Design and Preparation of Bioactive Ceramic Scaffolds with Hierarchical Pore Networks

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Supporting Information

S1. Experimental details

Synthesis of gel paste: The gel paste used for robotic deposition was prepared using tetraethyl orthosilicate (TEOS), triethyl phosphate (TEP), and calcium nitrate tetrahydrate (CaNT) as inorganic precursors, a triblock copolymer, poly(ethylene oxide)-poly(propylene oxide)-poly(ethylene oxide) (Pluronic F127, $EO_{100}PO_{65}EO_{100}$, average M_n = 12600), as the meso-structure-directing agent through an evaporation-induced self-assembly process, and methyl cellulose (MC, average M_n = 86000,) as both the macro-structure directing agent and binder. In a typical synthesis, 2.88 g of F127 is dissolved in 18.1 ml of ethanol (EtOH). Stock solutions, which were prepared by mixing 1.36 g of CaNT, 0.26 ml of TEP, 6 ml of TEOS, 0.95 ml of HCl (1M), 7.62 ml of EtOH and 2.86 ml of H_2O, were added to this solution after stirring them for 1h separately and were vigorously stirred together for another 4h at 40 °C. The reactant solution was sealed and aged at 40 °C for 24h without stirring and then evaporated at 40 °C and 40 %RH for 10-24 h without the seal until the volume of reactant solution was reduced to one-fifth of its original volume. 1.4 g of MC was then mixed with this sol solution to make the homogeneous gel paste. The molar composition of the gel paste was TEOS : CaNT : TEP : F127 : MC = 1 : 0.2 : 0.05 : 0.008 : 0.0006 in this case.

Robotic deposition of scaffolds: Scaffolds were fabricated by direct exclusion of the paste gel onto a heated substrate using a robotic deposition device. A commercially available gantry robotic deposition apparatus (DASA-DTR3-441) was used with specially-altered systems such as an actuator used for controlling the position of the deposition nozzle, an infusion pump, and a heat-control system (see Fig. S1). Three axes of motion control (x, y, and z-axis) were provided by the gantry system, and a material delivery assembly composed of a syringe acting as a reservoir was affixed on the z-axis motion stage. The z-axis motion stage assembly was mounted on a moving x gantry to enable the controlled motion of the mounted syringe in all three dimensions. The gel paste housed in the syringe was deposited through a cylindrical nozzle (17~26 gauge (G), 24 G (≈ 500 μm) is generally used). A linear actuator served to depress the plunger of the syringe at a fixed speed, so that the volumetric flow rate could be precisely controlled. The extrusion strength and speed were varied in the range of 200~250 μl/min and 5~10 mm/s, respectively, depending on the viscosity of the gel paste. The gel paste was extruded onto the

heated substrate (60~100 °C), leading to its fast condensation followed by both the evaporation of the solvent and the solidification of the MC. The shape and size of the scaffold can be designed at will and controlled by the computer system.

Fabrication of hierarchically porous scaffold: The fabricated organic-inorganic hybrid scaffolds were aged at 40 °C for 24 h and heat treated at 500-700 °C to remove the organic polymer template, in order to obtain the final calcined porous scaffolds.

In Vitro bioactivity: The assessment of the in vitro bioactivity of the hierarchically porous scaffolds was carried out in SBF at 37 °C. Before immersing it in SBF, the scaffold was treated using alternate soaking processes: The scaffold was soaked in 300 ml of calcium chloride ($CaCl_2$, 200 mM) for 10 sec and then rinse with excess water. The scaffold was subsequently soaked in potassium hydrogen phosphate trihydrate ($K_2HPO_4 \cdot 3H_2O$, 200 mM) and then rinsed with excess water. These steps were repeated 3times and the scaffold rinsed well. The scaffold was immersed in SBF after drying. SBF contained 142.0 mM Na^+, 5 mM K^+, 1.5 mM Mg^{2+}, 2.5 mM Ca^{2+}, 147.8 mM Cl^-, 4.2 mM HCO_3^-, 1.0 mM HPO_4^{2-}, and 0.5 mM SO_4^{2-}. Its chemical composition was similar to that of human plasma. The solution had a pH of 7.4 and was kept at 37 °C before use.

