Hip Resurfacings - How Well Do We Know Cast CoCrMo Alloys?

Introduction Today hip resurfacing (HR) arthroplasty is considered a favorable option for more active and younger patients. Even though HRs exhibit great clinical results, there is still concern about the emission of large amounts of wear particles and metal ions to the proprosthetic tissue, resulting in the formation of pseudotumors in some patients [1].

Therefore, a reduction of wear is desired. The alloy microstructure has been so far not considered as an important factor. Most manufacturers use cast alloy with high carbon (hc) content. Differences are mostly related to the applied heat treatment. Today as-cast, hot isostatically pressed (HIP) and solution annealed (SA) components are commonly used as well as the double heat treatment (HIP + SA). In literature there is no general agreement about the influence of heat treatment on clinical performance [2].

Methods The microstructure of HR retrievals from four different manufacturers where analyzed (M1-M4). All retrievals were made from hc CoCrMo cast alloy. The applied heat treatment differed: two retrievals had the as-cast condition (M1 and M2), one underwent a double heat treatment (M3) and one was hot isostatically pressed (M4). Additionally, a total hip replacement with large head configuration was viewed made by manufacturer 4. All samples were implanted for 600-800 days and had a head diameter of 44 or 46 mm. As reference a McKee-Farrar prosthesis made from low carbon CoCrMo cast alloy was analyzed. The time in-situ was 14 years and the diameter was 42 mm.

The subsurface microstructure was analyzed by means of scanning electron microscopy (SEM) with the application of energy-dispersive x-ray spectroscopy (EDS). For hardness measurements within different phases a nanodentener was used.

Fig. 1 large blocky hard phases within HR of M1 (l.) and fractures within these phases in the subsurface area (r.).

Fig. 2 hard phase within HR of M3 (l.) mixture of different phases (r.)

Results The microstructure of the HRs of the manufacturers 1, 2 and 4 exhibited large blocky phases (fig. 1). Hardness measurements showed a high hardness which, however, was significantly lower than that of Mo,Cr carbide. These hard phases exhibited large fractures when located in the subsurface region (<50 μm) indicating a high brittleness. Using the backscatter electron imaging mode at high magnification it was shown that this phase was a mixture of three different phases: dark phase (Cr,C), grey phase (Co,Cr), and bright phase (Mo,Co,Cr) (fig. 2). Particles detached from that mix-phase have a size of 5-15 μm leaving large pits (fig. 3 l.). The micro-structure of the McKee-Farrar prosthesis exhibited a comparably small fraction of hard phases which was confirmed to be Mo,Cr carbides by electron diffraction pattern analysis (fig. 3 r.).

Interestingly, the alloy of the large head THR by M4 exhibited a different microstructure than observed for the HR of the same manufacturer. Cr- and Mo-carbides were located along the grain boundaries (fig. 4 l.). Hard phases were also observed along grain boundaries of HR-M3. Even though its chemical composition was similar to chromium carbides it appeared much more brittle (fig. 4 r.).

Discussion Within the microstructure of three manufacturers (two as-cast, one HIP) hard blocky phases were observed which were claimed to be carbides. This study has shown that these phases actually are mixed phases of small carbides and at least two different intermetallic phases.

The hardness of this phase is significantly lower as it is the case for carbides. Within the subsurface region (<50μm) these mix-phases appear unable to accommodate the occurring strain and fractures. Thus, large particles detach and introduce third-body wear to the system. An increase of hard particles would lead to the disruption of the beneficial metallo-organic tribo layer earlier described by Wimmer et al [3]. An increase of wear rate may not be detected since wear debris is partially entraped in surface pits of former the mix-phase. Further, concern is related to the nature of wear debris emitted from the mix-phase. Electron diffraction pattern analysis suggests that it includes sigma-phase (Cr,Co,Mo). The immune reactions to nano-particles from these fairly inert phases are yet unknown and might differ from reactions to chromium oxide, CoCrMo alloy or carbides. Besides tribological concerns the mechanical properties of these alloys are suspected to be significantly lower than for alloys with actual carbides. Even though, the McKee-Farrar prosthesis was also made from as-cast alloy it did exhibit carbides and no intermetallic mix-phase. The same is true for the large head THR component by manufacturer M4. The authors assume that the occurrence of mixed phases is mainly linked to an insufficiently controlled cooling process of the cast which also strongly depends on the implant design. Hard phases along the grain boundary of the double heat treated component (M3) could not be exactly identified. Due to its apparently highly brittle nature the presence of carbide phase has to be doubted.

This study has shown that CoCrMo alloy used for HR exhibits microstructures and intermetallic phases which are not sufficiently considered in literature and may have a negative implication on clinical performance.

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References