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Novel Bioceramics of Calcium Phosphates Composed of Rod-shaped Particles

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Abstract: Fb-Tricalcium phosphate (β-$Ca_3(PO_4)_2$: β-TCP) is one of the most biocompatible materials with human bones and teeth. The difference in microstructure has a large effect on the reaction of β-TCP *in vivo*. Therefore micro-pores, as well as macro-pores, must be controlled for porous material design, although the size of micro-pores is too small for cells.

In this paper, porous granules of β-TCP with micro-pores of about 0.1 mm in size were prepared from porous hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$: HA) granules with calcium deficient composition synthesized by hydrothermal method. The β-TCP granules with about 40 %-60 % porosity were composed of rod-shaped particles of about 10-20 mm in length. Rod-shaped particles were locked together to make micro-pores, and the size of micro-pores formed by tangling of rod-shaped particles was about 0.1-0.5 mm. The particle size, shape, and the micro-pore size were controlled by our unique method.

Key words: calcium phosphate, β-TCP, hydroxyapatite, bioceramics, hydrothermal

Introduction

Porous materials of β-TCP have been known to be osteoconductive and biodegradable[1]. In addition, the authors reported that micro-pores of β-TCP with about 0.1-0.5 mm in size were significantly important for bio-resorption in bones[2], therefore micro-pores, as well as macro-pores, must be controlled for porous material design, although the size of micro-pores is too small for cells. The present paper deals with the preparation of novel porous β-TCP granules composed of rod-shaped particles with designed microstructure, especially in micro-pores.

Materials and Methods

Powders of α-tricalcium phosphate (α-$Ca_3(PO)_4$: α-TCP) and gelatin were used as the starting material. The aqueous slurry of α-TCP with gelatin was prepared. The slurry of α-TCP / gelatin was dropped into stirring vegetable oil at 70 °C, and then the oil was cooling down at 4 °C with keeping stirring. These granules were washed with ethanol, and then they were filtered and dried in air. To remove gelatin and to keep the crystal phase of α-TCP, they were heated at 1200 °C for 5 min, and then set in a 105 cm^3 autoclave with 10 cm^3 of water. The samples were exposed to vapor of water at the temperature from 40-160 °C under saturated vapor pressure for 10 h, and then the samples were heated at 900 °C for 3 h in air for preparation of β-TCP.

The produced phases were identified by powder X-ray diffractometry with graphite-monochromatized CuKa radiation, operating at 40 kV and 20 mA (XRD; Geiger flex 2027, Rigaku, Japan). The samples were dissolved in nitric acid of 0.1 $mol.dm^{-3}$, and then the chemical composition of them was analyzed by inductively coupled plasma spectrometer (ICP-MS; Seiko Instruments, SPQ 9000, Japan). The microstructure of specimens was observed by scanning electron microscope (SEM; JEOL, JSM-T300, Japan). Pore volume and distribution of pore diameter were measured by mercury intrusion porosimetry (MIP; Carlo Elba, Porosimeter 2000, Italy). Specific surface area was measured by using BET method.

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Results and Dissociation

The size of spherical particles of α-TCP with gelatin was depended on the stirring rate of vegetable oil and the viscosity of slurry. After heating at 1200 °C in air, porous spherical α-TCP granules were obtained. After hydrothermal treatment, α-TCP was changed into HA composed of rod-shaped crystals[3].

HA was formed at the temperatures above 40 °C, and then no phases other than HA were revealed by XRD for the samples treated at the temperatures above 105 °C. The produced HA was not stoichiometric HA, that was calcium deficient HA. In general, chemical formula of calcium deficient HA is described as follows: $Ca_{10-x}(HPO_4)_x(PO_4)_{6-x}(OH)_{2-x}\ nH_2O$. The authors reported that composition of this apatite could be controlled[4]. The Ca/P ratio of the samples increased from 1.50 to 1.63 with increasing treatment temperature, but the Ca/P ratio of the samples was lower than that of stoichiometric HA (stoichiometric Ca/P=1.67).

Porous HA granules prepared at the temperatures below 80 °C were composed of irregular shaped HA particles. In the contrast, the homogeneous porous structure was observed for the samples treated at the temperatures above 105 °C. Porous HA granules prepared by hydrothermal treatment at 105 °C were composed of rod-shaped crystals elongated along the *c*-axis[5]. The HA crystals were about 5 mm in length at 105 °C, about 10 mm at 120 °C and about 10-20 mm at 160 °C. Rod-shaped crystals were locked together to make micro-pores. The diameter of micro-pore was 0.1-0.5 mm in size. The porosity and the size of micro-pore increased slightly with increasing temperature of the hydrothermal treatment.

Calcium deficient HA tends to decompose easily into tricalcium phosphates by heating in comparison with stoichiometric HA[6]. Thus, porous granules of β-TCP were obtained from the porous granules of calcium deficient HA with Ca/P ratio of 1.50 by heating them at 900 °C for 3 h in air. The β-TCP granules with about 40-60 % porosity had almost the same micro-structure in comparison with the HA granules before heating. The β-TCP granules were composed of rod-shaped particles with about 10-20 mm in length (Fig.1), and it had almost same porosity as the samples before heating. Specific surface area of β-TCP granules prepared hydrothermal treatment at 160 °C and then sintering at 900 °C was about 7 $m^2.g^{-1}$ by BET measurement. The mean diameter of micro-pore of β-TCP granules

was slight larger than that of HA granules, the value was about 0.2 mm in size. The granules of β-TCP were harder than HA because of sintering which made bonding among particles.

Porous β-TCP with much amount of micro-pores prepared in this study should be more bio-degradable than the conventional materials. These porous granules must be suitable for the bone graft material and the scaffold of cultured bone. It is considered that the implant *in vivo* is probably first coated with plasma proteins and blood coagulation materials before cells adhesion take place, therefore micro-pores must effect the osteointegration process because such pores are similar in size to that of proteins. The micro-pores must make the protein adhesion to this materials surface[7].

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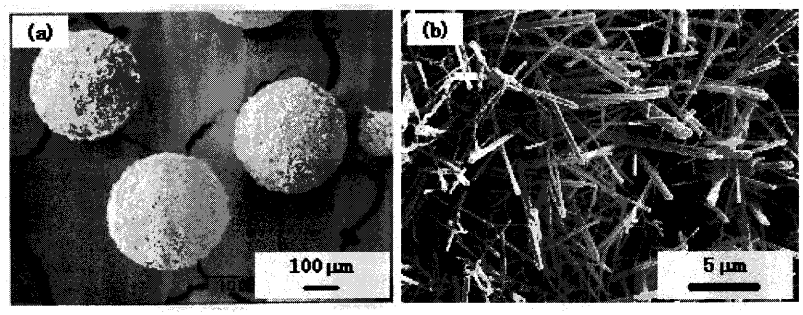

Fig.1 SEM image of β-TCP granules composed of rod-shaped particles, (a) x100 and (b) x3,000.