number of small metal particles also the surface area available for corrosion increased.

Wear metal particles originating from MoM total hip replacements are defined as nanoparticles, sizing below 100 nm (Doorn et al., 1998; Firkins et al., 2001). In contrast, the mean sizes of polyethylene particles from MoP bearings was about 500 nm, and are thus classified as microparticles (Maloney et al., 1995; Billi et al., 2012b). The mechanism of cell damage appears to be different after exposure to nano- or microparticles. Nano-sized particles could be phagocytized easier than micro-particles and can cause more mitochondrial and DNA damage (Papageorgiou et al., 2007). Furthermore, toxic and carcinogenic metals like cobalt and chromium are released from MoM bearings made of cobalt–chromium alloys (Witzleb et al., 2006; Milošev and Remškar, 2009). Metal particles and ions may spread throughout the body by blood and lymphoreticular dissemination and potentially have harmful effects on the immune system, the kidneys and the nervous system (Shea et al., 1997; Keegan et al., 2007). However, true extent of their dissemination is not yet known. Another problem is that the small size and low amounts of metal wear particles makes their characterization difficult (Milošev and Remškar, 2009).

The majority of metal and polyethylene particles are round and oval in shape (Billi et al., 2012a, 2012b). Cellular reaction to PE wear debris is dependent on the shape of the particles (Yang et al., 2002). Elongated particles generated a more active inflammatory response and stimulated more severe membrane proliferation and inflammatory cellular infiltration than globular PE particles (Yang et al., 2002). In regard to this result, determination of precise shape and chemical composition of wear particles is very important for understanding the local tissue response (Tsaousi et al., 2010; Sabokbar et al., 2003). In patients with MoM bearings an allergic hyper-reactivity and bacteriological effect of wear particles also has to be considered (Thomas et al., 2009; Hosman et al., 2010).

We have compared tribological properties and histological findings from two groups of revised components of hip prostheses that differ only in the bearing couple.

2. Materials and methods

2.1. Implant

All retrieved components were implanted at Valdoltra Orthopedic Hospital between 1997 and 2007 by senior high-volume surgeons using a direct lateral or anterolateral surgical approach. The diagnosis at first operation was osteoarthritis for all patients. Details on the operative technique and prophylaxis have been presented in our previous publications (Topolovec and Milošev, 2014; Milošev et al., 2012). Implant components were cementless. The acetabular component was Bicon-Plus cup (Plus Orthopedics, Rotkreuz, Switzerland, now Smith&Nephew Orthopedics). In the MoP group the acetabular cup consisted of a threaded shell made of commercial pure titanium and a polyethylene insert made of ultra-high-molecular-weight polyethylene (UHMWPE) according to International Organization for Standardization (ISO) standard 5834-1/2. Polyethylene, RCH-1000, was manufactured by Quadrant PHS, Deutschland GmbH, Vreden, Germany. Polyethylene was gamma-radiation sterilized (cobalt-60, dose 25 to 37 kGy) while sealed in a threefold punch in a nitrogen atmosphere. This material was not defined as cross-linked polyethylene; however, the dose (between 25 and 37 kGy) induced some cross-linking. In the MoP group the UHMWPW insert was combined with the femoral head made of stainless steel (AISI 316L, Lima, Udine, Italy). In the MoM group, the UHMWPE insert contained a metal inlay made of cobalt–chromium–molybdenum alloy (CoCrMo, Sikomet 21, low carbon Co−28Cr−6Mo) and was combined with the femoral head made of same material. In both groups the size of the femoral head was 28 mm.

The femoral component was SL-Plus stem (Plus Orthopedics, Rotkreuz, Switzerland, now Smith&Nephew Orthopedics), rectangular, dual-taper straight stem made of titanium–aluminum–niobium alloy (Ti−6Al−7Nb).

2.2. Retrievals

The study was approved by our Institutional Ethical Review Board. In the MoM group we examined 26 bearings removed from 26 patients after a median of 99 (27–163) months in situ. Time in situ was defined as the time between primary and revision operation. In the MoP group we examined 12 bearings removed from 12 patients after a median of 95 (23–135) months in situ. The groups did not differ significantly in regards to time in situ ($p=0.988$). All bearings had been removed due to aseptic loosening, either of the acetabular cup, the femoral stem or both prosthetic components.

In the MoM group there were 24 women and 2 men with a median age at revision of 68 (56–81) years. In MoP group there were 8 women and 4 men with a median age at revision of 74 (57–85) years. The groups differed significantly in regard to age at revision operation ($p=0.006$). We have also checked the clinical outcome using adopted UCLA activity score (Amstutz et al., 1984; Milošev Levašič). 24 patients in the MoM group and 10 patients in the MoP group responded to our questionnaire. The median UCLA activity score was 3.5 (1–9) for the MoM group and 4 (1–8) for the MoP group. The difference