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Shape fidelity, mechanical and biological performance of 3D printed polycaprolactone-bioactive glass composite scaffolds

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ABSTRACT

Direct ink writing (DIW) is a promising extrusion-based 3D printing technology, which employs an ink-deposition nozzle to fabricate 3D scaffold structures with customizable ink formulations for tissue engineering applications. However, determining the optimal DIW process parameters such as temperature, pressure, and speed for the specific ink is essential to achieve high reproducibility of the designed geometry and subsequent mechano-biological performance for different applications, particularly for porous scaffolds of finite sizes (total volume > 1000 mm^3) and controlled pore size and porosity. The goal of this study was to evaluate the feasibility of fabricating Polycaprolactone (PCL) and bio-active glass (BG) composite-based 3D scaffolds of finite size using DIW. 3D-scaffolds were fabricated either as cylinders (10 mm diameter; 15 mm height) or cubes ($5 \times 5 \times 5$ mm^3) with height/width aspect ratios of 1.5 and 1, respectively. A rheological characterization of the PCL-BG inks was performed before printing to determine the optimal printing parameters such as pressure and speed for printing at 110 °C. Microstructural properties of the scaffolds were analyzed in terms of overall scaffold porosity, and *in situ* pore size assessments in each layer (36 pores/layer; 1764 pores per specimen) during their fabrication. Measured porosity of the fabricated specimens—PCL: $\overline{x}$ =46.94%, SD = 1.61; PCL-10 wt%BG: $\overline{x}$ = 48.29%, SD = 5.95; and PCL-20 wt% BG: $\overline{x}$ =50.87%, SD = 2.45—matched well with the designed porosity of 50%. Mean pore sizes—PCL [$\overline{x}$ = 0.37 mm (SD = 0.03)], PCL-10%BG [$\overline{x}$ = 0.38 mm (SD = 0.07)] and PCL-20% BG [$\overline{x}$ = 0.37 mm (SD = 0.04)]—were slightly fairly close to the designed pore size of 0.4 mm. Nevertheless there was a small but consistent, statistically significant ($p < 0.0001$) decrease in pore size from the first printed layer (PCL: 0.39 mm; PCL-10%BG: 0.4 mm; PCL-20%BG: 0.41 mm) to the last. SEM and micro-CT imaging revealed consistent BG particle distribution across the layers and throughout the specimens. Cell adhesion experiments revealed similar cell adhesion of PCL-20 wt% BG to pure PCL, but significantly better cell proliferation – as inferred from metabolic activity – after 7 days, although a decrease after 14 days was noted. Quasi-static compression tests showed a decrease in compressive yield strength and apparent elastic modulus with increasing BG fraction, which could be attributed to a lack of adequate mechanical bonding between the BG particles and the PCL matrix. The results show that the inks were successfully generated, and the scaffolds were fabricated with high resolution and fidelity despite their relatively large size (>1000 mm^3). However, further work is required to understand the mechano-biological interaction between the BG particle additives and the PCL matrix to improve the mechanical and biological properties of the printed structures.

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