Materials Science and Engineering C 32 (2012) 1293–1298

Contents lists available at SciVerse ScienceDirect

Materials Science and Engineering C

journal homepage: www.elsevier.com/locate/msec

Design and production of sintered β-tricalcium phosphate 3D scaffolds for bone tissue regeneration

Carlos F.L. Santos [a], Abílio P. Silva [b], Luís Lopes [a], Inês Pires [c], Ilidio J. Correia [a,*]

[a] CICS-UBI — Centro de Investigação em Ciências da Saúde, Universidade da Beira Interior, Covilhã, Portugal
[b] Centro de Ciência e Tecnologia Aeroespaciais, Universidade da Beira Interior, Covilhã, Portugal
[c] Instituto de Engenharia Mecânica — Lisboa (IDMEC Lisboa/IST/UTL), Avenida Rovisco Pais, 1049-001 Lisboa, Portugal

ARTICLE INFO

Article history:
Received 21 November 2011
Received in revised form 10 February 2012
Accepted 6 April 2012
Available online 12 April 2012

Keywords:
β-TCP scaffolds
Bone regeneration
Computer Aided Tissue Engineering
Individualized scaffolds
Rapid prototyping

ABSTRACT

The characteristics of sintered β-tricalcium phosphate (β-TCP) scaffolds produced by 3D printing were studied by means of X-ray diffraction, Scanning Electron Microscopy, Fourier transform infrared spectroscopy, uniaxial compression tests and cytotoxicity tests, using human osteoblast cells.
The results reported include details of the β-TCP scaffolds' porosity, density, phase stability, mechanical behavior and cytotoxic profile. Collectively, these properties are fundamental for the future application of these scaffolds as bone substitutes for individualized therapy.

© 2012 Elsevier B.V. All rights reserved.

1. Introduction

Degenerative bone diseases and fractures are known to affect millions of people worldwide. Currently, it is expected that by the year 2020 the percentage of persons over 50 years of age affected by bone diseases will double [1].

Bone tissue has a remarkable regenerative capacity, but in cases of patients with limited healing, such as those with diabetes or poor nutrition, its regeneration is very slow and does not suppress the needs in cause. Natural bone regeneration involves the formation of new bone instead of fibrotic tissue, which is common in the regeneration process of other body tissues [2]. The mechanism of bone restoration is highly regulated and influenced by physiological, cellular and genetic factors [3].

Nowadays, clinical treatments have been based on replacing the lost bone with autologous bone grafts, allogeneic banked bone or xenogeneic sources as well as synthetic bone substitutes. However, all of them lead to limited degree of structural and functional recovery [4]. Moreover, the use of allogeneic or xenogeneic bone substitutes involves risks of immune rejection, and disease transmission [5].

In order to overcome these obstacles different studies have been carried out in the area of bone tissue engineering [6]. The primary goal of tissue engineering (TE) is to produce functional substitutes for damaged tissues [7]. So far, different three-dimensional (3D) scaffolds have been produced to act as temporary skeleton allowing new tissue to grow and restore the damaged one [6]. Nevertheless, the ideal scaffold is yet to be produced since it must have properties that allow the restoration of native tissue structure and function. Properties like biocompatibility, biodegradability, mechanical features, pore size and surface charge are very important to allow cell adhesion and proliferation, diffusion of nutrients and gases, and subsequently assure the success of tissue regeneration [8].

Lately, computer-aided technologies and its research tools have been incorporated into TE, creating a new field called Computer-Aided Tissue Engineering (CATE) [9]. As previously mentioned, a well succeeded bone restoration heavily depends on the structure and mechanical properties of the scaffold, so it is of vital importance to create 3D models suitable to be incorporated in the anatomic defect [6]. Additionally, computer-aided-design (CAD) can contribute to decrease the experimental trials as well as the production time of the scaffold [10].

