

# Determination of porosity from tomographic data of hydroxyapatite scaffold-like structures

Dominika Kalasova\*, Tomas Zikmund, Premysl Stastny, Martin Trunec, Jozef Kaiser

\*dominika.kalasova@ceitec.vutbr.cz



Central European Institute of Technology  
Brno University of Technology  
Brno, Czech Republic

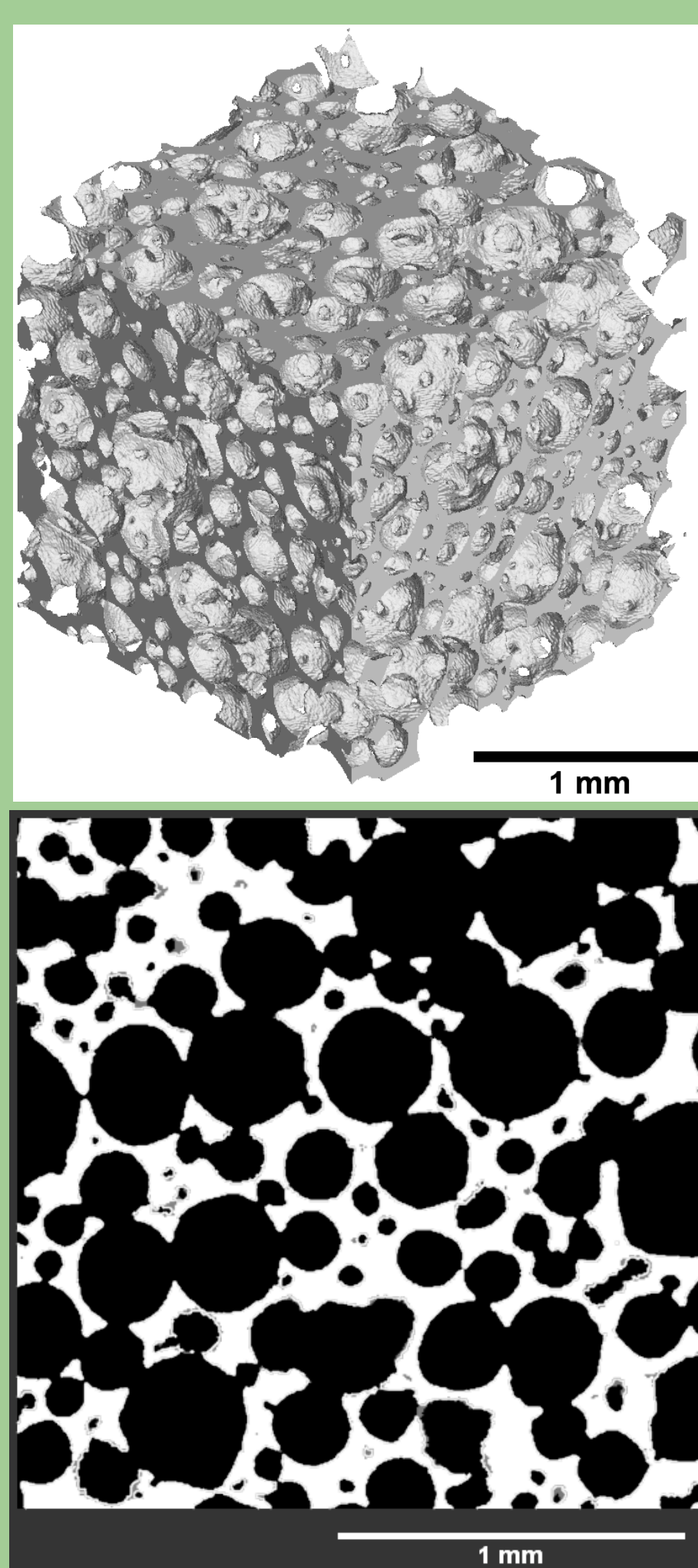


## Abstract

In many fields, researchers take advantage of knowledge of material's porosity. For obtaining quantitative information of single, enclosed cavities, a lot of methods have been developed. The situation gets complicated when pores are interconnected within the structure. This is the case of foams and scaffolds, which are used in modern biology research for tissue engineering.

