Porous Titanium with Chemical Treatment and Apatite Deposition

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Introduction: Mismatch of the elastic modulus between titanium and natural bone may lead to stress-shielding that deteriorate the implant-bone interface, resulting in bone resorption and subsequent implant loosening [1]. Porous titanium provides an advantageous alternative to solve the problem of mismatch of mechanical strength.

On the other hand, titanium has been known that can only form osteointegration at the interface, instead of bone-bonding. Therefore, surface modification is often performed to improve its biological performance. Solution–phase nature of chemical methods allows for fabricating a homogeneous bioactive surface layer throughout the inner pore of the implants, making it potentially to be used in endowing the porous titanium with bioactivity[2, 3]. But few reports attended to the study of surface modification on porous titanium blocks.

In this study, porous titanium blocks with three-dimensional interconnected porous structure were prepared. Alkali-heat (AH) and acid-alkali (AA) were used to pre-treat the porous samples. Then biomimetic coating was prepared on the AA and AH treated samples surface. Later, the bioactivity of the porous titanium with apatite deposition was investigated in vivo.

Methods: Porous titanium was fabricated according to previous study with minor revision [4]. Surface pretreatment process was completed by AA and AH respectively. Generally, for AA treatment, the porous titanium was soaked in a mixture of HCl and H_2SO_4 aqueous solution with equal volume at 70°C for one hour, and subsequently in 6mol/L NaOH solution at 70°C for 5 hour, washed, and dried at 40°C for 24 h. For AH treatment, the porous titanium was immersed in 10mol/L NaOH solution at 60°C for 24 h, washed gently with distilled water, and dried at 40°C for 24 h. The implants were then heated to 600°C at a rate of 5°C /min, maintained at the temperature for 1 h, and then allowed to cool to room temperature. To deposit biomimetic apatite coating on the porous titanium, the samples pre-treated by AA and AH were immersed in a highly supersaturated calcium phosphate solution (SCP) at 4℃ for 24 hours and then at 37℃ for another 48 hours. The pore structure of porous titanium was characterized by scanning electron microscopy (SEM). The surface structure after immersed in SBF and SCP was analyzed by SEM and X-ray diffraction (XRD). Samples with apatite deposition in SCP were randomly implanted into thighbone of dog with press-fit manners. At 2 months after the operations, the samples were harvested for histological analysis. The ingrowth bone area was statistical analyzed.

Results: The porosity of porous titanium was 80% in this experiment as determined by weight/volume method. SEM showed a complex porous structure in porous titanium: the macro-pores were interpenetrating through the pore size in the range of 10-100μm and the walls of porous titanium were rough, and the micro-pores with a size of several micrometers could also be observed in the wall.

Both AA and AH pre-treatment successfully penetrated to the center of the implant with micro-porous structures. In AA treated samples, a porous network structure was formed, while a needle-like porous structure and grooves was formed on the AH treated surface. After immersed in SCP for 3 days, the biomimetic coatings were homogeneously distributing on the whole outer and inner surface of both AA and AH treated porous titanium although the deposited apatite showed different morphology. Histological and histomorphometric observation showed that both of the two types of implants bonded to bone tissue directly, near 100% pores were filled with ingrowth bone tissue and there was no significant difference in bone filling and bone area in the implanted samples. The samples showed high bioactivity for bone regeneration.

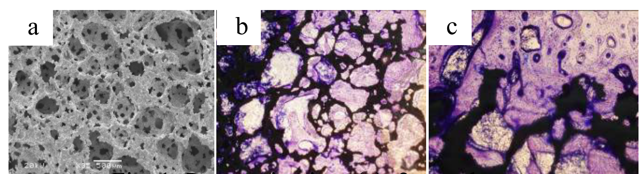

Fig. 1. Porous titanium (a); 2 months post implantation of AA (b) and AH (c) pre-treatment following with apatite deposition porous titanium

Conclusions: Both AA and AH treatment successfully penetrated to the center of the porous titanium with special micro-porous structures. It is possible to deposit a biomimetic apatite coating within porous titanium implants with AA and AH treatment, after immersed in SCP. For both types of apatite coated porous titanium implants, histological observation and histomorphometric analysis shows that both of them showed excellent bone growth and bone-bonding and no significant difference in osteointegration. Therefore, with inter-connected porous structure, both porous titanium with AA and AH pre-treatment and following with apatite coating are with high bioactivity and beneficial for the osteointegration thus suitable for load bearing bone substitute applications.

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