Guest editorial

Metal release mechanisms in hip replacement

Adverse health effects induced by metal ions released from biomedical devices in the human body are one reason for failure of an implant system. In this issue of Acta Orthopaedica, two publications address this issue dealing with Co-Cr-Mo-based hip replacements. The studies complement each other: Steens et al. (2006) report on a patient with severe Co ion poisoning, leading to—amongst other things—blindness, after an unsuitable revision operation that caused extensive wear of the metal femoral head in a ceramic cup. This is a "worst-case" scenario with a clear message: combination of materials in implants must be done with care! The other publication, by Witzleb et al. (2006), compares the release rates of metal ions in two implant design systems: total hip replacement and hip resurfacing arthroplasty. The necessity of taking into account not only the materials used but also the design of the implant system in predicting system performance is clearly illustrated by these two articles.

The release of metal ions from metallic implant materials is influenced by chemical, biological and mechanical factors. From the corrosion point of view, Co-28Cr-6Mo implant alloys (similarly to all materials used in the human body) show a relatively high resistance to dissolution, due to the spontaneous formation of a highly protective passive film on the alloy surface. However, as in all cases of passive metals, damage to the passive film by either chemical or mechanical means increases the release of metal ions to the surroundings. In hip implants, micromotion leads to continuous mechanical activation of the surface (i.e. removal of the protective passive film)—typically followed by a fast repassivation reaction. Regarding metal ion release into the surroundings, it is not only the generation of wear debris that is crucial, but also the electrochemical behavior of the alloy and its constituents during the repassivation process. Considering the electrochemistry of the Co-Cr-Mo alloy and of the alloying elements themselves, it becomes clear that not only the intensity of metal dissolution, but also the dissolution mode, can vary in different kinds of surroundings. For instance, under the chemical conditions usually prevailing in the body, no stable Co oxides exist and thus formation of soluble Co species instead of solid Co oxides is favored. On the other hand, Cr(III) oxides are very stable, and therefore substantial dissolution of Cr (of solely electrochemical origin) can be expected to happen only under sufficiently high oxidizing conditions, in the electrochemical stability region of soluble Cr(VI) species. Taking both of these factors into consideration, selective dissolution of Co from a Co-Cr-Mo alloy can be expected (and has been observed under laboratory conditions) during activation/repassivation cycles. The electrochemical conditions that prevail can thus influence the concentration and the chemical speciation of the released alloying elements, the latter also being of importance for subsequent biological reactions. In the worst case, the disturbance of the biological equilibria by release of metal species may be such that metal dissolution rates are further increased as a result. In such a case, an autocatalytic failure mode would be observed.

To obtain an in-depth understanding of the critical factors and mechanisms at play, the different parameters influencing material degradation and hence metal ion release should be studied systematically. In the laboratory, a materials scientist would carry out experiments using a high number of well-defined samples under controlled electrochemical, chemical and mechanical conditions, and various types of analysis of materials, solutions

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and surfaces would be undertaken. Clearly, such an approach is more difficult in in vivo studies. However, in vitro experiments inherently lack a direct correlation with the real case, as any reasonable simulation of the in vivo conditions is difficult. For example, the interactions between different species of biomolecules and metal surfaces are quite complex and may differ for each system. It can be shown easily that metal surface reactions depend on the types of simulated body fluids used. However, understanding of interactions between metals and biological molecules in detail is a different story. A basic understanding of the most critical factors, however, is a prerequisite for the design of reasonable in vitro experiments.

Returning to the publications in the present issue, the reader may question the origin of the different metal release rates in the different types of hip replacements. As the authors conclude, the findings may have different explanations. Since the metal ion release results from tribocorrosion, the biomechanical situation of the different types of implant designs must be analyzed and compared. On the other hand, the material itself—and especially its surface—play a critical role in the mode of metal ion release. As the condition of the material may be different in different designs, it cannot be directly concluded that the design itself has led to the observed increase in metal release.

In conclusion, it is generally recognized today that metal ion release from implants is an important factor in determining the success or failure of the system. However, we lack detailed mechanistic understanding of the complex reactions involved. To improve this understanding, true collaboration between researchers in the relevant fields of science is required.

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