Acta Biomaterialia 8 (2012) 1230–1238

Contents lists available at SciVerse ScienceDirect

Acta Biomaterialia

journal homepage: www.elsevier.com/locate/actabiomat

Magnesium alloys for temporary implants in osteosynthesis: In vivo studies of their degradation and interaction with bone

Tanja Kraus [a], Stefan F. Fischerauer [b], Anja C. Hänzi [c], Peter J. Uggowitzer [c], Jörg F. Löffler [c], Annelie M. Weinberg [b,*]

[a] Department of Pediatric Orthopedics, Medical University Graz, 8036 Graz, Austria
[b] Department of Pediatric and Adolescent Surgery, Medical University Graz, 8036 Graz, Austria
[c] Laboratory of Metal Physics and Technology, Department of Materials, ETH Zurich, 8093 Zurich, Switzerland

ARTICLE INFO

Article history:
Received 1 August 2011
Received in revised form 14 October 2011
Accepted 4 November 2011
Available online 11 November 2011

Keywords:
Magnesium
Biodegradation
Growing rat skeleton
In vivo small animal imaging
Microfocus computed tomography (μCT)

ABSTRACT

This study investigates the bone and tissue response to degrading magnesium pin implants in the growing rat skeleton by continuous in vivo microfocus computed tomography (μCT) monitoring over the entire pin degradation period, with special focus on bone remodeling after implant dissolution. The influence of gas release on tissue performance upon degradation of the magnesium implant is also addressed. Two different magnesium alloys – one fast degrading (ZX50) and one slowly degrading (WZ21) – were used for evaluating the bone response in 32 male Sprague–Dawley rats. After femoral pin implantation μCTs were performed every 4 weeks over the 24 weeks of the study period. ZX50 pins exhibited early degradation and released large hydrogen gas volumes. While considerable callus formation occurred, the bone function was not permanently harmed and the bone recovered unexpectedly quickly after complete pin degradation. WZ21 pins kept their integrity for more than 4 weeks and showed good osteoconductive properties by enhancing bone accumulation at the pin surface. Despite excessive gas formation, the magnesium pins did not harm bone regeneration. At smaller degradation rates, gas evolution remained unproblematic and the magnesium implants showed good biocompatibility. Online μCT monitoring is shown to be suitable for evaluating materials degradation and bone response in vivo, providing continuous information on the implant and tissue performance in the same living animal.

1. Introduction

In recent years extensive research on magnesium and its alloys as potential biodegradable implant materials has been carried out [1–7]. Biodegradable magnesium alloys are more suitable for load-bearing implant applications than their polymeric counterparts due to their superior mechanical strength. Moreover, since their elastic properties resemble those of bone, they are considered ideal for hard tissue implants employed in fracture stabilization because stress shielding is avoided and bone regeneration is enhanced [1,2]. Previous in vivo and in vitro studies have shown that magnesium alloys exhibit good biocompatibility with no systemic inflammatory reaction or affection of the cellular blood composition [3–6]. In addition, high mineral apposition rates and increased bone mass were found around degrading Mg implants in bone [7]. The beneficial influence of magnesium has been emphasized further in a study showing that the bone–implant interface strength and osseointegration are significantly greater for magnesium than for conventional titanium materials [8]. Using materials that degrade in physiological environments renders subsequent surgical intervention for implant removal after tissues healing [1,3]. This is of great benefit because morbidity related to repeated surgery is reduced and additional health costs are avoided. It makes temporary implants also very attractive in pediatric cases – which are, as potential end application, in the focus of this study – where the growing bone is less interfered with and its regeneration after fracture is supported.

Specific properties must be fulfilled in order to use biodegradable implants as material for osteosynthesis in a growing skeleton. The key issues include (i) an adequate stability during fracture healing, requiring sufficient strength to hold the replaced fracture; (ii) degradation and full regeneration of the bone structure within 12–15 months, requiring a moderate and homogeneous degradation performance in equilibrium with the bone healing process; and (iii) biocompatibility, requiring an adequate biological response. Magnesium is considered to meet many of these requirements. However, the fact that its degradation is accompanied by hydrogen gas formation ($Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$, [9]) has abated the optimistic predictions for its use in osteosynthesis, because its degradation generally results in considerable gas accumulations

* Corresponding author. Tel.: +43 316 385 13761; fax: +43 316 385 13775.
E-mail address: annelie.weinberg@t-online.de (A.M. Weinberg).

1742-7061/$ - see front matter © 2011 Acta Materialia Inc. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.actbio.2011.11.008