Scaffold design using individualized patient data allows the production of more accurate and specific models, capable of fitting perfectly into the patient's bone defect. Using today's image acquisition technology, such as CT or Magnetic Resonance Imaging (MRI), it is possible to obtain an accurate 3D anatomic model of the tissue/area of interest [11]. Based on the data collected in daily routine clinic examinations and using CAD and computer-aided-manufacturing (CAM) programs, a 3D volume of the tissue can be rendered and then be used in the production of a patient specific physical model through rapid prototyping (RP) techniques [11].

* Corresponding author at: Centro de Investigação em Ciências da Saúde, Faculdade de Ciências da Saúde, Universidade da Beira Interior, Av. Infante D. Henrique, Covilhã, Portugal. Tel.: +351 275 329 002; fax: +351 275 329 099.
E-mail address: icorreia@ubi.pt (I.J. Correia).

0928-4931/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.msec.2012.04.010

Calcium phosphate based materials are commonly used in biomedical applications because of their osteoconductive and osteoinductive properties [12]. Since hydroxyapatite is the major mineral phase present in the bone, it is usually the first selection for scaffold production to be used in bone regeneration [10]. Conversely, hydroxyapatite's low biodegradability level is a handicap for bone replacement. In recent studies, β-tricalcium phosphate (β-TCP) has been used for the production of scaffolds and revealed better results for bone formation and degradation rate, than those obtained for hydroxyapatite [11–15].

In the present research work, β-TCP scaffolds were produced by 3D printing using patient's specific CT data and the mechanical and biological properties of sintered 3D scaffolds were characterized.

2. Materials and methods

2.1. Materials

The material used for the 3D printing of the scaffolds was a commercially available β-TCP powder, purchased from Panreac® (Barcelona, Spain) with 90% of the particle diameter (d90) lower than 36.24 μm and a mean particle size of 11.64 μm, measured in a Beckman Coulter® LS Variable Speed Fluid Module Plus (Brea, CA, USA). Human osteoblast cells (CRL-11372) were purchased from American Type Culture Collection (VA, USA). Amphotericin B, L-glutamine, Dulbecco's Modified Eagle Medium-F12 (DMEM-F12), ethanol (EtOH), glutaraldehyde, penicillin G, phosphate-buffered saline (PBS), streptomycin and trypsin were purchased from Sigma (Sintra, Portugal). Fetal bovine serum (FBS) was purchased from Biochrom AG (Berlin, Germany). The 3-(4,5-dimethylthiazol-2-yl)-5-(3carboxymethoxyphenyl)-2-(4-sulfophenyl)-2H-tetrazolium, inner salt (MTS) was purchased from Promega. T-flasks and 96-well plates were purchased from Nunc (Denmark).

2.2. Methods

2.2.1. 3D anatomic modeling

Anonymous CT data from a patient's hand was obtained from Centro Hospitalar da Cova da Beira in standard Digital Imaging and Communications in Medicine (DICOM) format, and imported in CAD software — Lightwave (NewTek, San Antonio, TX, USA), in order to render a 3D volume. About 700 slices were reassembled and slice matrices, with a dimension of 512×512, were obtained with a pixel (voxel) size of 219×219×300 voxels. This data was used to create the hand model (Fig. 1).

Due to tissue density differences it was possible to distinguish skin, muscle and bone in the CT image, by applying black and white gradients in the Lightwave software. This step allowed the creation of an accurate skeleton hand model.

Later, the 3D geometrical vector based model, also known as polygon triangular mesh, which is the equivalent to the mathematical boundary of the volume/tissue, was created with Lightwave software [10], allowing the edges of the model to be defined.

Since the mesh created with Lightwave software was very irregular and sharp edged, it was necessary to export it into another 3D modeling program, called MeshLab (Open Source Program). The use of this software allowed the obtention of a more accurate and clean version of the bone tissue volume. The left hand's ring finger proximal phalange was isolated in order to facilitate the scaffold's fabrication by the 3D printing process.

