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INFLUENCE OF HEAT TREATMENT ON THE DEGRADATION BEHAVIOUR OF DEGRADABLE MAGNESIUM BASED IMPLANTS

K. Bracht[1], N. Angrisani[1], J. Seitz[2], S. Besdo[3], J. Reifenrath[1]

[1]Small Animal Clinic, University of Veterinary Medicine Hannover, Germany
[2]Institute of Material Science, Leibniz University Hannover, Germany
[3]Institute of Continuum Mechanics, Leibniz University Hannover, Germany

katja.sabine.bracht@tiho-hannover.de

Abstract: *Aim of the study was to characterise the influence of heat treatment on the degradation behaviour and stability of degradable magnesium based implants. For this purpose two groups (untreated/ heat treated) of LAE442 pins were separately analysed in an in vitro and in vivo study. The corrosion behaviour was evaluated during 8 weeks degradation in SBF (in vitro) and 48 weeks degradation intramedullary in the rabbit tibia (in vivo). The analyses were made by using µ-computed tomography and three-point-bending tests. Heat treatment led to altered mechanical and corrosion properties of LAE442.While the initial stability declined significantly a reduction of the degradation rate over either in vitro and in vivo evaluation period is determined. If these alterations are still reasonable for osteosynthesis implants remains to be investigated in further projects.*

Keywords: *in vitro, in vivo, heat treatment, degradable, magnesium implant*

Introduction

Degradable magnesium based implants were in the main focus in a lot of research projects. Their favourable properties are the good biocompatibility and - in comparison to conventional materials like titanium or steel - mechanical characteristics close to the natural bone. A further benefit is an avoided second surgery which implies additional medical risks and financial investments. In studies concerning magnesium implants, in general a correlation between degradation rate and biocompatibility could be found. Previous studies (e.g. [1]) mainly deal with LAE 442 due to its preferable slow degradation rate and osteointegrative properties. Zhou et al. reported on an increased corrosion resistance caused by T6 heat treatment of the magnesium alloy AZ91D [2]. Therefore, aim of this study was to examine the influence of heat treatment on the preferred magnesium alloy LAE 442 in an in vitro and in vivo model with focus on µCT and three-point-bending tests.

Methods

Extruded cylindrical implants (n = 52, Ø 2,5 mm; 25 mm length) of LAE 442 (approx. 90 wt% magnesium, 4 wt% lithium, 4 wt% aluminium and 2 wt% rare earth) were produced at the Institute of Material Science (Leibniz University Hannover, Germany) according to previously published studies [3]. Half of the implants were additionally heat treated in an oven (T5 heat treatment, 205°C, 16h).

<u>In vitro study:</u> five randomly chosen implants of each group (heat treated/untreated) were stored in warmed (37°C), pH-buffered simulated body fluid (SBF) for eight weeks. Temperature and pH value were controlled daily. Change of the SBF was performed when the pH became near 8.

<u>In vivo study</u>: The experiment was conducted under a protocol approved by an ethics committee, in accordance with German federal welfare legislation (33.12.-42502-04-11/ 0640). New Zealand White Rabbits (n =8, female, adult, 3-4 kg body weight) were used and randomly assigned to one of the groups (heat treated (n = 8) or untreated (n = 8) implants respectively). The pins were implanted intramedullary in both tibiae as previously described [4]. After surgery the animals received an analgesic and antibiotic treatment for 10 days. A clinical examination (behaviour, additional bone, gas development, inflammatory reactions) was performed daily. Every two weeks and after eight weeks every four weeks a µ-computed tomography (XtremeCT, Scanco Medical, Zurich, Switzerland; 41 µm projections; 100 at 0-180°; integration time: 100 ms) was performed. 48 weeks after surgery the rabbits were euthanised. The implants were explanted and analysed by three-point-bending.

Data of the µCT scans were evaluated using the software µCT Evaluation Program V6.0; Scanco Medical, Zurich, Switzerland. After contouring every slice by hand, a threshold of 138 was used for computation. Mean values and standard deviations of implant volume and density were calculated. The implants´ stability was determined by three point bending before and after in vitro (8 weeks) and in vivo degradation (48 weeks) using a universal testing machine Z250 (Comp. Zwick, Ulm, Germany). Maximum applied force until failure was measured and compared between heat treated and untreated implants. Statistical analysis was carried out by student’s t-test (p-value 0.05).

