Abstract ID 33

MECHANICAL PROPERTIES OF BONE TISSUE ENGINEERING BIOCERAMIC SCAFFOLDS ASSESSED THROUGH MICRO-CT BASED FINITE ELEMENT MODELS

Luca D'Andrea[(1)], Dario Gastaldi[(1)], Francesco Baino[(2)], Enrica Verné[(2)], Martin Schwentenwein[(3)], Thomas Prochaska[(3)], Pasquale Vena[(1)]

[(1)]Department of Chemistry, Materials and Chemical Engineering, Laboratory of Biological Structure Mechanics(LaBS)– Politecnico di Milano, Italy
[(2)]Department of Applied Science and Technology (DISAT), Politecnico di Torino, Italy
[(3)]Lithoz GmbH Mollardgasse 85a/2/64-69 1060 Vienna/AUSTRIA
luca.dandrea@polimi.it, dario.gastaldi@polimi.it, francesco.baino@polito.it, enrica.verne@polito.it, mschwentenwein@lithoz.com, tprochaska@lithoz.com, pasquale.vena@polimi.it

Keywords: Bone Tissue Engineering scaffolds, computational models, micro-CT based models, glass-ceramic, hydroxyapatite

Summary: Assessing the mechanical properties of bone substitutes is of paramount importance in load-bearing applications. Glass-ceramics and hydroxyapatite are broadly recognized as suitable materials for Bone Tissue Engineering (BTE) thanks to their biocompatibility and bioactivity. However, the mechanical properties in the early stage after implantation may be not adequate, being affected by the intrinsic brittle nature of the constituent material as well as by defects induced by the manufacturing process and inadequate design of scaffold micro-architecture. In this study, two kinds of bioceramic scaffolds produced by additive manufacturing technologies are considered: glass-ceramic scaffolds obtained through the robocasting technique and hydroxyapatite scaffolds obtained through stereolithography. Specifically, the former exhibits a fiber distribution along with two perpendicular directions on parallel layers with a 90° tilting angle between two adjacent layers, whereas the latter closely replicates the architecture of a polyurethane foam used as virtual model. The mechanical properties of both scaffolds have been obtained through micro-Computed Tomography (micro-CT) based Finite Element Modeling. The micro-CT scans for the two classes of scaffolds have a pixel size of 5 μm and 10.5 μm, respectively; these spatial resolutions allow for the identification of micro-cracks induced by the sintering process as well as the deviation of the final geometry from the original design of the microstructure induced by the temperature treatment after printing. Elastic properties were assessed by applying 6 different unit macroscopic strains (one for each strain component) on a Representative Volume Element (RVE). As voxel-type finite element grids were used, each pixel was corresponding to one cubic finite element. The full elastic tensor is obtained thus providing elastic properties along any direction in the three-dimensional (3D) space. The strength was obtained through a damage-based cyclic algorithm. The non-symmetric tension/compression strength mismatch was assumed through a Drucker-Prager criterion. The constitutive parameters for the glass-ceramic and hydroxyapatite were assessed through micro-mechanical laboratory tests. In particular, elastic modulus was assessed through nanoindentation tests on glass-ceramics, while nanoindentation and micro-bending tests were used for hydroxyapatite samples. The micromechanical bending tests were performed on a set of samples exhibiting a characteristic size similar to that of the trabecular microstructures of the 3D-printed scaffolds manufactured through the same printing technique (stereolithography). The obtained results have shown that the robocasted glass-ceramic scaffold exhibited an elastic modulus and strength which were weakly affected by initial fractures and small defects, while larger defects due to imperfect connections between perpendicular fibers affected the mechanical properties more substantially, especially along the direction perpendicular to the printing plane with an elastic modulus up to one-tenth of that of scaffold without this kind of defect. The HAp scaffolds exhibited an elastic modulus about one-tenth that of the bulk material, and quadratic dependency with the porosity. The uniaxial compressive stress-strain behaviour shows the typical trend of a foam-like structure, showing a compressive strength of 3% respect to the bulk material's tensile strength.