Simultaneously, solid cylinder β-TCP scaffolds, with a diameter and length of 10 mm and 20 mm respectively, were designed in Solidworks 2010 (Concord, MA, USA) and produced with the purpose of studying the influence of sintered temperature on the mechanical strength, phase stability and also to evaluate possible limitations in the fabrication process. Fig. 2 shows a comparison between virtually designed and printed models used to perform those assays.

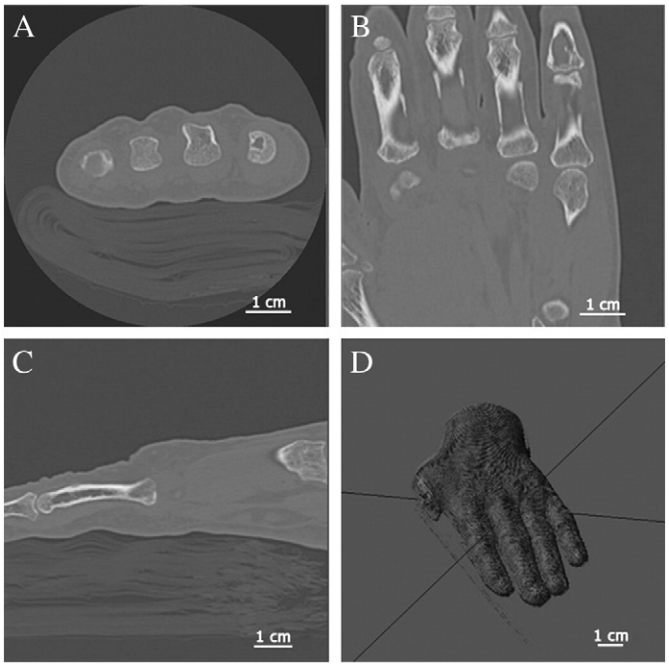

Fig. 1. Multiplanar 2D Images acquired from a CT scan and 3D hand volume. Z-axis (A), Y-axis (B), X-axis (C), images acquired by CT. Patient's hand generated 3D volume is presented in (D).

2.2.2. Production of β-TCP scaffolds

The 3D models were printed in a ZCorporation® 3D Printer (Portsmouth, NH, USA) Zprinter 310 Plus model. Successive 2D profiles were then printed on a freshly laid layer of powder until the whole model was completed. The printed binder would join the respective profiles of each layer together. The part is completed upon removal of the unbound powder and suitable post-processing [16]. In order to obtain 3D printed samples with an adequate mechanical strength and accurate dimensions, factors such as the printing layer thickness and binder saturation level were optimized. In the present work the layer thickness was defined as 0.0875 mm, by doing so the β-TCP particle size was included in the machine's resolution since, as stated before, d90 ≤ 36.24 μm.

In order to characterize the models obtained by 3D printing, different geometries were produced, namely a real scale proximal phalange, cylindrical solid scaffolds (used in the mechanical test), and porous cylindrical scaffolds with two different geometries.

The mechanical strength of the scaffold is a key feature to be taken into account, since this property is fundamental for the application of this 3D construct in bone tissue regeneration. In the present work, green bodies (name applied to the non-sintered models) were very brittle, and consequently it was fundamental to increase their mechanical strength through a sintering process.

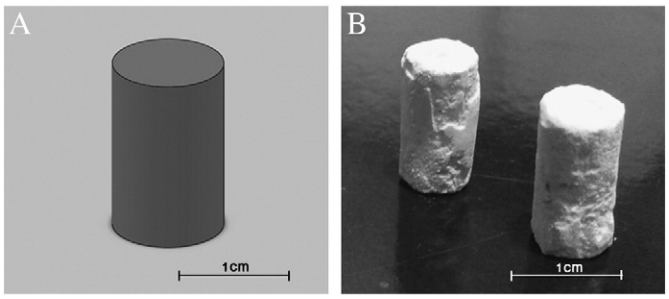

Fig. 2. Image of a Solidwork's virtual model (A) and a printed model (B).

Download English Version:

https://daneshyari.com/en/article/10614747

Download Persian Version:

https://daneshyari.com/article/10614747

Daneshyari.com