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EFFECT OF INTERNAL ARCHITECTURE ON MECHANICAL PROPERTIES OF POLYCAPROLACTONE SCAFFOLDS FOR TISSUE REGENERATION

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Abstract

The aim of the study was to investigate the influence of internal architecture of 3D printed scaffolds on their mechanical properties. The polycaprolactone scaffolds with six different internal architectures fabricated by rapid prototyping method were tested in this study. The scaffolds were plotted using a 330 μm dispensing needle, layer by layer with lay-down pattern of the fibers: 00/150/300; 00/300/600; 00/450/900, 00/600/1200, 00/750/1500 and 00/900/1800. Morphological analyses and mechanical properties examinations were performed. The obtained scaffolds had structures with high open porosity (50-60%) and interconnected pores ranging from 380 to 400 μm. The different lay-down pattern and the angle deposition of successive fiber layers resulted in different internal architecture and pore shape of the constructs, what was confirmed by scanning electron microscopy and microtomography analyzes. The geometries 00/900/1800 and 00/600/1200 were characterized with the most regular shape of pores between all analyzed architectures. The pores for 00/150/300 and 00/300/600 were not regular and arranged as a ladder-like helicoid structures. The lay-down pattern of the fibers affected significantly the mechanical properties of the scaffolds. The Young's modulus (E) of the scaffolds was increasing with increase of the angle deposition between successive layers. The scaffolds were also subjected to cyclic loading and again geometry and mechanical properties were under investigation. For all type of scaffolds the differences of mechanical properties after dynamic compression have been noticed. The geometries 00/900/1800 and 00/600/1200 exhibited the highest Young's Modulus after dynamic compression according to the rest of analyzed samples. According to the conducted research there is a clear correlation between internal architecture of polymeric scaffolds and their mechanical properties.

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Introduction

The number of critical bone defects caused by injury, cancer or aging of the world population is increasing. Techniques currently used to repair these defects suffer from several disadvantages, such as a lack of mechanical and biological matching of bone characteristics, the requirement of second surgery and the risk of pathogen transmission. Scaffolds made of bioresorbable polymers are a promising alternative as they temporarily support regeneration of the damaged site and undergo complete degradation after new tissue is formed. Fabrication of bioresorbable polymers scaffolds for tissue engineering becomes a popular research topic in present days. Biodegradable and biocompatible scaffolds are required for 3D implants as a temporary support for cell growth and cell adhesion. There are several fabrication methods currently used for creating 3D porous structures with high porosity and interconnected pores. A rapid prototyping (RP) is one of the most interesting one. It allows for fabrication scaffolds with predesigned external geometry and internal architecture as well as required mechanical properties. For the cell culture survival on the scaffolds 3D constructs needs characterize with interconnecting porous to allow the culture media 3D flow in order to ensure continuous supply of nutrients and metabolites. Tissue formation is generated on porous scaffolds. Mechanical strength of the human body implant is directly connected with internal architecture of the scaffold and has to be tailored according to the different implant application. The goal of the present study was to determine the changes of the mechanical properties of fibrous PCL scaffolds with differnet internal architecture. Scaffolds with different lay-down pattern were investigated to select the optimal fiber lay-down orientation for bone tissue engineering.

Materials & methods

Cylindrical porous scaffolds (height: 4mm, diameter: 6mm) with three-dimensional orthogonal periodic porous architectures, were manufactured by Bioscaffolder® machine (SYSENG, Germany) from ε- polycaprolactone granulate (Sigma Aldrich PCL, average Mn ca. 70-90kDa), (FIG.1). The melted polymer was plotted with a 330μm dispensing needle layer by layer, with lay-down pattern of the fibers: 00/150/300; 00/300/600; 00/450/900, 00/600/1200, 00/750/1500 and 00/900/1800. The temperature of the fabrication process was between 900 and 1000C. After samples fabrication the internal architecture were investigated by

