INTRODUCTION:
The in-vivo corrosion of magnesium alloys has the potential to provide a new mechanism which would allow degradable metal implants to be applied in musculoskeletal surgery [1]. This would particularly be true if magnesium alloys with predictable in-vivo corrosion rates could be developed. Since the magnesium corrosion process depends on the corrosive environment, the corrosion rates of magnesium alloys under standard in-vitro environmental conditions are not directly comparable to results of corrosion rates obtained from an animal model. However, synchrotron-radiation based microtomography (SRµCT) is an accurate non-destructive method to evaluate materials and bone in the micrometer range [2]. Since there is no established non-destructive method for measuring in-vivo corrosion, we asked the research question whether or not SRµCT can be used for in-vivo corrosion measurements of magnesium alloys.

METHODS:
Two gravity cast magnesium alloys (AZ91D, LAE442) were used in this study. Standardized immersion and electrochemical tests according to ASTM standards were performed. The in-vivo corrosion tests were carried out by intramedullary implantation of magnesium alloy rods into guinea pig femur. Animal studies were performed according to a governmental approved protocol. Following fixation in paraformaldehyde, the specimens were scanned in a microtomography device utilizing synchrotron radiation at the Hamburger Synchrotronstrahlungslabor HASYLAB at Deutsches Elektronen-Synchrotron DESY (Fig. 1). At beamline W2, the specimens were imaged by attenuation microtomography using a 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 recorded [3]. The specimens were investigated in five different positions of the z-axis to obtain a high spatial resolution. Further, these separately reconstructed datasets were finally stacked to form an entire dataset. The voxel edge size of the tomogram was 10 µm. The residual implant volume was analyzed using VGStudio Max 1.2® software. Absorption tomography produces 3-D images of the linear X-ray attenuation coefficient \( \mu \). The attenuation of the X-rays passing through a material can be described using the equation

\[
I = I_0 e^{-\mu d}
\]

(Eq. 1)

where \( I_0 \) is the energy of the incident X-ray beam, \( I \) is the energy of the exitation beam, \( \mu \) is the linear attenuation coefficient of the material for a certain photon energy, and \( d \) is the sample thickness. Because \( \mu \) depends strongly on the atomic number, it contains information about the chemical composition of each voxel. This fact is considered in distinguishing between the remaining metallic magnesium alloy and the corrosion layer (Fig. 2). The corrosion products have different attenuation coefficients that can be distinguished by SRµCT (Fig. 2). 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 [4], where the weight loss (\( W \)) is substituted by the reduction in volume (\( \Delta V \)) multiplied by the standard density (\( \rho \)) resulting in

\[
CR = \frac{\Delta V}{A \cdot t}
\]

(Eq. 2)

where \( CR \) is the corrosion rate, \( \Delta V \) 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.

RESULTS:
SRµCT could be used to determine in-vivo corrosion of magnesium alloys in guinea pig femur (Fig. 3). We found that in-vivo corrosion was about four orders of magnitude lower than in-vitro corrosion of the tested alloys (Table 1). Furthermore, the tendency of the corrosion rates obtained from in vitro corrosion tests were in the opposite direction as those obtained from the in vivo study.

DISCUSSION:
Synchrotron-radiation based microtomography (SRµCT) is an excellent non-destructive method for displaying in-vivo corrosion with a high spatial resolution. Synchrotron sources are ideal for this method, since they provide a monochromatic, parallel beam with a high intensity. The results of this study suggest, that the conclusions drawn from in-vitro corrosion tests can not be used to predict in-vivo corrosion rates of the same magnesium alloys. Therefore, the use of SRµCT for measuring in-vivo corrosion is a valuable tool for further studies on magnesium alloys as a biomaterial.