Advanced Materials Research Vol. 1125 (2015) pp 437-440
© (2015) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMR.1125.437

Submitted: 2015-01-03
Revised: 2015-04-23
Accepted: 2015-05-27

Porous Magnesium Scaffolds for Bone Implant Applications: A Review

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Keywords: Porous magnesium, Scaffolds, Bone implant, Biodegradable metals, Tissue ingrowths.

Abstract. For over two decades, various porous polymeric and metallic-based implants have been used as load-bearing scaffold for mechanical attachment and tissue ingrowths. Porous implants designed for biological fixation of prostheses in bone replacement and enhance mechanical demand as load-bearing material. Therefore, studies on the effect of using parameters, such as pore size, pore structure, and porosity with respect to cell adhesion as well as tissue ingrowths have been extensively reported. This article aims to report the current status and future challenge on using porous magnesium scaffold for bone implant application. Techniques on manufacturing technology for producing porous magnesium scaffold will also be highlighted.

Introduction

Metallic materials including titanium alloys, stainless steels and cobalt-chromium-based alloys play an important role for bone fracture fixation applications. However, those current biomaterials have a potential of release toxic metallic ions or particles from their wear and biodegradation processes that may risks the local inflammation on the implant sites [1,2]. Furthermore, some researchers have been reported that permanent bone plate gives occurrences of osteoporosis in the surrounding bone tissues due to the mismatch in elastic modulus, creating stress shielding [3,4]. When implant materials have that clinical case, second surgery which may increase the risk for the patient, may subsequently have to be conducted for implant replacement. For this reason, the use of biodegradable metallic implants, including magnesium-based materials have been proposed for bone implant that supports tissue ingrowths.

Magnesium is one of the abundant materials founded in adult human body. There are about 30 grams of magnesium existed in bone and muscle [5]. Based on its physical and mechanical properties, the elastic modulus of magnesium is closer to human bone, while its density is lower and specific strength is higher [6]. Magnesium is also the fourth most abundant cation that supports human metabolism and toxic free [7]. Recent studies also shown that dissolved magnesium ions will promote bone cell attachment and tissue growth at the implants sites [7].

However, the challenge on biodegradable materials is to find a match between the corrosion rate of the implant and bone tissue ingrowths. In clinical, the high degradation rate of magnesium implant is one of the major obstacles for the broader applications. Some researchers, have been proposed to modified the alloying elements of magnesium implant materials [6,7], while the other focuses on surface treatment [8]. This paper reviews the development and potential use of porous magnesium as a degradable scaffold bone implant application. The production process of porous scaffolds and the assessment of their properties and biocompatibility are also highlighted.

Porous magnesium for bone implant material

Mammalian bone is typically has an open inter-connected porous structures, and like other connective tissues, it also composed with cells, extracellular matrix, and vascular system. Bone's extracellular matrix is calcified, compacted with collagen-based fibers, and very highly ordered [9]. The architectural of bone tissue is arranged in compact, cortical, porous cellular or cancellous structures. These two types of bone tissue have the same composition but different in proportions of organic and inorganic materials, percentage of porosity and hierarchical organization of bone tissue. The properties of bone depend on macro, micro- and nano-scale of hierarchical structures as presented on Fig. 1 [5].

Engineering of bone tissues is now a promising clinical strategy to regenerate bone structure. This approach is a combination of cells with osteogenic activity and osteoinductive signal molecules in the appropriate engineering scaffold material. Tissue engineering offers an effective way to repair or replace the diseased or damaged tissues which are draws from the cell biology, biotechnology and materials sciences [7,9]. In the in vitro study, engineering bone tissue designed in three-dimensional (3D) scaffolds made of metallic-based [7,8], synthetic biodegradable polymer [10] or bioceramics [11] materials; act as substrates for osteoblast cell culture and bone tissue ingrowths. Other studies have been using an injectable system for bone tissue engineering as minimally invasive treatments [11,12]. Several injectable gels have been used to carry bone cells in order to heal bone fracture, such as: collagen [12], alginate [13], and fibrin gel [14]. However, there is a limitation of using bone injectable system, mainly that the substances cannot be molded to mimic the shapes of 3D cell culture models of bone.