Results

<u>In vitro study:</u> During the first days the pins of both groups showed a development of gas bubbles which decreased after 3-4 weeks. SBF solution had to be changed every 2-3 days in the first two weeks and biweekly after week three at the untreated group whereas a biweekly change of SFB was sufficient in the heat treated group during the whole observation period. The mechanical

stability of the heat treated group initially was significant lower than the stability of the untreated group (Fig. 1). After in vitro degradation stability of untreated implants generally approximate heat treated implants so that no statistically significant differences could be found. The values after 8 weeks in vitro corrosion in SBF were in the range of the initial stability of heat treated implants (Fig. 1).

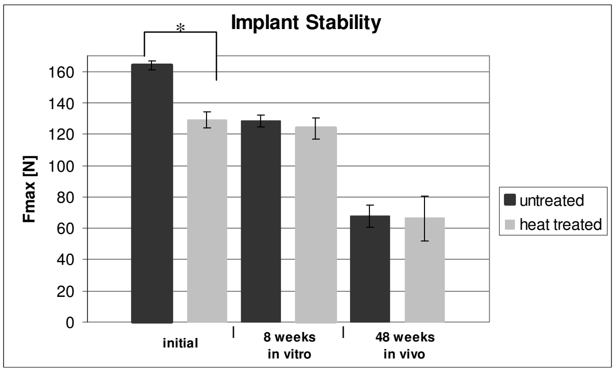

Figure 1: Implant stability of untreated/ heat treated implants: initial stability was lower in heat treated implants, whereas values of both groups were similar after in vitro and in vivo degradation (* statistically significant differences)

In vivo study: All implants were clinically tolerated without signs of lameness or pain. The evaluation of the µ-CT scans showed a decrease of implant volume and density in both groups, although these decreases were enlarged in the untreated group approximately after half of the observation period (Fig. 2).

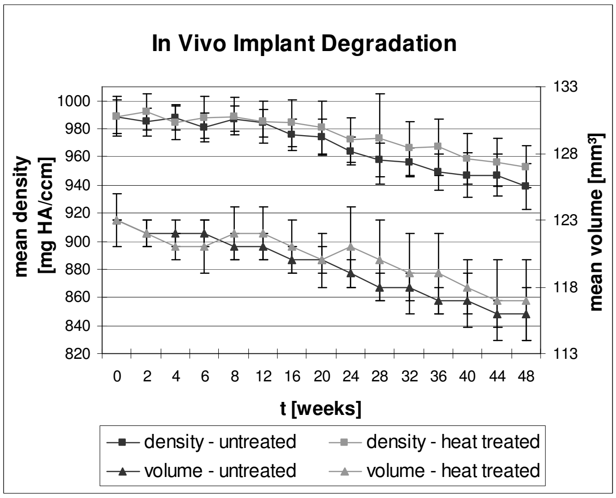

Figure **2**: Implant density and volume during 48 weeks in vivo degradation: heat treated implants showed a slightly lower decrease in implant volume and density over time

However, the standard deviations of the heat treated group showed a larger range in the values for density and volume compared to the untreated group.

Corresponding to corrosion in SBF the mechanical strength after 48 weeks in vivo degradation was similar for both groups. The mean F(max) was significantly lower than after 8 weeks in vitro corrosion.

Discussion

The present study evaluated in vitro and in vivo degradation behaviour including stability of heat treated and untreated extruded LAE442 implants. The performed heat treatment obviously decreased the initial stability. Furthermore a supplementary increase in corrosion resistance could be seen. Similar observations are described by Zhang et al. who found an increase in corrosion resistance after T6 treatment of Mg-AZ91D alloys [2]. They showed a reduction of the corrosion rate by 30-60%. The present study could show that a similar effect was found for LAE442 and even for in vivo corrosion behaviour over 48 weeks. Besides approximated values for the maximum applied force (F(max)) after either in vitro and in vivo degradation this reduction of the corrosion rate was also represented by the changes of mean implant volume and density during the in vivo experiments. After half of the implantation period untreated implants showed a higher decrease of both volume and density compared to heat treated pins.

Since a slow degradation rate is mandatory in terms of a good biocompatibility [4] a reduced corrosion resistance is generally favourable for magnesium based implants. Therefore heat treatment seems to be a valuable tool to alter corrosion properties. But due to the required initial strength which is needed for osteosynthesis in weight loaded bones and the still sufficiently slow degradation rate of untreated pins it remains to be investigated if the alteration of the strength by a heat treated implant is a criterion of exclusion for the orthopaedic use.

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