Proceedings of the Canadian Society for Mechanical Engineering International Congress 2022
CSME Congress 2022
June 5-8, 2022, Edmonton, AB, Canada

Printing PCL/nHAp scaffolds with mechanical properties appropriate for trabecular bone substitutes

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ABSTRACT

Background: Biomedical scaffolds used to treat bone defects must mimic the mechanical properties of native tissue, while simultaneously supporting cell function. Previous research indicates that scaffolds meant to treat trabecular bone defects should possess an elastic modulus of ~100MPa (typical for trabecular bone) and a pore size ≥250µm for cellular functionality. With extrusion-printing technology, scaffolds printed using polycaprolactone reinforced by 30% nano-hydroxyapatite (PCL/30%nHAp) with $0^o/90^o$ lay-down structures (lattice without an offset; staggered with) offer promise as trabecular bone substitutes; however, there is limited information regarding the effect of structural features (e.g., strand diameter, distance between adjacent strands) on mechanical properties. The primary objective of this study was to identify and compare relationships linking scaffold mechanical properties with structural features. The secondary objective pertained to offering suggestions for the development of PCL/30%nHAp scaffolds with desired mechanical properties for substituting trabecular bone.

Methods: PCL/30%nHAp scaffolds with both lattice and staggered structures were designed, printed (EnvisionTEC) and subjected to compressive mechanical testing (MTS Bionix). Various strand diameters (D=0.45-0.6mm) and distances between strands (L=1-1.5mm) were employed to create L/D ratios ranging from 1.67-3.04 with pore sizes ranging from ~0.4-1mm. From stress-strain curves, elastic modulus (E_C), yield strength, and resilience modulus were characterized. Mechanical properties were assessed as a function of L/D using power-law based regression and compared using overall tests of coincidence. For the development of trabecular bone substitutes, specific L/D ratios corresponding to a targeted E_C=100 MPa were identified for both lattice and staggered structures.

Results: Power-law regression explained a high degree of variance in mechanical properties (R^2=0.78-0.93). Staggered and lattice designs exhibited different ($p<0.05$), overlapping relationships with staggered geometry offering superior mechanical properties at low L/D ratios; vice versa for lattice geometry. Using E_c=100MPa as a minimum targeted value, staggered and lattice scaffolds should possess L/D ratios no greater than 1.74 and 1.59, respectively. Related, when using a strand diameter of ~0.5mm, staggered and lattice scaffolds should exhibit L/D≥1.5 to ensure a 250µm pore size needed for cellular activity. Accordingly, it is suggested that, for the development of trabecular bone substitutes, the ratio of L/D be within a range of 1.5-1.74 for staggered structures and 1.5-1.59 for lattice structures.

Conclusions: Scaffolds printed from PCL/30%nHAp with lattice and staggered structures offer promise for treating trabecular bone defects. This study identified the effect of structure features on scaffolds mechanical properties and provided suggestions for developing scaffolds with desired mechanical properties for substituting trabecular bone.