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Image-based analysis of 3D-printed scaffolds for bone augmentation

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INTRODUCTION: Rapid prototyping technology, especially 3D printing (3DP) has become attractive for fabrication of bone augmentation scaffolds. One main advantage of 3DP is the ability to create scaffolds with controlled open porosity for osteointegration [1]. Porosity analysis on the different length scales, however, is a major challenge. In addition to the classical methods for the integral determination (intrusion, gravimetry), we used image-based pore's characterization using synchrotron-radiation-based micro computed tomography (SRµCT).

METHODS: Scaffolds (d = 3 mm, h = 6 mm) were fabricated out of hydroxyapatite (HA) granulate using an experimental 3D printer [1] with the spatial resolution of 106 dpi and the slice thickness of 200 µm. The green bodies were sintered at 1250 °C to achieve the necessary mechanical stability. SRµCT was performed at the beamline BW 2 (HASYLAB at DESY, Hamburg, Germany) in absorption contrast mode using the photon energy of 24 keV and the voxel size of 4.1 µm. 3D data were reconstructed by the filtered back-projection algorithm. The distance transform for quantitative 3D porosity characterization was obtained by the Gigatools software [3].

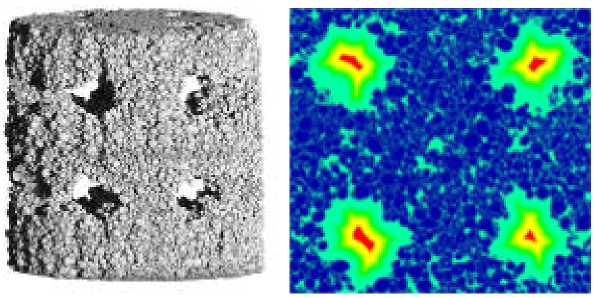

Fig. 1: 3D representation of a SRµCT tomogram of a 3D-printed HA scaffold to visualize the macro-pores realized by 3DP (left). The right image shows a distance map of one characteristic slice of the scaffold. Material is blue colored. The other colors represent distances in air to the scaffold material.

RESULTS: Fig. 2 shows the cross-section of a single HA granule. Here, the nano-porous structure is easily seen. An integral determination of this nano-porosity is obtained interpreting the histograms of the tomograms comparing dense and porous HA. The macro- and micro-porosity above the spatial resolution of the tomographic imaging is comprehensively quantified calculating the distance maps of the binarized 3D data (cp. Fig. 2B). The determination of the threshold is difficult to fix. Therefore, the mean porosity versus all possible threshold levels was analyzed, in detail.

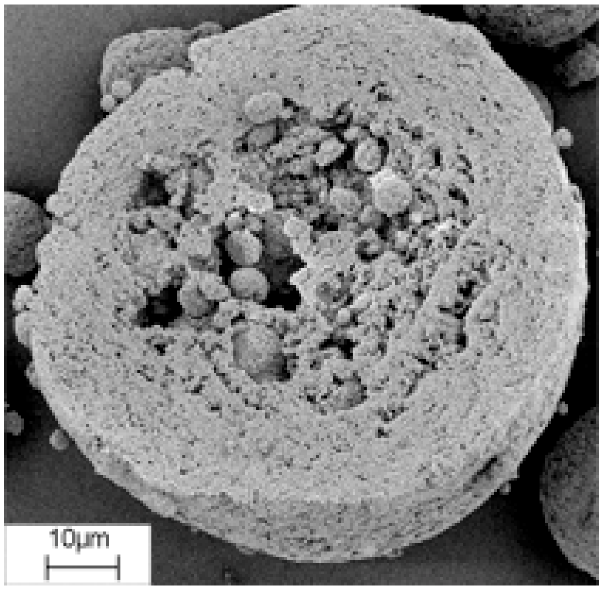

Fig. 2: SEM cross-section of HA granule with nano-pores.

DISCUSSION & CONCLUSIONS: The true micrometer resolution of SRµCT allows the precise determination of the granules shape, the pore sizes and the pore size distribution of the investigated porous scaffolds. The interconnectivity of 3D printed pore structures can be analyzed on the scale well below the cellular level. Furthermore, the determination of the intergral nano-porosity becomes possible non-destructively. This information is crucial for the optimization of the scaffold fabrication process and, finally, for the osteointegration.

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