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Development and evaluation of tetrapod-shaped granular artificial bones

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ABSTRACT

We have developed a novel form of granular artificial bone “Tetrabones” with a homogeneous tetrapod shape and uniform size. Tetrabones are four armed structures that accumulate to form the intergranular pores that allow invasion of cells and blood vessels. In this study we evaluated the physicochemical characteristics of Tetrabones in vitro, and compared their biological and biomechanical properties in vivo to those of conventional β-tricalcium phosphate (β-TCP) granule artificial bone. Both the rupture strength and elastic modulus of Tetrabone particles were higher than those of β-TCP granules in vitro. The connectivity of intergranular pores 100, 300, and 400 μm in size were higher in Tetrabones than in the β-TCP granules. Tetrabones showed similar osteoconductivity and biomechanical stiffness to β-TCP at 2 months after implantation in an in vivo study of canine bone defects. These results suggest that Tetrabones may be a good bone graft material in bone reconstruction.

1. Introduction

Trauma, disease, and developmental abnormalities resulting in skeletal defects often incur considerable morbidity. Although the use of autogenous bone, as blocks or in granular form, has long been considered the gold standard in terms of grafting material, this approach has several disadvantages, including donor site morbidity and the restricted quantity and shape of the tissue [1,2]. For these reasons calcium phosphate-based artificial bone materials such as hydroxyapatite and tricalcium phosphate (TCP) have been widely used in clinical practice [3–6]. These materials are used in various forms, including blocks, pastes, and granules, depending on the indication and type of bone defect.

The ideal granular artificial bone should be biocompatible and biodegradable, and exhibit controlled porosity, good pore interconnectivity, and biomechanical strength [7]. However, it has not yet been established which type of granular calcium phosphate-based artificial bone materials possess the best osteoconductive potential and biomechanical properties [8]. One problem with conventional granular calcium phosphate-based artificial bones is that they have irregular shapes and sizes, which may compromise their performance. To circumvent this problem we have designed and fabricated a novel granular artificial bone taking advantage of its tetrapod shape.

In the field of civil engineering tetrapods are used to protect harbors against the force of the ocean and the consequent erosion, capitalizing on their high mechanical strength, low center of gravity, and stability to external forces [9]. These advantages led us to hypothesize that tetrapods could be scaled down for application as artificial bone. We expected that their structural characteristics would provide better mechanical stability and control over intergranular pores.

In this study we fabricated novel tetrapod shaped granular artificial bone (hereafter referred to as “Tetrabones”) by injection molding using microparticles of α-tricalcium phosphate (α-TCP). We first studied the physicochemical characteristics of Tetrabones in vitro, and then evaluated its biological and biomechanical properties in a canine model *in vivo* in comparison with β-TCP granules, which are widely used in clinical practice.

2. Materials and methods

2.1. Fabrication of Tetrabones

2.1.1. Materials

A mix of 60/40 wt.% α-TCP powder (Taihei Chemical Industrial Co., Tokyo, Japan) and binder (composed of 55% olefin resin, 30%

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