Magnesium as a biomaterial and its biological interactions

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Abstract: To investigate different magnesium alloys as a biodegradable material for implants it is necessary to understand the degradation process in the biological environment. The following study shows interactions of pure magnesium with various physical and chemical environmental parameters according to the parameters within the application area.

Keywords: Mg degradation, implant, biomaterial, in vitro

Introduction

Magnesium is studied as bio corroding implant material. The in-vitro degradation shows different kinetics compared to the degradation in vivo. Daters published in literature are not comparable because of different degradation systems and measuring parameters. The aim of this study is to describe the interactions and the behaviour of pure magnesium in different fluid systems and under different physical conditions. Thus we would like to be able to predict the in vivo corrosion with in vitro data.

Methods

Literature data show different model fluids to simulate the in vivo degradation system in vitro. As a result, the degradation kinetics cannot be compared because of different components in the fluids that have an impact on the corrosion process. Fig 1 shows the model fluids described in literature used for in vitro degradation studies.

A new dynamic in vitro test device as shown in figure 2 has been designed to investigate the influence of physical flow conditions on the degradation process. This system is able to mimic different flow characteristic such as pulsatile flow with different flow rates.

Table 1: Ionic composition of the model fluids

<table>
<thead>
<tr>
<th>[mMol/l]</th>
<th>serum</th>
<th>NaCl</th>
<th>c-SBF</th>
<th>r-SBF</th>
<th>m-SBF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>142</td>
<td>153</td>
<td>142</td>
<td>142</td>
<td>142</td>
</tr>
<tr>
<td>K</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Mg</td>
<td>1,5</td>
<td>1,5</td>
<td>1,5</td>
<td>1,5</td>
<td>1,5</td>
</tr>
<tr>
<td>Ca</td>
<td>2,5</td>
<td>2,5</td>
<td>2,5</td>
<td>2,5</td>
<td>2,5</td>
</tr>
<tr>
<td>Cl</td>
<td>103</td>
<td>153</td>
<td>147,8</td>
<td>103</td>
<td>103</td>
</tr>
<tr>
<td>HCO3</td>
<td>27</td>
<td>4,2</td>
<td>27</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>HPO4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>SO4</td>
<td>0,5</td>
<td>0,5</td>
<td>0,5</td>
<td>0,5</td>
<td></td>
</tr>
</tbody>
</table>

A new dynamic in vitro test device as shown in figure 2 has been designed to investigate the influence of physical flow conditions on the degradation process. This system is able to mimic different flow characteristic such as pulsatile flow with different flow rates.

Table 2: ICP-OES contaminations of the Mg samples

<table>
<thead>
<tr>
<th>element</th>
<th>amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>0,7 [µg/l]</td>
</tr>
<tr>
<td>Ni</td>
<td>- [mg/l]</td>
</tr>
<tr>
<td>Cu</td>
<td>- [mg/l]</td>
</tr>
<tr>
<td>Mn</td>
<td>0,012 [mg/l]</td>
</tr>
</tbody>
</table>

Within the second study, the Mg samples were located in flow direction in the middle of the test chamber. Thus, the model fluid flow was directed against the thin site of the sample (Figure 2). The samples were exposed to saline at flow...
velocities of 1,3mm/s, 3,3mm/s and 6,6mm/s respectively. Weight loss and concentration of Mg\(^{2+}\) in the solution were measured to characterise the rate of degradation.

**Results**

The degradation rate depends directly on the composition of the model fluid which is used in the degradation test. Figure 2 shows the results of the degradation process in four different fluids. The data illustrate that only by changing the fluid, the rate of degradation changes.

In the case of c- and r SBF; these solutions only differ in the amount of chloride and HCO\(_3^-\), the degradation of c-SBF is three times faster than that of r-SBF. The low rate of degradation in NaCl solution is due to pH change. The same test is performed with CO\(_2\) control to stabilize the buffer stability and thus keep the pH value constant. In this study we also investigated porcine blood serum as a model fluid. Figure 4 shows that the degradation rate increases only by gassing the fluid with CO\(_2\). This results in a stable pH value over the test period.

Porcine serum lead to the lowest degradation rate within our study. With respect to the ion composition of r-SBF there is no difference between these two solutions. The influencing factor of this solution seems to be the amount of proteins. Figure 4 exemplarily depicts an EDX spectrum of a magnesium sample in serum. The spectrum of this serum immersed Mg in comparison to r-SBF Mg shows a high amount of carbon on the sample surface. This C-signal is an indication of a protein layer formation on the sample surface which has a passivation effect on the Mg. The EDX spectrum of r-SBF Mg also reveals a small C-peak, but is related to the sample fabrication process. The dynamic corrosion study shows an increased corrosion by increasing the test fluid velocity (Figure 6). Pitting corrosion is found in the area with a direct exposure to the fluid flow as depicted in figure 7.

**Discussion**

The study shows the importance of knowing the influence of the chosen model fluid on the degradation process. To be able to compare experimental data, we need to know the exact composition of the degradation fluids used in different studies. Furthermore, the data shown in this study demonstrate the possibility to design in vitro studies that resemble the in vivo situation by choosing the appropriate degradation fluid and physical parameters. Dynamic flow models seem to be superior to just static incubation tests. The degradation of magnesium in protein containing solutions revealed a slower and decreased degradation process. The primary reason for that seems to be the formation of a protein layer on the surface of the sample. In further studies the mechanism of the degradation protection by the protein layer will be investigated; one aspect will be to find out the kind of protein with highest impact on the protection.

**Acknowledgement**

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