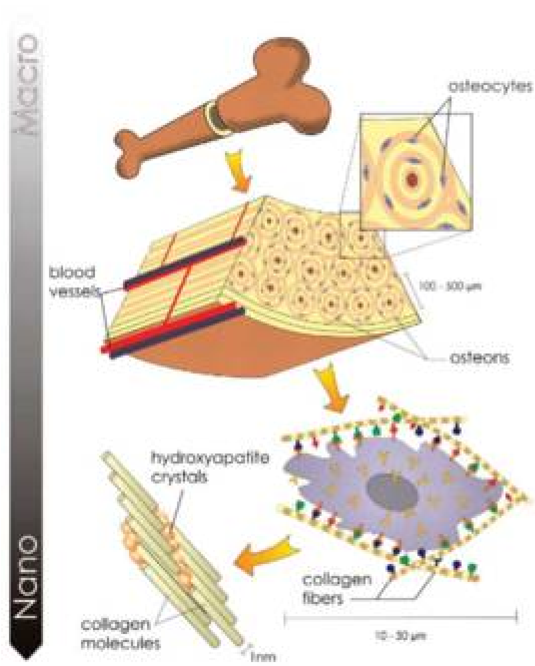

Fig. 1. Schematic of hierarchical structure of bone.

Other approach is to use porous metallic-based implant similar human bone tissue architectures [10,14]. Pore size and pore structure's interconnectivity are important in that they can affect how much cells can penetrate and grow into the scaffold and what quantity of materials and nutrients can be transported into and out of the scaffold. Pore architectures and interconnectivity of bone scaffold should support cell seeding, cell migration, matrix deposition and vascularization, as well as mass transport from and to the cells. Promotion of cell adhesion and bone ingrowths is also depend on the pore size of the scaffolds [15]. Therefore it has been suggested by some researchers that the optimum pore size bone ingrowth promotion was in the range of 100-500 µm [15,16]. Also, the interconnection porous structure is needed to achieve sufficient nutrient and oxygen transport to support cell viability inside the bone engineered scaffold.

Rapid prototyping technology for the fabrication of porous magnesium

Functionalities of cell and tissue will be enhanced by using porous metallic structure or engineered scaffolds. It supports cell adhesion and growth by providing high surface area within a three-dimensional structure. Scaffold porosity also provides adequate space, permits cell suspension, and cell penetration inside the structure. Therefore, the system may promote extracellular matrix (ECM) production, nutrients transport, and excrete waste products [17].

To date, porous metallic scaffolds can be produced by using conventional techniques or advanced processing methods. The selection of the technique depends on the requirements of the final application. To secure the aims of using engineering scaffold for bone regeneration, selection of materials, design and manufacturing methods, as well as additional surface modification are very important. One of advanced technology used to produce porous magnesium scaffolds is rapid prototyping (RP) technology [17,18]. RP is generally categorized as solid freeform fabrication (SFF) or additive manufacturing (AM). It is include in a group of advanced manufacturing processes in which objects can be built layer by layer in additive manner directly from computer data such as Computer Aided Design (CAD), Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) images. This method is able to control the porous and interconnected architecture inside the scaffold based on 3D bone CT scan images [18].

Concluding remarks

Porous Magnesium has promising properties to be used as biodegradable bone implant materials. It degrades in human body physiological environment and in the same time promotes bone ingrowths with is improved mechanical strength compare to biodegradable polymers materials. Although it has high biodegradation rate, however, the surface coating and Mg alloying strategy have been applied to enhanced corrosion resistance of porous magnesium implant. Rapid prototyping technology allows the manufacturing of porous magnesium structure similar to the bone architecture. Those advancements open more potential applications of porous magnesium implant as candidate materials for biomedical and tissue engineering fields.