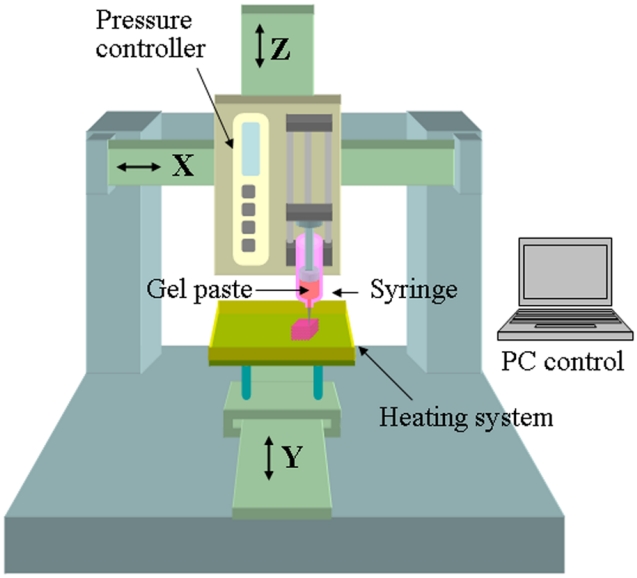

Figure S2. Schematic illustration of robotic deposition apparatus

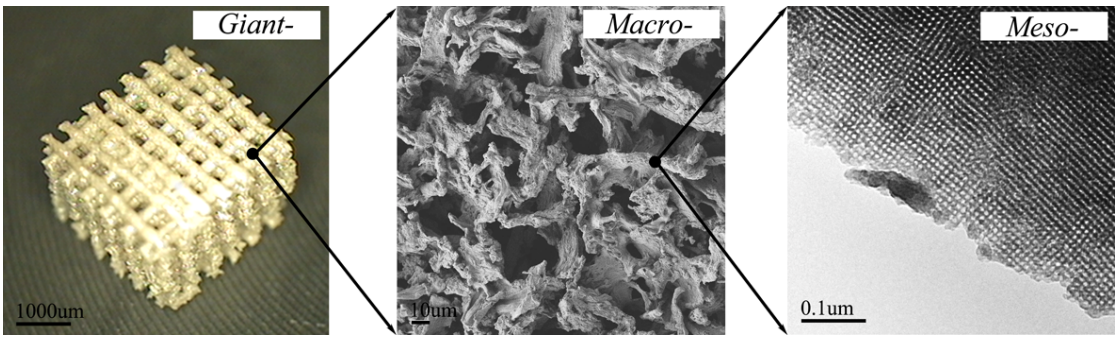

Figure S3. Image of hierarchical 3D porous structured scaffold with giant-pore (optical image, left), macro-pore (SEM image, middle) and meso-pore (TEM image, right).

