Porous titanium scaffolds with aligned pore structure for bone tissue engineering

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Introduction : Porous titanium (Ti)-based materials have attracted increasing interest for applications in bone tissue engineering because of their good mechanical properties and biocompatibility compared to other bioceramics or biopolymers [1,2]. Ti-based porous materials were produced using various manufacturing methods, such as the space holder method, the rapid prototyping method, and the replication of polymeric sponge, freeze casting method. Among them, camphene-based freeze casting was used as fabrication method of highly porous titanium because large pores can be easily created by using this method. Although a higher porosity and larger pore size generally induce a faster bone ingrowth into the pores, they inevitably reduce the strength of the materials [3]. Therefore, creating aligned pore structure was necessary to produce highly porous and unidirectionally strong materials. In this study, fabrication of aligned large pores controlled by temperature gradient and casting time was demonstrated.

Methods : Titanium hydride (TiH_2)/camphene slurries with various composition (10, 15, and 20 vol.%) were prepared by ball-milling at 60 °C for 24 h[4]. Prepared slurries were directionally solidified from a cold copper plate which attached to hot Teflon cylinder. After solidification, they kept at 42 °C oven for various times, in order to allow an excessive growth of camphene dendrites. The green bodies were then freeze dried to remove the frozen camphene. Thereafter, the samples were heated up to 400 °C at a slow heating rate, up to 1300°C at a fast heating rate, and heat treated for 2 h [4]. The porous structures of the samples were characterized using scanning electron microscopy and μ-CT. In order to evaluate their mechanical properties, their compressive stress–strain behaviors were monitored.

Results and Discussion: Fig 1. shows the SEM images of well-aligned Ti scaffolds. Regardless of the freezing time, all of the fabricated samples showed a highly aligned pore structure. Large elongated pores and honeycomb-like pores were formed parallel and normal to the freezing direction. That indicate camphene dendrites grew successfully in a preferred direction. Also, as the casting time increased, the pores became larger up to 300 μm. 3-D images of aligned porous titanium were visualized by μ-CT. It was observed that the pore structure was uniform through the entire sample, as shown in Fig. 2. Aligned sample showed much higher compressive strength than non-aligned, as shown in Fig. 3. This suggests that the compressive strength of porous titanium can be improved significantly by creating aligned pores.

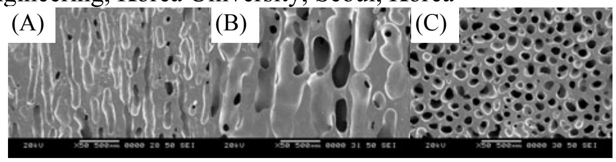

Fig 1. SEM micrographs of the aligned porous Ti scaffolds(10 Vol.% of TiH_2 contents) produced with various casting times of (A) 1 day (B) 7 day (C) 1 day (normal direction)

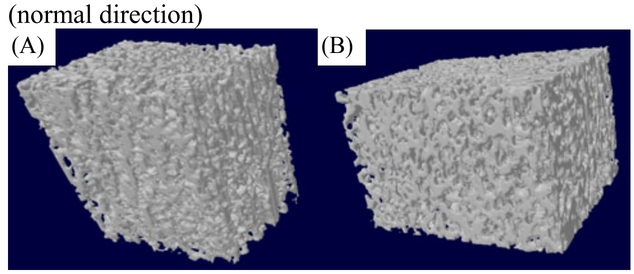

Fig 2. μ-CT images of the aligned porous Ti scaffolds with various TiH_2 contents (A) 15 Vol.% (B) 20 Vol.%

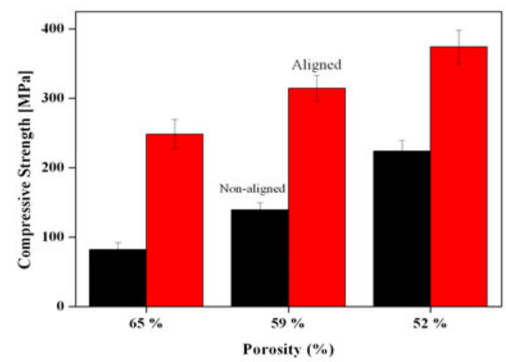

Fig 3. Compressive strength of the aligned porous titanium scaffolds as a function of the porosity.

Conclusions: Highly aligned porous titanium scaffolds were successfully fabricated using the camphene-based freeze casting method. Aligned pores were initially formed via unidirectional freeze casting at a relatively low temperature and then remarkably enlarged by subsequent treatment at 42 °C for various times. Reasonably high compressive strengths, ranging from 250 to 370 MPa, were achieved owing to a creation of the aligned pores. All of the fabricated samples exhibited large pores, which should allow them to find very useful applications in the field of bone regeneration.

References:

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