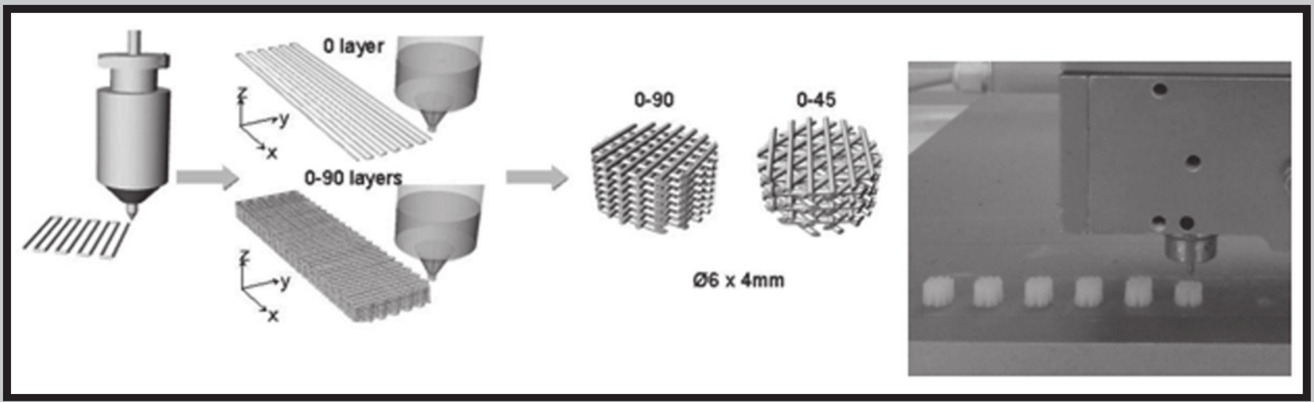

FIG. 1. Samples manufactured using Bioscaffolder® machine (SYSENG, Germany)

scanning electron microscope (HITACHI SU8000) and computed microtomography (SkyScan 1172). Static and dynamic compression tests were carried out using ElectroForce 5100 BioDynamic (BOCE, USA) at room temperature, at a crosshead speed of 1mm/min, up to 10% of compressive strain. At the beginning mechanical properties of the samples were studied in static compression tests. Then cyclic load (frequency 1Hz, 3600 cycle number) were applied to the scaffolds. After the dynamic tests, the same samples were tested in static compression conditions again.

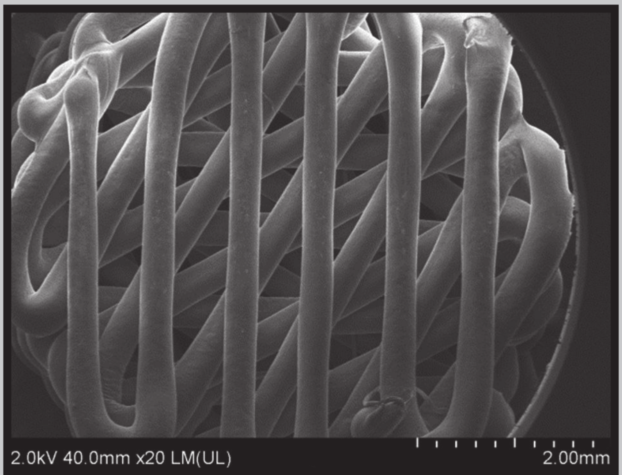

FIG. 2. Scanning Electron Microscopy (SEM) images of samples with internal architecture A) 00/150/300; B) 00/300/600; C) 00/450/900, D) 00/600/1200, E) 00/750/1500 and F) 00/900/1800.

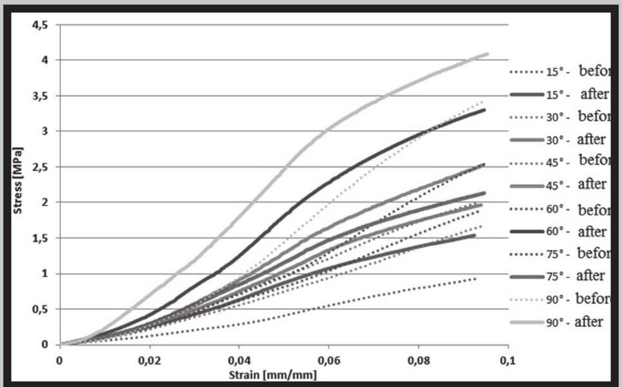

FIG. 3. Results of compression tests before and after cyclic load.

Results & discussion

The SEM and μCT observations of the microfibers scaffolds showed a well-defined internal geometry with regular interconnected pores ranging from 380 to 450μm with uniform distribution, as well as with high porosity (45-55%) (Fig. 2). The extruded filaments had a regular circular geometry with diameter of 300μm, corresponding to the used nozzle tip (330μm) (FIG.2). Delaminating of the layers wasn't noticed. The compression tests before and after cyclic loads were performed to show the influence of internal architecture on the mechanical properties of the scaffolds in dynamic conditions. Mechanical properties analysis showed big differences in elastic modulus between the tested scaffolds. The results indicate that the samples with lay-down pattern orientation 00/900/1800 and 00/600/1200 had the highest Yong's modulus before and after cyclic loading (FIG.3). Moreover, all analyzed samples had stiffened up after dynamic compression. The connections between layers remained consistent under compression in all tested constructions.

Conclusions

This study shows that scaffold architecture is relevant from a mechanical point view, since pore size and shape influence stiffness of the 3D constructs. The 3D plotter is able to fabricate structures with high reproducibility and flexibility, and it offers a wide variety of solutions in term of different architecture and geometrical configurations. The study demonstrates that PCL scaffolds with internal orientation 00/900/1800 and 00/600/1200 have the best mechanical properties among tested samples. This type of scaffold can be applied to produce highly functionalized 3D construct for bone tissue engineering aplications.

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