Characterization of Degradable Magnesium Alloys as Orthopaedic Implant Material by Synchrotron-Radiation-Based Microtomography

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Magnesium alloys represent a new class of degradable implant materials in orthopaedic surgery with a high primary stability. These alloys provide a 3-fold higher tensile yield strength and a 4-fold higher E-modulus compared to current implants made of degradable polymeric materials as PLLA [1,2]. Furthermore, in comparison to current metallic implant materials such as titanium or stainless steel magnesium alloys provide mechanical parameters which are more isoelastic to bone (fig.1). Therefore, magnesium alloys represent a more suitable material for bone-implant contact. Due to their magnetic properties and rare earth components magnesium alloys are visible in magnetic resonance and computer tomography without artifacts, which are seen in current metallic implant materials. Degradable polymers, however, are not visible in radiographs [1].

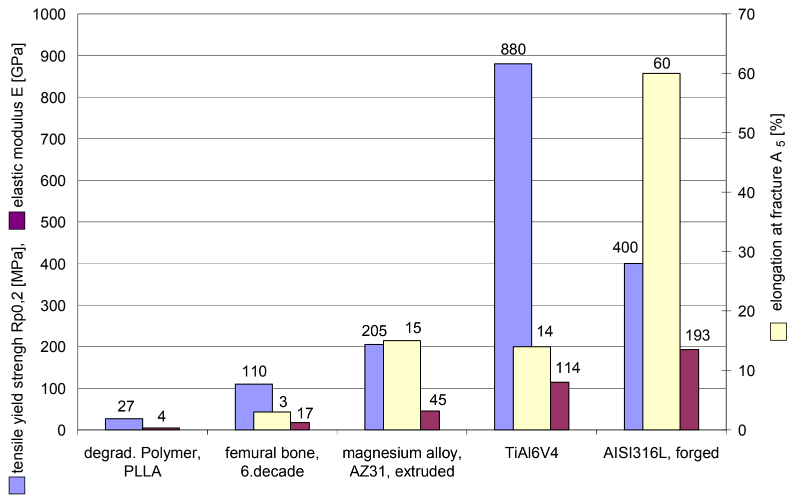

Figure 1: Mechanical properties of implant materials

In order to assess whether these alloys are degradable in bone, pins of 1.5 x 20 mm of different magnesium alloys were manufactured and implanted in both femura of guinea pigs. Postoperatively radiographs of the guinea pigs femura were taken regularly. The bone specimens were harvested 6 and 18 weeks postoperatively. Radiographs were graded for radiographically visible pin corrosion. Unfortunately, it is difficult to determine the degradation at advanced pin corrosion on plane radiographs (fig.2). Therefore, synchrotron-radiation-based microtomography (XTM) was used to characterize the degradation process of magnesium alloys (fig.3).

The XTM measurements were carried out at beamline BW2 using a photon energy of 24.0 keV. The projection data contain radioscopic images consisting of 1536x692 pixels with a magnification of 2.17 acquired at 720 rotation angles for one sample. The observation area was kept to the center of the bone specimen. Two- and three-dimensional reconstructions were performed by projection data, which were acquired 11.4 mm distal from the most proximal point of the trochanter major (fig.3, fig.4). These detailed reconstutions allowed morphologic characterization of bone-implant interaction.

Figure 2: plane radiograph of a guinea pig femur, 18 weeks after pin implantation

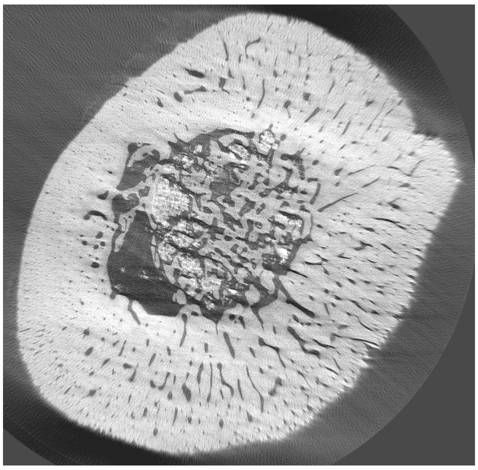

Figure 3: 2D transversal reconstruction of femur (fig.2) 11.4 mm distal from the most proximal point of the trochanter major

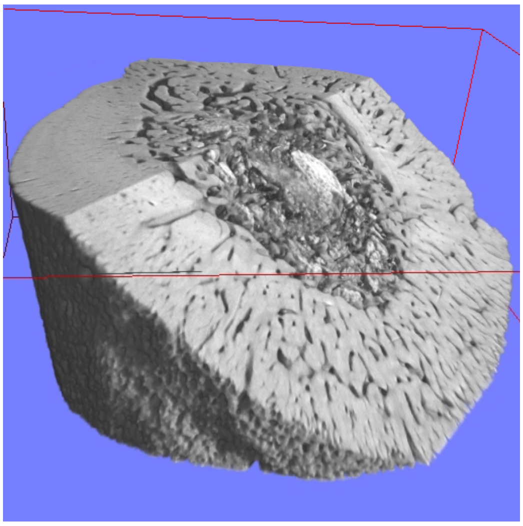

Figure 4: 3D reconstruction of same femur as in fig.2, 18 weeks after implantation

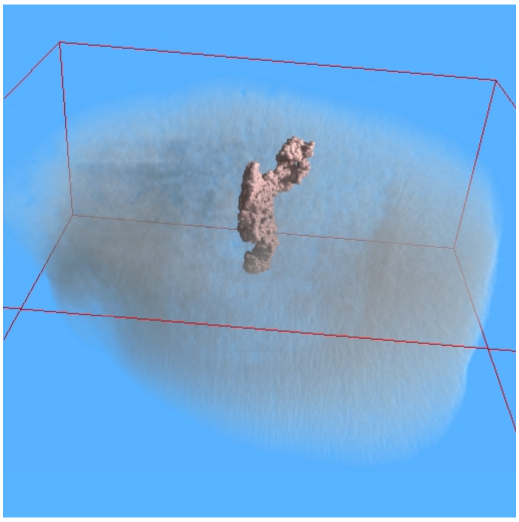

Figure 5: region growing of residual magnesium alloy, same bone specimen as in fig.4

Magnesium alloys are almost completely degraded 18 weeks after implantation. Small amounts of magnesium alloys are detectable with XTM while new bone formation cannot be differentiated from magnesium residuals in plane radiographs (fig.2). New cortical bone formation can be seen during the degradation process (fig.4, right side of cortical bone). There is a radial structure in this new bone formation which is different from original cortical bone (fig.4, left side of cortical bone). Magnesium implants are in direct bone contact and the degraded magnesium pins are replaced by endostal bone formation (fig.3). The residual implant volume can be measured by voxel-growing analysis (fig.5).

From the results of this study there is a strong rationale that magnesium alloys are replaced by new bone formation during degradation. Additional cortical bone formation appears while degradation progresses. Since orthopaedic implants for bone, tendon and ligament fixation have to maintain their stabilization properties over at least 12 weeks, magnesium alloys may represent an ideal alloy for future application in orthopaedic implants. However, besides material research further issues regarding safety and efficacy must be addressed.

References

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