Design and Characterization of Scaffolds with Interconnected Pores and Central Canal

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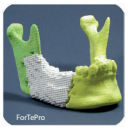
INTRODUCTION

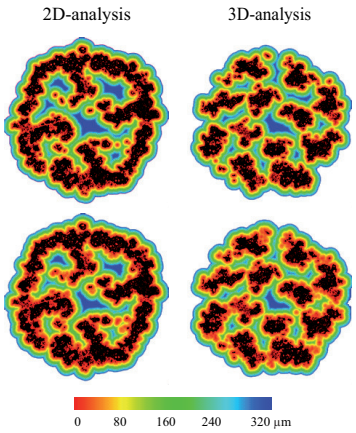


To reconstruct bony tissue within large defects, highly porous biocompatible scaffolds based on hydroxyapatite granulates can serve as 3D templates for initial cell attachment and subsequent tissue formation. The design of the scaffolds has to fulfill different criteria to ensure cell viability and function. 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 nanoporosity and the detailed morphology of micro- and macropores under in vitro conditions.

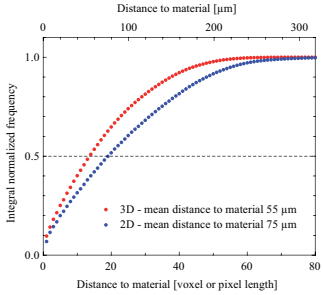
SCAFFOLD DESIGN

Three different open porous scaffolds A, B and C of cylindrical shape (D = 4 mm, H = 6 mm) were designed layer-by-layer and realized 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 larger blood vessels and medium flow. Perpendicular to this main channel, 48-72 channels with diameters between 180 and 700 μm allow cell migration. Finally, the designs ensure that the total X-ray absorption is comparable in all directions perpendicular to the main channel axis.
As building material, spray-dried hydroxyapatite granulates were used. Each scaffold was statically loaded with 80 μl cell suspension containing 200'000 cells isolated from human tooth. The cell-scaffold constructs were harvested after 28 days.

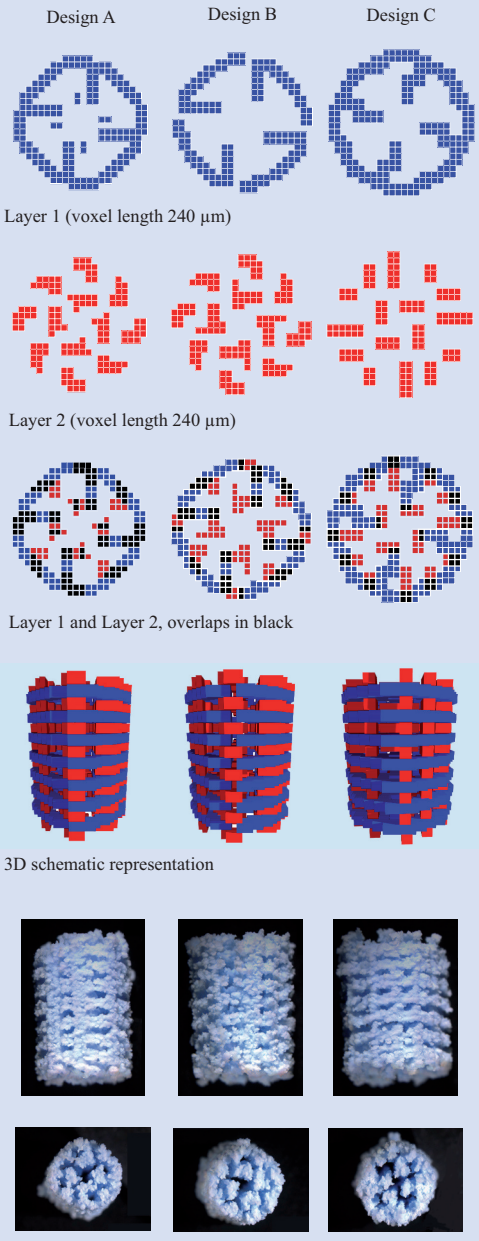
POROSITY ANALYSIS



The distance map is used to quantify the pore architecture. Here, the minimal distance of each pixel (2D analysis) or voxel (3D analysis) to material is determined. 2D analysis only gives an upper limit, because material can be present above and below. Consequently, the mean value for the distance transform is larger for the 2D analysis than for the 3D analysis. Hence, the 3D analysis is necessary to characterize the pore architecture.



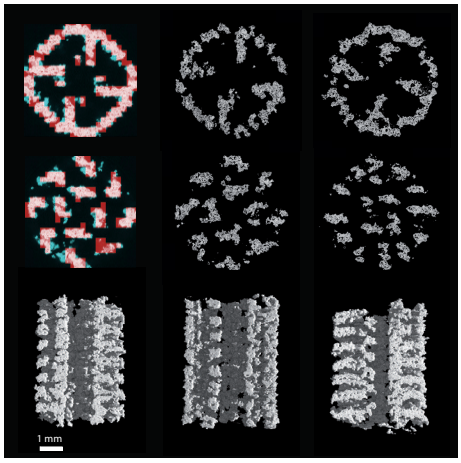
BIOMIMETIC SCAFFOLDS FOR BONE AUGMENTATION



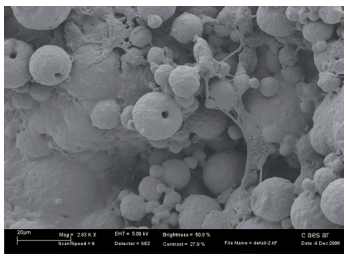
Photographs of the scaffolds realized by 3D printing and sintering at 1240 °C.

SRμCT

SRμCT measurements were carried out in absorption contrast mode at the beamlines BW2 and W2 (HASYLAB at DESY, Hamburg, Germany) using the photon energy of 24.5 keV and 30 keV. The higher photon energy of 30 keV is better suited for the total absorption of the scaffolds. Here, the pixel length corresponds to 3.7 μm [B. Müller et al. (2001) Proc. SPIE 4503:178-88] and the spatial resolution determined by the modulation transfer function to 7.4 μm.



Two selected slices representing layer 1 and 2 of each design are shown. Image registration (shown for Design A in light red) has been performed to calculate the exact shrinking parameter of the sintered scaffolds. The shrinkage is 20% in x- and y- and 19% in z-direction.
3D representations of the tomograms of designs A, B and C are given on the bottom. The virtual vertical cuts offer a look at the central openings with a diameter of 0.7-1.0 mm which provide space for medium flow in vitro and cavities for blood vessels a or nerves in vivo.



This SEM image provides a look at the micro-structure of the scaffold. Cells span between the hydroxyapatite granules. The rounded structures offer a large surface for cell attachment. Histological analysis also shows an association of cells on the biomaterial.

CONCLUSION AND ACKNOWLEDGEMENT

SRμCT allows non-destructively analyzing the porosity of ceramic scaffolds from millimeter to nanometer scale. Therefore, the method provides complementary information to classical histology, avoiding any kinds of preparation artifacts as the result of sectioning. Another advantage of the digital 3D data is the possibility to apply computer vision tools such as distance mapping and registration to study pore size distribution and exact shrinking parameters. As histological analysis uncovered, the 3D hydroxyapatite scaffolds are suitable for the osteogenic differentiation by progenitor cells.

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