Acknowledgements

The authors would like to acknowledge the financial support from UTM Tier-1 (vote# 03H12), MOHE-FRGS (vote# 4F128) and UTM RU (vote# 00G670) grants.

References

[1] J.J. Jacobs, J.L. Gilbert and R.M. Urban, Corrosion of metal orthopaedic implants, J Bone Joint Surg 80 (1998), 268–282.

[2] C. Lhotka, T. Szekeres, I. Steffan, K. Zhuber and K. Zweymuller, Four-year study of cobalt and chromium blood levels in patients managed with two different metal-on-metal total hip replacements, J Orthop Res 21 (2003), 189–195.

[3] W.F. Ng, M.H. Wong and F.T. Cheng, Cerium-based coating for enhancing the corrosion resistance of bio-degradable Mg implants, J Mater Chem Phys 119 (2009), 384-388.

[4] Y. Xinyu, C. Minfang, Y. Meng, W. Jun and L. Debao, In vitro corrosion resistance and cytocompatibility of nano-hydroxyapatite reinforced Mg–Zn–Zr composites, J Mater Sci Mater Med 21 (2010), 1321-1328.

[5] J.M. Anderson, A. Rodriguez and D.T. Chang, Foreign body reaction to biomaterials, Semin Immunol 20 (2008), 86-100.

[6] M.P. Staiger, A.M. Pietak and J. Huadmai, Magnesium and its alloys as orthopedic biomaterials: a review, Biomaterials 27 (2006), 1728-1734.

[7] N.E.L. Saris, Magnesium: an update on physiological, clinical and analytical aspects, Clin Chim Acta 294 (2000), 1-26.

[8] L. Longchuan, G. Jiancheng and W. Yong, Evaluation of cyto-toxicity and corrosion behaviour of alkali-heat-treated magnesium in simulated body fluid, Surf Coat Tech 185 (2004) 92-98.

[9] M.A. Liebschner and M. Wettergreen, Scaffold pore space modulation through intelligent design of dissolvable microparticles, Methods Mol Biol 868 (2012), 71-89.

[10] M. Takaya, K. Hashimoto and Y. Toda, Application of magnesium to biomaterials for hard-tissue, J JILM 50 (2000), 343-347.

[11] T. Zdeblick and T.B. Ducker, The use of freeze-dried allograft bone for anterior cervical fusions, Spine 16 (1991), 726–729.

[12] H. Tsuchida, J. Hashimoto, E. Crawford, P. Manske and J. Lou, Engineered allogeneic mesenchymal stem cells repair femoral segmental defect in rats. J Orthop Res 21 (2003), 44-53.

[13] Q. Shang, Z. Wang, W. Liu, Y. Shi, L. Cui and Y. Cao, Tissue-engineered bone repair of sheep cranial defects with autologous bone marrow stromal cells, J Craniofac Surg 12 (2001), 586-593.

[14] C. Perka, U. Arnold, R.S. Spitzer and K. Lindenhayn, The use of fibrin beads for tissue engineering and subsequential transplantation, Tissue Eng 7 (2001), 359-361.

[15] S. Thelen, F. Barthelat and L.C. Brinson, Mechanics Considerations for Microporous Titanium as an orthopedic implant material, J Biomed Mater Res 69A (2004), 601-610.

[16] T.M. Freyman, I.V. Yannas and L.J. Gibson, Cellular materials as porous scaffolds for tissue engineering, Prog Mater Sci 46 (2001), 273-282.

[17] J. Banhart, Manufacture, characterisation and application of cellular metals and metal foams, Prog Mater Sci 46 (2001), 559-632.

[18] G.A. Fielding, Effects of silica and zinc oxide doping on mechanical and biological properties of 3D printed tricalcium phosphate tissue engineering scaffolds, Dent Mater 28 (2012), 113-122.