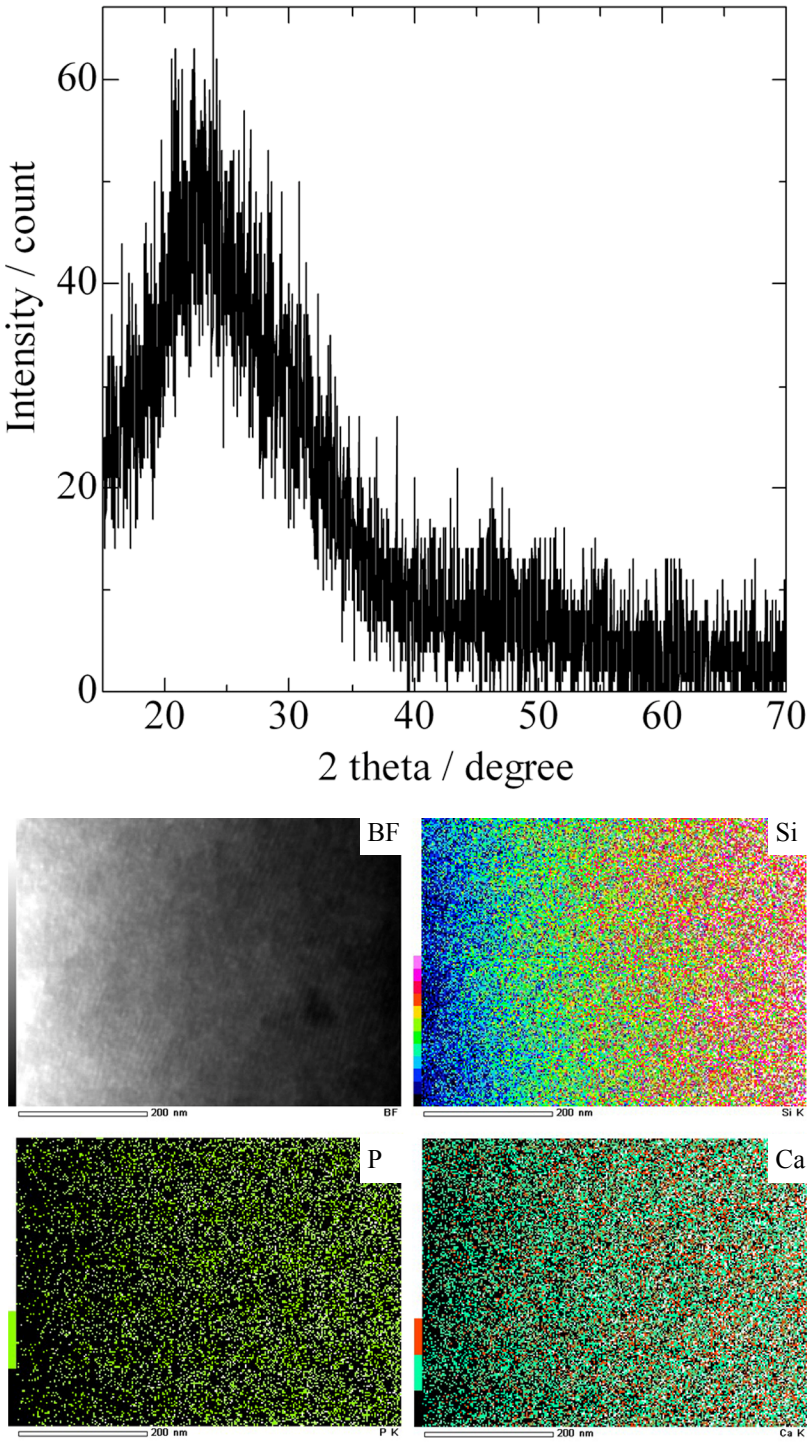

Figure S4. XRD (upper) and quantitative mapping image from TEM (lower) of hierarchical porous BG scaffold. Obtained data revealed that the Ca and P species were not aggregated or separated out and were distributed homogeneously in the silica network.

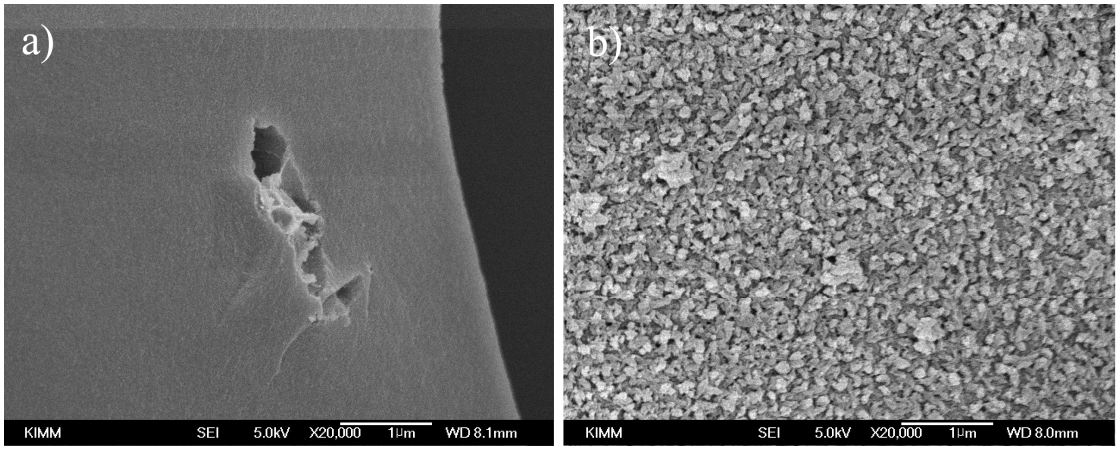

Figure S5. SEM images of hierarchical porous scaffold after immersing in SBF for 0 (left) and 24h (right).