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In vitro and in vivo studies on a Mg–Sr binary alloy system developed as a new kind of biodegradable metal

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Magnesium alloys have shown potential as biodegradable metallic materials for orthopedic applications due to their degradability, resemblance to cortical bone and biocompatible degradation/corrosion products. However, the fast corrosion rate and the potential toxicity of their alloying element limit the clinical application of Mg alloys. From the viewpoint of both metallurgy and biocompatibility, strontium (Sr) was selected to prepare hot rolled Mg–Sr binary alloys (with a Sr content ranging from 1 to 4 wt.%) in the present study. The optimal Sr content was screened with respect to the mechanical and corrosion properties of Mg–Sr binary alloys and the feasibility of the use of Mg–Sr alloys as orthopedic biodegradable metals was investigated by in vitro cell experiments and intramedullary implantation tests. The mechanical properties and corrosion rates of Mg–Sr alloys were dose dependent with respect to the added Sr content. The as-rolled Mg–2Sr alloy exhibited the highest strength and slowest corrosion rate, suggesting that the optimal Sr content was 2 wt.%. The as-rolled Mg–2Sr alloy showed Grade I cytotoxicity and induced higher alkaline phosphatase activity than the other alloys. During the 4 weeks implantation period we saw gradual degradation of the as-rolled Mg–2Sr alloy within a bone tunnel. Micro-computer tomography and histological analysis showed an enhanced mineral density and thicker cortical bone around the experimental implants. Higher levels of Sr were observed in newly formed peri-implant bone compared with the control. In summary, this study shows that the optimal content of added Sr is 2 wt.% for binary Mg–Sr alloys in the rolled state and that the as-rolled Mg–2Sr alloy in vivo produces an acceptable host response.

1. Introduction

In recent years magnesium and its alloys have attracted great attention as degradable materials for orthopedic implants due to their degradability, similar mechanical properties to cortical bone and the biocompatibility of magnesium ions [1–5]. A number of Mg alloys had been under investigation for potential clinical applications, such as AZ91 [4,5], WE43 [5,6], Mg–Ca [2], Mg–Zn [7] and Mg–Mn–Zn [6] alloys. Animal tests have proved that these Mg alloys gradually degrade within bone and the corroding products show anabolic effects on peri-implant bone with an appropriate inflammatory response in the short term [2,5,8]. However, the rapid corrosion rate of the above Mg alloys might limit their clinical application [2,5,7].

An approach to this challenge is alloying, which is well known as one of the most effective methods to improve the corrosion resistance as well as mechanical properties of Mg. From the medical point of view, there are only a small number of alloying elements which can be tolerated in the human body and can also retard the corrosion rate of Mg alloys suitable for inclusion in biodegradable Mg alloys, including Ca, Zn, Mn and perhaps a very small amount of low toxicity rare earth elements [2,6,9,10].

Strontium, along with Ca and Mg, belongs to group 2 of the periodic table and shares similar chemical, biological and metallurgical properties. Recently Fan et al. [11] reported that Sr could improve both the mechanical properties and corrosion resistance of alloy AZ91Din NaCl solution. Argo et al. [12] indicated that an increasing amount of Sr addition to Mg–Al alloys could increase the high temperature tensile properties and reduce their corrosion rate.

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