In-vivo corrosion rates of magnesium alloys determined by synchrotron-radiation based microtomography (SRµCT)

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The in-vivo corrosion of magnesium alloys can be used as a new mechanism allowing *degradable* metal-implants to be applied in muscoloskeletal surgery [1]. This would particularly be true if magnesium alloys with a predictable corrosion rate could be developed. Therefore, the in-vivo corrosion rate has to be investigated. In this approach we used absorption-contrast microtomography (µCT) to determine corrosion rates calculated from implant volume reduction during the implantation period (Figure 1). By using monochromatic synchrotron radiation a spatial resolution of a few micrometers and a high density resolution can be achieved.

Synchrotron-radiation based microtomography (SRµCT) is an excellent non-destructive method for displaying specimens with a high spatial resolution. Synchrotron sources are ideal for this tomography, since they provide a monochromatic, parallel beam with high intensity. Absorption tomography produces 3-D images of the linear X-ray attenuation coefficient μ_l which contains information about the chemical composition of each voxel. Therefore, the corrosion products compared to the metallic bulk material can be displayed in different attenuation values and can therefore be distinguish form the bulk material at various photon energies (Figure 2).

Different magnesium alloys were implanted into the femura of guinea pigs. After 18 weeks the femura were explanted and fixated in buffered formalin. At beamline HARWI I (W2) the specimens were imaged by attenuation microtomography using photon energy of 31 keV. Exposed to the parallel X-ray beam, the sample was precisely rotated stepwise 0.25° in the angular range 0-180°. After each step the absorption image was recorde. The specimens were investigated in five different positions of the z-axis to obtain a high spatial resolution. Further these separately reconstructed data were finally stacked to form an entire data set. The voxel edge size of the data set was equal to 10 µm. The residual implant volume (Figure 3) was analysed using VDStudio Max 1.2® Software (Volume Graphics GmbH, Germany). After segmentation of the gray values followed by a 3D region growing method the remaining metallic magnesium alloy was separated from the surrounding bone matrix and the corrosion layer.

Thus, the remaining non-corroded sample volume as well as the sample surface was determined in three dimensions non-destructively on a micrometer scale. Assuming a homogeneous magnesium alloy, the reduction of the implant volume could be converted into a corrosion rate by using a modification of the ASTM standard equation for weight loss, where the weight loss (W) is substituted by the reduction in volume (ΔV) multiplied by the standard density (ρ) resulting in

$$CR = \frac{\Delta V}{A \cdot t} \qquad \text{(Eq. 1)}$$

,where CR is the corrosion rate (mm/year), ΔV is the reduction in volume that is equal to the remaining metal volume subtracted from the initial implant volume, A is the implant surface area exposed to corrosion and t is the exposure time in hours.

It has been shown that synchrotron-radiation based microtomography in attenuation mode can be used as a fully three-dimensional, non-destructive technique for non-destructive local corrosion measurements on a micrometer scale [2]. This new approach to local corrosion measurements has to be evaluated in more details and compared to other local corrosion techniques.

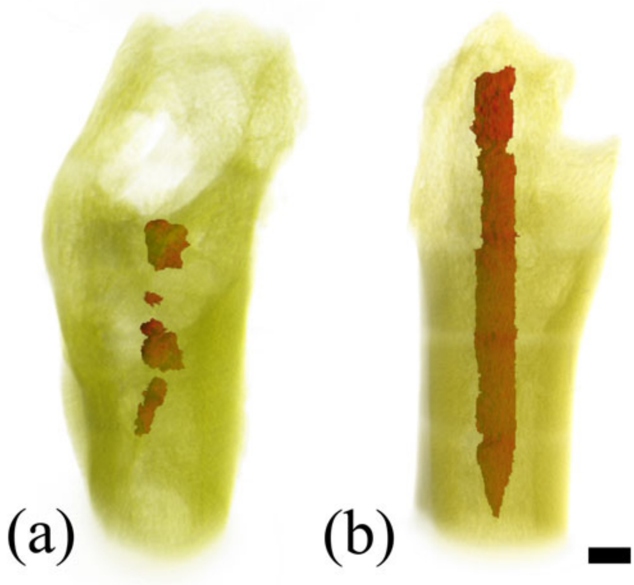

Figure 1: 3D reconstruction of remaining magnesium alloy (red) segmented from the bone matrix (brown) by region growing method [2]. (a) shows corroding magnesium alloy AZ91 after 18 weeks of implantation; (b) shows the magnesium alloy LAE442 after 18 weeks of implantation. Bar = 1.5 mm.

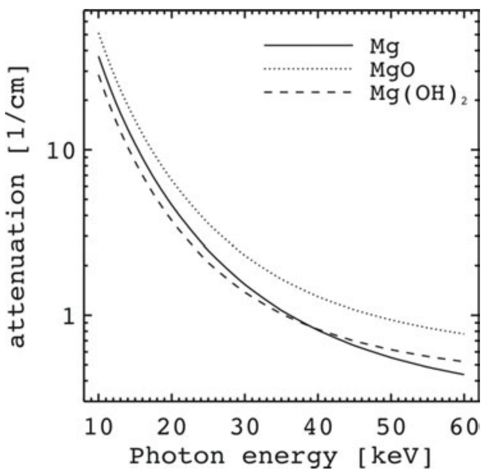

Figure 2: Attenuation of pure magnesium and its corrosion products.

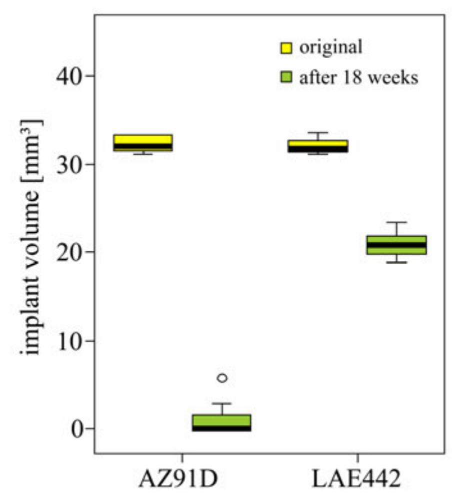

Figure 3: Reduction in implant volume after 6 and 18 weeks of implantation determined by SRμCT [2].

References

[1] F.Witte, V.Kaese, H.Haferkamp, A.Meyer-Lindenberg, E.Switzer, H.Windhagen, Biomaterials **26**, 3557 (2005)

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