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Design and Characterization of Interconnected Porous Scaffolds with Central Cavity

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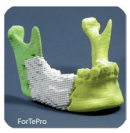
INTRODUCTION

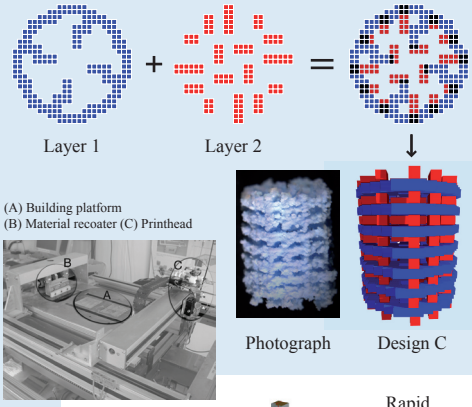


To reconstruct bony tissue of large cavities, highly porous biocompatible scaffolds based on hydroxyapatite granulates can serve as 3D templates for initial cell attachment and subsequent tissue formation. The design of the scaffolds has to fulfill different criteria to ensure cell viability and function. These include nanoporosity to allow diffusion of molecules for nutrition and signaling, micropores to ensure cell migration and capillary formation as well as macropores for arteries and veins.
Synchrotron radiation-based micro computed tomography (SRμCT) is a unique, non-destructive technique to characterize the scaffolds with respect to the integral nano-porosity and the detailed morphology of micro- and macropores under in vitro conditions.

GENERAL DESIGN

As model systems open porous scaffolds (design A, B and C) of cylindrical shape (D = 4 mm, H = 6 mm) were fabricated by 3D printing using the pixel size of 240 μm. Similar to the compacta, they exhibit a denser outer structure to provide the mechanical stability. A central channel provides space for blood vessels, nerves, or medium flow. Starting from this main channel, 48-72 micro-channels several hundred micrometers thick form an interconnected network. As building material, nano-porous spray-dried hydroxyapatite (HA) granulates were used.

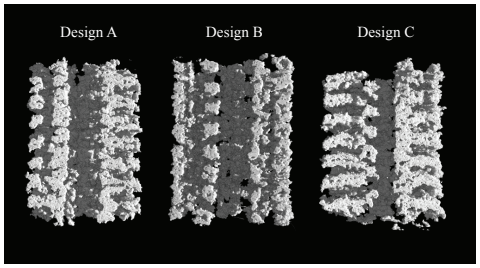
SCAFFOLD FABRICATION



(1) layer of hydroxyapatite powder is spread out (2) binding solution is dropped onto powder (3) after platform is lowered, next layer of powder is spread out (4) printed component shown in red

SRμCT

SRμCT measurements were carried out in absorption contrast mode at the beamline W 2 (HASYLAB at DESY, Hamburg, Germany) using the photon energy of 30 keV. The pixel length corresponds to 3.7 μm.



The virtual vertical cuts through the 3D reconstructed tomograms offer a look at the central cavities with a diameter of 0.7-1.0 mm. They provide space for medium flow in vitro and cavities for blood vessels or nerves in vivo.

REGISTRATION

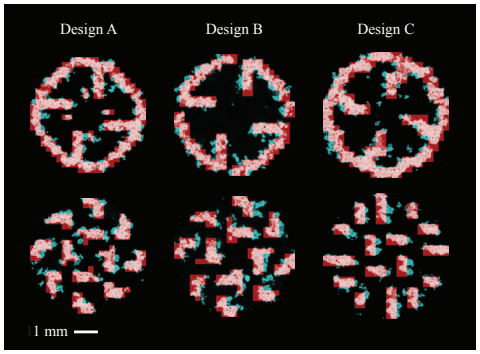
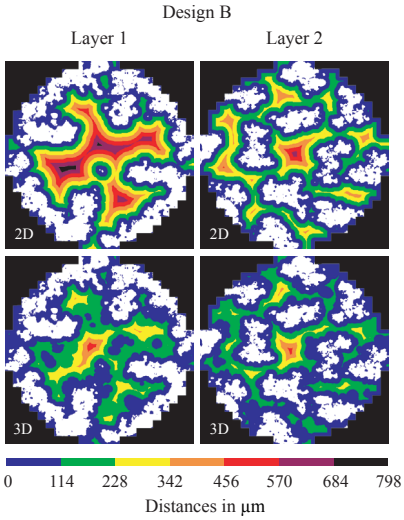


Image registration has been performed to calculate the exact shrinking parameter of the sintered scaffolds. The shrinking is almoste isotropic and corresponds to (73 ± 2)%. The mask is red-colored, material outside mask blue and material inside mask white. Relative to the mask, (31 ± 2)% are red-colored and (27 ± 3)% blue, independent on design.

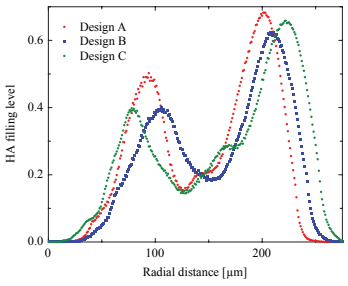
DISTANCE MAP



Mean distance to material	Design A	Design B	Design C
2D analysis	133 μm	148 μm	143 μm
3D analysis	100 μm	98 μm	98 μm

The distance map is used to quantify the pore architecture. 2D analysis only gives an upper limit, because material can be present above and below the layer. Consequently, the mean value for the distance transform is larger for the 2D than for the 3D analysis (s. table).

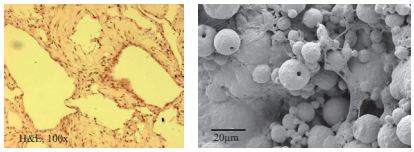
RADIAL DENSITY



Starting from the center of the scaffold, the plots represent the radial density distribution. Precise values of the scaffold's and the central cavity's diameter can be measured. The distribution of building material averaged for layer 1 and 2 varies with the design.

CELL BIOLOGY

The scaffolds were statically loaded with 80 μl cell suspension containing 200'000 cells isolated from human tooth and cultured for 28 days. The H&E staining (left) shows an association of cells and extracellular matrix on the decalcified scaffold. On the right, the SEM image shows cells spanning between the nano-porous HA granulates.



CONCLUSION & ACKNOWLEDGEMENT

The digital, 3D data non-destructively obtained by SRμCT are the perfect basis for visualization and quantification of the scaffold morphology. The application of standard software, however, is difficult because of the huge data size in the range of GB and hence specific code was developed. The distance mapping clearly demonstrates that the 2D analysis overestimates the mean distance to the material by 30 to 50%. The perfect connectivity of the micro-channel network can be verified by component labeling. 3D registration algorithms are shown to allow for the precise measurement of the shrinking as the result of the sintering process, which is crucial for patient-specific implant planning. The central cavity enlarges the surface area accessible for cell penetration and enhances medium flow in vitro. It also provides space either for natural in-growth or surgical incorporation of blood vessels or nerves. The authors thank HASYLAB at DESY, Hamburg, Germany, for beamtime allocation (I-05-028 and II-20060035 EC).