7th International Bernd Spiessl Symposium, June 16-18, Basel, Switzerland

# Comparative Study on Morphology and Mechanics of Bone Scaffolds Fabricated by Rapid Prototyping

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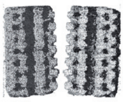
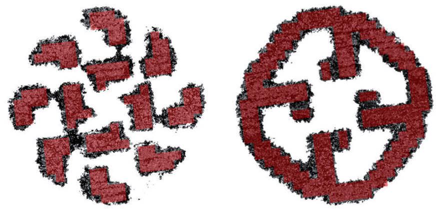
## INTRODUCTION



There is an increasing need for porous scaffolds to treat large bone defects resulting from tumor surgery and trauma. In order to substitute and to support the reconstruction of larger osseous defects, porous scaffolds fabricated from tri-calcium phosphate (TCP) play a more and more important role, especially since calcium phosphate phases are vital constituents of bony tissues. The poster reports on three-dimensionally printed, micro-porous TCP scaffolds with a nature-analogue architecture. The phosphoric acid treatments have been optimized to obtain physiologically relevant compression strengths. The obtained mechanical parameters of various scaffold designs are correlated to the scaffold morphology on the micrometer scale, whereas the micro-morphology was uncovered by micro computed tomography. Here, we compare the quality factor of alpha-TCP constructs and the ones between different designs. Furthermore, the distance maps of the scaffolds are extracted for comparison. These distance maps are the basis to study the accessibility of the scaffold by living cells.

## SRµCT

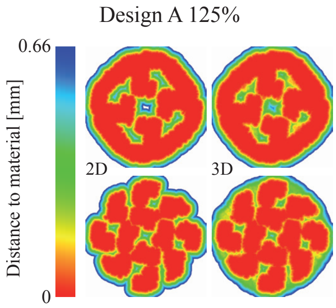
Synchrotron radiation-based micro computed tomograpy (SRµCT) allows the non-destructive three-dimensional (3D) visualisation of the micro-porous TCP scaffolds.



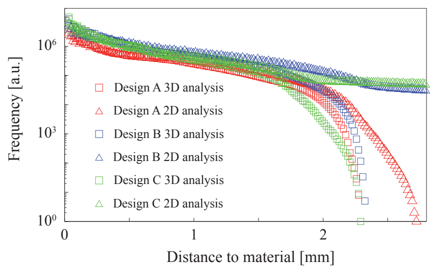
Two slices through the dataset of design A (scale 200%) representing layers 1 and 2, and in red the corresponding original designs. Good matching between the printed scaffolds and the pattern can be seen.

From the registered datasets, a quality factor describing the scaffold similarity to the design can be derived according to [1].

## DISTANCE MAPPING



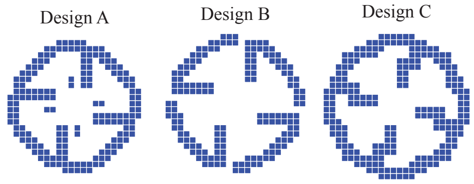

The pore size distribution can be determined by distance mapping. The 2D analysis slightly overestimates the distance to material compared to full 3D analysis. The distance histogram shows the compactness of the material. Clear differences between 2D and 3D analysis can be seen especially in the range above 2 mm.



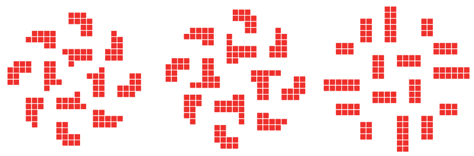

## BIOMIMETIC SCAFFOLDS FOR BONE AUGMENTATION

Three different cylindrical designs were printed layer-by-layer with the multi-colour 3D-printing system (Spectrum Z510, Z-Corporation, USA) by rapid prototyping. As raw materials a powder mixture (di-calcium phosphate anhydrous and calcium carbonate) and 20% phosphoric acid as an anorganic binder has been used. The layer thickness was set to 125 µm and the binder-volume ratio corresponded to 0.371. Residual TCP in the pores was removed with compressed air.

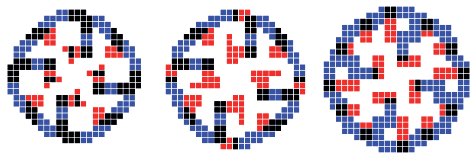
Design A Design B Design C



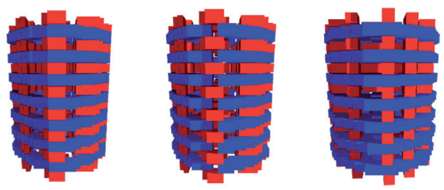
Layer 1 (voxel length 240 µm)



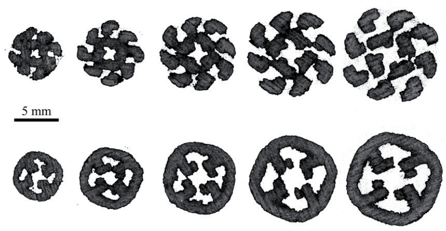
Layer 2 (voxel length 240 µm)



