The Mechanisms of Debris Formation in Metal-on-Metal Hip Joints

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Early trials with metal-on-metal (MOM) hip implants failed due to poor design, high friction values as well as carcinogenic tissue reactions which together with the successful start of the Charnley metal-on-polymer prostheses led to their renunciation in the 70s [1]. However, low wear values in the regime of 2 – 20 µm/a and fairly low friction values (µ = 0,12 – 0,25) from improved prosthesis brought up a renaissance of metallic hard-hard bearings around 1988 [2,3]. Although the wear rates for MOM pairs are known to be lower when compared to combinations with polymer, wear particles are still generated due to the continuous sliding of the articulating surfaces. For implants made from cobaltbase alloys (CoCr29Mo6) the literature gives a variety of particle sizes found in-vivo but most authors assume a mean particle size far below 250 nm, most in the range of 50 nm [4,5]. Unfortunately, reasons for the generation of particles of this size were never explained.

In the present study, a disc-on-pin wear test was performed on a commercially available cobaltbase alloy CoCr29Mo6 with a low carbon content (LC). All tests were conducted in Ringer´s solution under self-mating conditions with a sliding speed of 0,1 m/s. Hertzian theory leads to a nominal contact pressure of 370 MPa, which is significantly higher when compared to in-vivo conditions, where pressures are in the range of 40 MPa. Nevertheless, the goal of this study was to show the feasibility to mimic in-vivo wear mechanisms with a simple in-vitro wear test. Therefore, transmission electron microscopy (TEM) was carried out on disc-on-pin samples as well as on samples from explanted MOM prostheses. For investigation of the plastically deformed subsurface of the metals, preparation of the TEM specimen was crucial. Hence, a novel technique was applied which enables the preparation of subsurface cross-sections without generating any artefacts. Observation of the samples was done using an accelerating voltage of 120 keV. Dark field imaging in combination with diffraction pattern helped to identify phases. Complementary to the TEM work, worn surfaces were studied with a scanning electron microscope (SEM) and collected debris from the wear test was compared with particles found in-vitro.

The SEM results clearly show that the acting wear mechanisms in-vivo and in-vitro are comparable. Both, abrasion as well as tribochemical reaction can be found on the worn surfaces. However, only transmission of the worn subsurface brings about a clear insight on the mechanisms of particle generation in MOM hip implants since the metallurgical processes beneath the surface have a distinct impact on the wear mechanisms and directly control the particle size, respectively. With the novel TEM preparation technique it becomes possible, for the first time, to understand the origins of nanosize debris formation which is generated in metallic hip replacements and directly responsible for detrimental tissue reactions.

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