

Understanding physiological magnesium corrosion – an *in vitro* approach

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INTRODUCTION: Biodegradable metals like iron or magnesium are promising candidates for implants. They are just temporarily needed to mechanically support the healing process of the injured or pathological tissue. In this context, Mg alloys for biomedical applications have gained new interest during the last decade. First applications as degradable stents have been evaluated and are already clinically used. In contrast to corrosion resistant metals the designated complete degradation or corrosion of magnesium alloys in a host specific manner is the major challenge. In addition the *in vivo* condition is a dynamic and very complex environment which is difficult to reproduce *in vitro*. This fact is of utmost importance since *in vitro* and *in vivo* observations produce in many cases contradicting results.

The current aim of our research is a thorough comprehension of the mechanisms and prediction of magnesium corrosion by using complex *in vitro* approaches which should simulate *in vivo* conditions.

METHODS: Pure magnesium (99.99%), Mg₄Y₂Nd_{0.5}Gd_{0.5}Dy (WE43-X) and Mg₁₀Gd₁Nd (E11) alloys were produced by permanent mould casting under protective gas Ar-0.3% SF₆. Samples of 5 mm diameter were produced by electrical discharge machining.

All immersion experiments were performed under cell culture environment (37°C, 21% O₂, 5% CO₂, 95% rH). Due to the low weight of the samples (~0.05 g) the osmolality measurements were performed in 1 mL of the respective solution (amount of metal 4x lower than required by standard procedures). As media Hank's balanced salt solution (HBSS) and Dulbecco's modified eagle medium Glutamax-I (DMEM), both containing 10% FBS were used. pH changes were monitored online using a 24-channel SDR SensorDish Reader in 24-well plates with integrated pH-electrodes (PreSens GmbH). The osmolality of the solutions was measured using a cryoscopic osmometer (Gonotec) and element release was determined by ICP-OES. Additionally the influence of oxygen content during corrosion was analysed. Examination of the corrosion layer was performed by XPS, and element analysis by atom probe experiments were performed on water free polished surfaces for samples incubated in HBSS and DMEM (with and without FBS).

RESULTS: HBSS showed a higher corrosion potential than DMEM. Without proteins the pH in the vicinity of the samples was raised above 9 and the mean of the calculated osmolality was 51 mM for pure Mg, 52 mM for WE43 and 63 mM for E11. With proteins both parameters were decreased.

The element release during corrosion was not uniform. Determined by ICP-OES an initial release of magnesium was prevalent, the release of other alloying elements was delayed. This feature is modulated under the influence of proteins. The amount of oxygen in solution was decreased drastically by magnesium corrosion. However, oxygen did not alter the speed of corrosion.

The element distribution at the surface of the specimen is significantly altered under the influence of proteins. Moreover, due to cell culture conditions additional corrosion products were found next to the common Mg(OH)₂. This was predominantly MgCO₃, and for HBSS also Mg(PO)₄. When proteins are present the corrosion layer is significantly altered.

DISCUSSION & CONCLUSIONS: The speed of magnesium corrosion is influenced by the composition of the corrosion medium and explicitly by proteins. The corrosion rate can be altered significantly depending on the treatment of the specimen. The ultimate goal is the establishment of a reproducible *in vitro* testing system which can be correlated to *in vivo* results.