Layer 1 and Layer 2, overlap in black



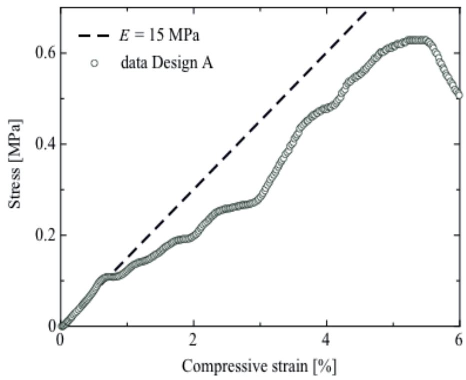
3D schematic representation




Selected slices through the datasets of design A printed at different scaling factors (from left to right 100%, 125%, 150%, 175% and 200%).

## MECHANICAL TESTS

The mechanical tests were done using the universal testing machine D020 (Zwick GmbH&Co, Ulm, Germany). The Young's moduli have been determined from the linear fits within the initial stages of compression (dashed line).




The steps in the stress-strain curve result from the successive cracking of the scaffold layers.

Severe differences in mechanical stability between the designs were found. Post-hardening with phosphoric acid (20%) was performed on all specimens. Crucial to scaffold stability is the storage period after treatment. Double treatment (P2) leads to a relevant decrease of scaffold weight compared to single treatment (P1), while no significant increase in stability was observed.

| Scaffold serie | Length [mm] | Diameter [mm] | Weight [g] | Young's Modulus [MPa] |
|---|---|---|---|---|
| $A1_{n9}P2$ | 7.58 | 5.38 | 158.22 | 104.4 ± 1.38 |
| $A2_{n7}P2$ | 7.59 | 5.34 | 159.86 | 153.5 ± 1.73 |
| $A3_{n8}P2$ | 7.42 | 5.37 | 157.25 | 145.5 ± 2.24 |
| $A4_{n9}P2$ | 7.50 | 5.35 | 154.67 | 135.3 ± 1.43 |
| $A5_{n10}P1$ | 7.49 | 5.37 | 167.10 | 146.5 ± 1.90 |
| $A6_{n10}P1$ | 7.52 | 5.41 | 167.70 | 130.4 ± 1.73 |
| $A7_{n10}P1$ | 7.61 | 5.38 | 170.70 | 130.2 ± 1.81 |
| $B1_{n7}P2$ | 7.57 | 5.68 | 153.71 | 64.5 ± 1.41 |
| $B2_{n7}P2$ | 7.44 | 5.66 | 153.43 | 70.1 ± 1.00 |
| $B3_{n8}P2$ | 7.44 | 5.72 | 155.75 | 59.6 ± 0.93 |
| $B4_{n8}P2$ | 7.54 | 5.67 | 156.00 | 66.6 ± 1.14 |
| $B5_{n10}P1$ | 7.53 | 5.62 | 171.20 | 74.5 ± 1.13 |
| $B6_{n10}P1$ | 7.19 | 5.67 | 172.50 | 97.7 ± 1.34 |
| $B7_{n9}P1$ | 7.60 | 5.71 | 171.89 | 75.0 ± 1.57 |
| $C1_{n8}P2$ | 7.68 | 6.06 | 174.50 | 60.5 ± 0.76 |
| $C2_{n6}P2$ | 7.61 | 6.05 | 176.00 | 59.7 ± 0.90 |
| $C3_{n9}P2$ | 7.62 | 6.07 | 178.22 | 52.1 ± 0.76 |
| $C4_{n9}P2$ | 7.76 | 6.09 | 176.89 | 40.5 ± 0.62 |
| $C5_{n9}P1$ | 7.54 | 6.04 | 184.88 | 64.3 ± 0.87 |
| $C6_{n10}P1$ | 7.50 | 6.04 | 182.60 | 68.2 ± 0.89 |
| $C7_{n8}P1$ | 7.68 | 6.11 | 197.88 | 53.5 ± 0.77 |

## CONCLUSION AND ACKNOWLEDGEMENT

Rapid prototyping is a suitable technique for creating tri-calciumphosphate scaffolds. The distance map reveals the presence of few large pores and channels, while only few micro-pores can be found. Further investigation is needed to improve the removal process of excess material to increase micro- and nano-porosity as well as the post-hardening procedure with $H_3PO_4^-$. The amount of phosphoric acid during post-hardening should be set as low as possible to excessive matereial loss material which correlates with decreased mechanical stability. The mechanical stability should be improved to endure the interactions of the mandible and the maxilla, e.g. during mastication.

The authors thank HASYLAB at DESY Hamburg, Germany, for beamtime allocation (I-05-028 and II-20060035 EC).

[1] F.C. Fierz *et al.* Biomaterials **28** (2008), 3799-3806