Acta Biomaterialia 8 (2012) 1648–1658

Contents lists available at SciVerse ScienceDirect

Acta Biomaterialia

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

Prediction of permeability of regular scaffolds for skeletal tissue engineering: A combined computational and experimental study

S. Truscello [a,c], G. Kerckhofs [b,c], S. Van Bael [a,c], G. Pyka [b,c], J. Schrooten [b,c], H. Van Oosterwyck [a,c,*]

[a] Division of Biomechanics and Engineering Design, Katholieke Universiteit Leuven, Celestijnenlaan 300c PB 2419, 3001 Leuven, Belgium
[b] Department of Metallurgy and Materials Engineering, Katholieke Universiteit Leuven, Kasteelpark Arenberg 44 PB 2450, 3001 Leuven, Belgium
[c] Prometheus, Division of Skeletal Tissue Engineering Leuven, Katholieke Universiteit Leuven, O&N I Herestraat 49 PB 813, 3000 Leuven, Belgium

ARTICLE INFO

Article history:
Received 5 July 2011
Received in revised form 6 December 2011
Accepted 12 December 2011
Available online 16 December 2011

Keywords:
Bone tissue engineering
Computational fluid dynamics
Scaffold
Laser manufacturing

ABSTRACT

Scaffold permeability is a key parameter combining geometrical features such as pore shape, size and interconnectivity, porosity and specific surface area. It can influence the success of bone tissue engineering scaffolds, by affecting oxygen and nutrient transport, cell seeding efficiency, in vitro three-dimensional (3D) cell culture and, ultimately, the amount of bone formation. An accurate and efficient prediction of scaffold permeability would be highly useful as part of a scaffold design process. The aim of this study was (i) to determine the accuracy of computational fluid dynamics (CFD) models for prediction of the permeability coefficient of three different regular Ti6Al4V scaffolds (each having a different porosity) by comparison with experimentally measured values and (ii) to verify the validity of the semi-empirical Kozeny equation to calculate the permeability analytically. To do so, five CFD geometrical models per scaffold porosity were built, based on different geometrical inputs: either based on the scaffold's computer-aided design (CAD) or derived from 3D microfocus X-ray computed tomography (micro-CT) data of the additive manufactured (AM) scaffolds. For the latter the influence of the spatial image resolution and the image analysis algorithm used to determine the scaffold's architectural features on the predicted permeability was analysed. CFD models based on high-resolution micro-CT images could predict the permeability coefficients of the studied scaffolds: depending on scaffold porosity and image analysis algorithm, relative differences between measured and predicted permeability values were between 2% and 27%. Finally, the analytical Kozeny equation was found to be valid. A linear correlation between the ratio Φ^3/S_s^2 and the permeability coefficient k was found for the predicted (by means of CFD) as well as measured values (relative difference of 16.4% between respective Kozeny coefficients), thus resulting in accurate and efficient calculation of the permeability of regular AM scaffolds.

1. Introduction

Bone tissue engineering scaffolds are porous materials which assist the healing of large or non-healing bone defects when combined with osteoprogenitor cells and appropriate growth factors [1,2]. A porous scaffold must behave as a carrier for cells and molecules during in vitro culture, and it also has to support the external loads after in vivo implantation [3]. Thus, the scaffold architecture is a crucial factor in fulfilling this combination of mechanical and biological requirements. The mechanical properties (i.e. scaffold stiffness) and the geometrical parameters such as pore shape and size, pore interconnectivity and specific surface area have been shown to influence the success of bone scaffolds [4–6]. The scaffold permeability is a key parameter that best represents all the aforementioned geometrical features [7]. It affects the way in which nutrients (such as glucose) and oxygen disperse through the porous scaffold [8], it influences cell seeding efficiency [9], scaffold degradation [10], three-dimensional (3D) in vitro cell culture [10] and ultimately in vivo bone formation [11]. On the one hand, attaining an optimal value for the permeability is not straightforward, as it depends on the desired biological outcome (e.g. a high-permeability value was found to improve in vivo bone formation [3], whereas a lower value was found to enhance cell seeding efficiency [9]). On the other hand, quantifying and controlling the permeability is crucial to understanding its effect on tissue regeneration.

The intrinsic permeability coefficient k of an open porous structure is a measure of the ability of a fluid medium to flow through it and, in the simplest formulation, it can be determined

* Corresponding author at: Division of Biomechanics and Engineering Design, Katholieke Universiteit Leuven, Celestijnenlaan 300c PB 2419, 3001 Leuven, Belgium. Tel.: +32 16 327067; fax: +32 16 327994.
E-mail address: Hans.VanOosterwyck@mech.kuleuven.be (H. Van Oosterwyck).

1742-7061/$ - see front matter © 2011 Acta Materialia Inc. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.actbio.2011.12.021