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Synthesis, characterization, and biological studies of sintered porous titanium with three different pore morphologies

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Abstract: Integrating implants with the surrounding bone tissue is a significant challenge in medical engineering. A promising option with appropriate biological and mechanical characteristics is porous titanium, which can be employed in mineralizing bones and ingrowth applications. In the present study, titanium foams were fabricated using titanium hydride powder and the following space holders: (1) needle-shaped urea, (2) spherical urea, and (3) cubic sodium chloride. All samples were characterized by means of scanning electron microscopy with an energy-dispersive X-ray spectrometer, X-ray diffraction, and mechanical compression testing. Our results revealed that powder metallurgy is suitable for producing titanium foam with various pore morphologies. The shape of sample pores replicates the type of space holders. Also, the influence of three distinct pore morphologies on the human primary osteogenic sarcoma cell line, MG-63, was evaluated. *In-vitro* investigation showed that samples with sharp-cornered pores increase the attached cellular filopodia to the foams after seeding. This result is helpful in porous titanium applications for restoring bone defects.

Keywords: Cell biology; Osteoblast; Prostheses and implants; Titanium foam.

1 Introduction

Dental implants and artificial joints made of foamy titanium (Ti) alloys are of high interest these days [1, 2]. This desirability is due to corrosion resistance, proper biocompatibility, low density, high energy absorption, high surface area, and desirable mechanical properties of both Ti materials and foam architecture [3]. In order to produce Ti implants with a porous structure, researchers propose the space holder technique, rapid prototyping, powder deposition, pressurized gas bubble expansion, and the sintering of powder [4]. The space holder sintering method can yield highly porous metallic foams with desirable pore size, shape, volume, and low-cost production. The materials employed for space holders are sodium chloride, urea, ammonium hydrogen carbonate, magnesium, sodium fluoride, and starch [5].

An implant with a porous structure enables new cell formation, cellular activities, and the transfer of oxygen and nutrients in bone tissue regeneration [6]. Furthermore, a porous implant allows it to control and minimize stress shielding by modifying the elastic modulus [7]. In order to achieve proper tissue regeneration, it is required to balance the biological performance-related factors of porous Ti implants [8]. The distribution of pores, size of pores, morphology of the pores, and total porosity degree are essential in biological and physical balancing [9].

It has been demonstrated that macropores play a vital role in the penetration of cells into the implant and increasing the rate of new tissue formation [10]. Therefore, macropores can control the reconstruction speed [11]. Other studies show that implants with interconnected macropores play a remarkable role in controlling the penetration of nutrients and medications into cells [12]. An extensive body of literature in recent years showed that pore geometry and shape influence the permeability and mechanical properties of porous implants and cell behavior [13]. The effects of scaffold porosity and pore size on mechanical properties have been evaluated *in vitro* and *in vivo* [14]. However, fewer studies have investigated the pore shape. Therefore, there is no consistent and clear conclusion regarding the appropriate geometry of the pores and bone cell response. Furthermore, these studies are inconclusive because evaluation methods are subjective with unstable experimental conditions [7, 9, 15].

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