Porous Magnesium Scaffolds For Bone Implant Application: A Reviews

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Porous Magnesium Scaffolds for Bone Implant Applications: A Review

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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 and pore structure, porosity with respect to cell adhesion as well as tissue ingrowths have been extensively reported. This article aims to report the development and potential use of porous magnesium scaffold for bone implant application. Techniques on producing porous scaffold materials will also 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, Nagels et al 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 30g 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 [2,7].

However, the challenge on biodegradable materials is finding 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 [4,6], 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 scaffold is reported and the assessment of its properties and biocompatibility 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 [20]. The architectural of bone tissue is arranged in compact or cortical bone and porous cellular or cancellous bone. 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].

Bone tissue engineering is a promising way to regenerate bone tissue. This approach is a combination of cells capable of osteogenic activity and osteoinductive signal molecules with an appropriate material. Tissue engineering is an effective way to repair or replace the diseased or damaged tissues which are draws from the cell biology, biotechnology and materials sciences [7]. In the in vitro, bone tissue engineer uses to design an engineered three dimensional (3D) bone scaffolds made of synthetic biodegradable polymers [9] or bioceramics [6,10] and act as substrates for 3D culture of osteoblast or other applicable bon cells. From that, by using an injectable system for bone tissue engineering has been developed as minimally invasive treatments. Several injectable gels have been used to carry cells in order to engineer bone. Some researchers that have been using an injectable system are Tsuchida et al using collagen [11], Shang et al using alginate [12], and Perka et al using fibrin [13] gels. There are limitations while using the injectable system such as the substances cannot be moulded to the shapes of the bone defects when injected in situ or that they cannot follow the shapes of 3D cell culture molds in vitro.

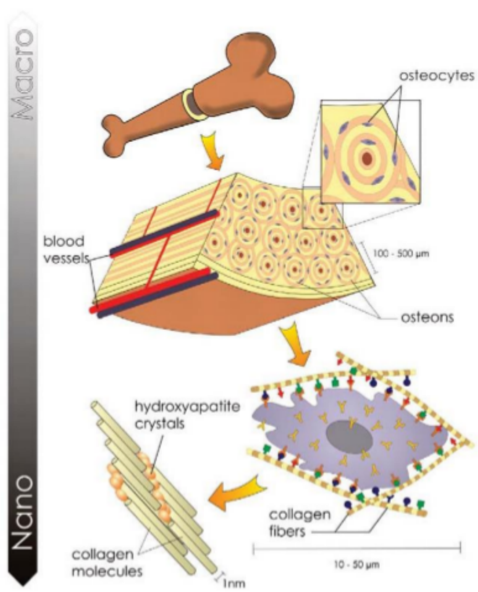

Figure 1: Schematic of hierarchical structure of bone

Other approach is to use a porous metallic-based implant that imitates human bone tissue architectures. Today, a new class of materials, known as porous materials is developing for tissue engineering [9]. Pore size and 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. In other words, pore size distributions, porosity and the interconnectivity of the scaffold should be sufficient for cell seeding, cell migration, matrix deposition, vascularization and mass transport of nutrients from and to the cells. Promotion of cell adhesion and bone ingrowths is related to the porosity pore size of the scaffolds [14]. In previous research, the optimum pore size for promoting bone ingrowth is in the range of 100-500 μm [14,15]. An interconnection porous structure is needed to achieve sufficient nutrient transport and cell ingrowths.

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 will support the adhesion and growth of a large number of cells by providing a large surface area and pore structure within a three-dimensional structure. Porosity provides adequate space, permits cell suspension, and penetrates the three-dimensional structure. These porous structures also promote extracellular matrix (ECM) production, transport nutrients from nutrient media, and excrete waste products [16].

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 successfully using the scaffold for regenerate new bone, selection of the scaffold material and design, the method by which to construct them, and the possible additional surface modification are very important. One of advanced technology used to produce porous magnesium scaffolds is rapid prototyping (RP) technology. 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) data. This method is able to control the porous and interconnected architecture of the scaffold based on 3D images [17].

Concluding remarks

Porous Magnesium (Mg) has promising properties as a biodegradable bone implant materials. It can degrade in human body physiological environment and in the same time promote bone ingrowths, while its mechanical strength is better than biodegradable polymers materials. Although it has high biodegradation rate, the surface coating and 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 a potential application of porous magnesium implant as promising candidate materials for biomedical and tissue engineering fields.

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