Improving the Mechanical Performance of Bioceramic Scaffolds for Biomedical Applications

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The optimal approach to address the problems associated with the repair of bone-related lesions is to develop artificial biomaterials, with bone-like mechanical properties (low density and stiffness and high strength and toughness) and able to interact with the tissues, so that they can actively induce bone regeneration. A strategy to achieve this type of interaction with surrounding tissue and to stimulate cell penetration and proliferation after implantation is to use porous matrices of osteophilic materials, such as bioceramics (HA, TCP …) and bioglasses (45S5, 13-93 …). The porosity of this structures must be interconnected and with a certain interconnection size, to allow vascularization, cell penetration and nutrient diffusion into the scaffold. In conventional porous scaffold fabrication methods (solvent casting, fibre meshing, gas foaming, melt moulding, freeze drying, *etc*) it is difficult to precisely control pore size, geometry, and spatial distribution, and therefore to achieve the required degree of interconnectivity it is necessary to produce very high porosities, which translate into very low strengths that severely limits the range of applications. To overcome this hurdle, three different strategies are investigated in this study.

Optimizing the scaffold macropore architecture using robocasting as the fabrication method. This technique, also known as direct ink writing, consists of the robotic deposition of highly concentrated colloidal suspensions (inks) capable of fully supporting their own weight during assembly thanks to their carefully tailored composition and rheological properties. Thus, a 3D structure is printed directly as a network of ink rods extruded through a deposition nozzle of certain diameter mounted on a 3-axis motion stage, controlled independently by a computer-aided direct-write program. The high level of control over pore architecture provided by robocasting makes possible to achieve the required degree of pore interconnectivity with relatively low porosities, which improves significantly the mechanical properties of the scaffolds.

Improving the intrinsic strength and toughness of the individual bars composing the scaffold. Since rod microporosity reduces the intrinsic mechanical properties of the rods (the micropores act as starting flaws for cracking) dense, defect free struts are desirable. This can be achieved through optimization sintering and densification and/or through the incorporation of a reinforcing agent (*e.g.*, graphene-based nanoplatelets) to the bioceramic microstructure.

Adding a biodegradable polymeric phase. Despite the improvement in pore architecture achieved by robocasting and in the intrinsic properties of the individual bars, the main limitation of these ceramic scaffolds still lies in their intrinsic brittleness and the poor mechanical resistance associated to their porosity. Infiltrating the bioceramic scaffold with biodegradable polymers to obtain either fully-impregnated structures or coated structures improves the scaffold's mechanical performance, both in terms of strength, due to defect healing and stress shielding mechanisms; and toughness, as a consequence of a crack bridging mechanism produced by polymer fibrils.

To quantify the mechanical enhancement attained through these approaches, the mechanical performance of the developed materials is evaluated under compressive and bending stresses. The obtained results are compared with values reported in the literature for bone tissue and their implications concerning the use of bioceramic robocasted scaffolds in load-bearing bone tissue engineering applications are discussed.

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