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Subsurface micro-structural changes below different contact zones of MoM hip implants

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Metal-on-metal hip arthroplasties have several limitations including the release of toxic metal particles and ions. It is necessary to minimize this release in order to avoid harm to the human body.

To evaluate the wear behaviour of metal-on-metal hip replacements it is essential to understand the micro-structural changes in the sub-surface region. Previous studies revealed that cobalt chromium metal-on-metal implants are able to change their mechanical behaviour to adjust to load. The reason for this is the mechanical mixing. This means that a nano-crystal layer is formed by rotating clusters of atoms that incorporate denatured proteins from the interfacial medium. This is followed by a layer of rhombic shaped nano-crystals in between sheared ε-martensite lathes, twins, and stacking faults [1]. Although the primary wear zone has been well characterized, the sub-surface structure of the stripe wear and the non-contact zone of the hip ball have yet to be analysed.

For this study a 28-mm cobalt chromium alloy (ASTM F1537) femoral head and acetabular cup (DePuy International, Leeds, UK) were analysed. The implant was simulator tested for 5 million cycles with the application of micro-separation resulting in a clearly visible stripe wear appearance [2].

In order to visualize the sub-surface microstructure a transmission electron microscope (TEM) was used. Specimens were taken from primary, stripe, and non-contact zone. Two different methods of sample preparation were used for each zone. A special sample preparation of the surface cross section was necessary. Specimen slices of 400µm thickness were thinned by dimple grinding and ion milling. The final thickness of the specimen center was 40 nm. Furthermore, specimens of same thickness were made by using a focused ion beam (FIB).

The TEM micrograph of the primary wear zone of the ball confirmed the presence of a sub-surface layer of nano-crystals. The depth of this layer was 200nm and the grain diameter approximately 35-40 nm. A layer of orientated ε-martensite was found below the first layer. The diffraction pattern of this region confirmed the occurrence of nano-crystals. In the stripe wear zone the micrograph revealed a nano-crystal layer under the surface with a thickness of only 50nm and a grain diameter of 15-20nm. There was ε-martensite region in the shape of a saw blade beneath this first layer. With Energy Dispersive X-ray Analysis (EDX) the distribution of chemical elements was measured in the nano-crystal layer. The carbon and oxygen content was highest closest to the surface which proves the occurrence of mechanical mixing. It was necessary to validate that the observed nano-structure was a result of wear and not of the manufacturing process. Therefore, the non-contact zone of the ball was analysed. When compared to the stripe wear zone a nano-crystal layer with similar thickness but smaller grain diameter (<15nm) was observed. The ε-martensite layer below was randomly oriented.

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