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3D Printing of Polycaprolactone Scaffold with Multiscale Porosity Via Incorporation of Sacrificial Sucrose Particles

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Abstract : Bone tissue engineering has drawn significant attention and various biomaterials have been tested. Polymers such as polycaprolactone (PCL) offer excellent biocompatibility, reasonable mechanical properties, and biodegradability. However, PCL scaffolds suffer a critical drawback: a lack of micro/mesoporosity, affecting cell attachment, tissue integration, and mineralization. It also results in a slow degradation rate. While 3D-printing has addressed the issue of macroporosity through CAD-guided fabrication, PCL scaffolds still exhibit poor smaller-scale porosity. To overcome this, we generated composites of PCL, hydroxyapatite (HA), and powdered sucrose (PS). The latter serves as a sacrificial material to generate porous particles after sucrose dissolution. Additionally, we have incorporated dexamethasone (DEX) to boost the PCL osteogenic properties. The resulting scaffolds maintain controlled macroporosity from the lattice print structure but also develop micro/mesoporosity within PCL fibers when exposed to aqueous environments. The study involved mixing PS into solvent-dissolved PCL in different weight ratios of PS to PCL (70:30, 50:50, and 30:70 wt%). The resulting composite was used for 3D printing of scaffolds at room temperature. Printability was optimized by adjusting pressure, speed, and layer height through filament collapse and fusion test. Enzymatic degradation, porogen leaching, and DEX release profiles were characterized. Physical properties were assessed using wettability, SEM, and micro-CT to quantify the porosity (percentage, pore size, and interconnectivity). Raman spectroscopy was used to verify the absence of sugar after leaching. Mechanical characteristics were evaluated via compression testing before and after porogen leaching. Bone marrow stromal cells (BMSCs) behavior in the printed scaffolds was studied by assessing viability, metabolic activity, osteo-differentiation, and mineralization. The scaffolds with a 70% sugar concentration exhibited superior printability and reached the highest porosity of 80%, but performed poorly during mechanical testing. A 50% PS concentration demonstrated a 70% porosity, with an average pore size of 25 µm, favoring cell attachment. No trace of sucrose was found in Raman after leaching the sugar for 8 hours. Water contact angle results show improved hydrophilicity as the sugar concentration increased, making the scaffolds more conductive to cell adhesion. The behavior of bone marrow stromal cells (BMSCs) showed positive viability and proliferation results with an increasing trend of mineralization and osteo-differentiation as the sucrose concentration increased. The addition of HA and DEX also promoted mineralization and osteo-differentiation in the cultures. The integration of PS as porogen at a concentration of 50%wt within PCL scaffolds presents a promising approach to address the poor cell attachment and tissue integration issues of PCL in bone tissue engineering. The method allows for the fabrication of scaffolds with tunable porosity and mechanical properties, suitable for various applications. The addition of HA and DEX further enhanced the scaffolds. Future studies will apply the scaffolds in an in-vivo model to thoroughly investigate their performance.

Keywords : bone, PCL, 3D printing, tissue engineering
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