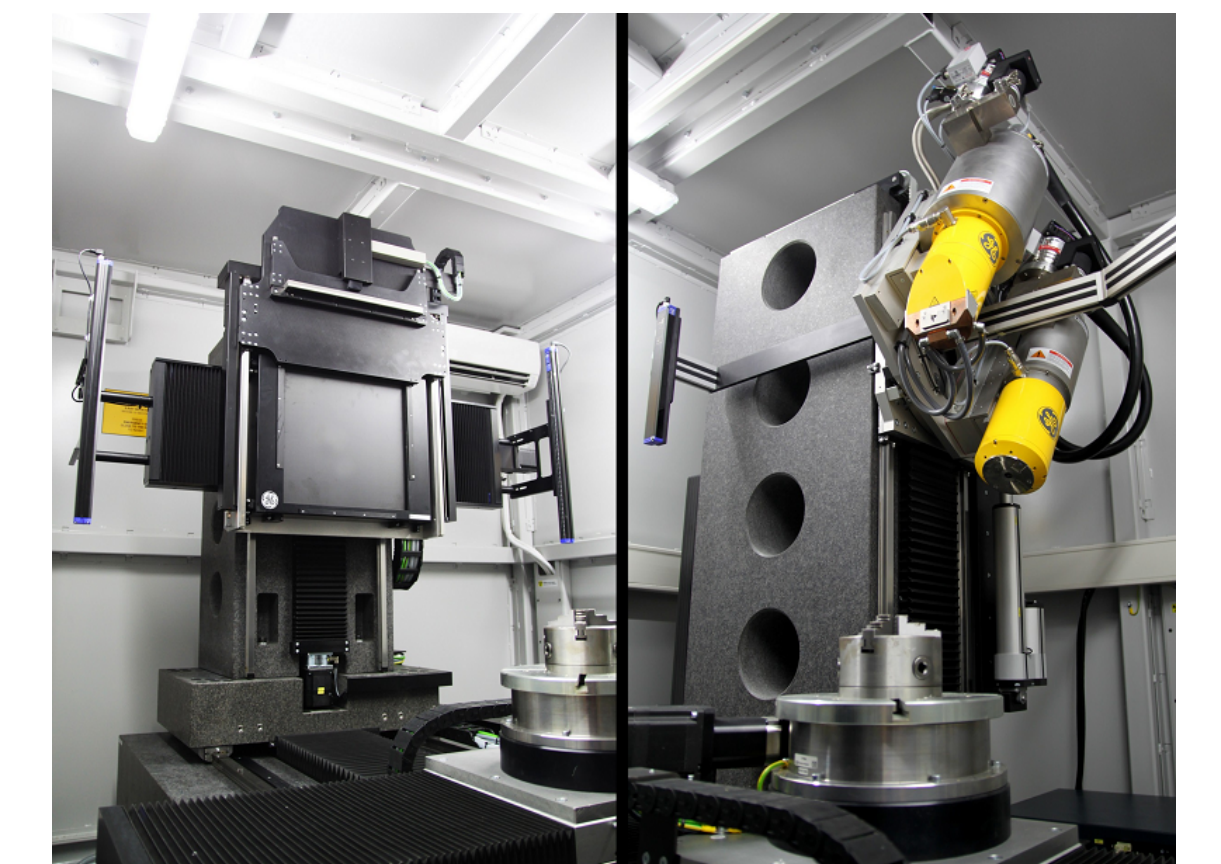
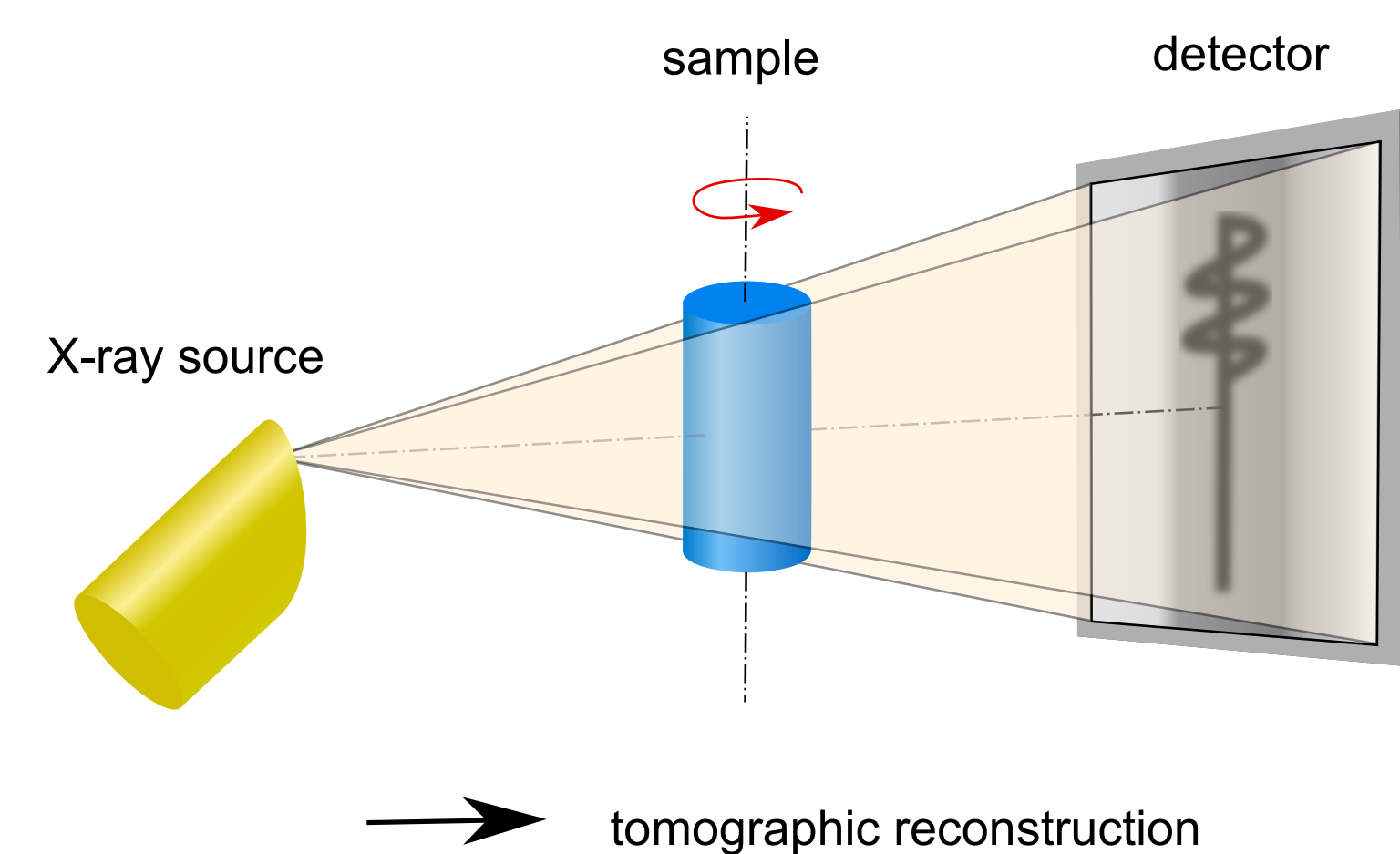
X-ray computed microtomography ( $\mu$ CT) is a nondestructive method for 3D imaging of materials. For getting quantitative information about porosity in foams or scaffolds scanned with  $\mu$ CT, many software offer various approaches. In this work, different software for pore analysis are compared. As a testing sample, a tomographic data of hydroxyapatite foam for bone replacement were used. It was scanned on GE phoenix L240 with linear voxel size 5  $\mu$ m. The material was segmented from background using Otsu method implemented in ImageJ.

**Figure 1:** 3D render (up) and slice (down) of segmented  $\mu$ CT data of hydroxyapatite foam. Grey (in the 3D render) or white (in the slice) correspond to the material, the background colour corresponds to the air.



## X-ray computed tomography

X-ray computed tomography (CT) is a nondestructive method for imaging of inner structure of materials. The sample is placed between the X-ray tube and the detector. A lot of projections from different angles of rotation of the sample are recorded. From these projections, slices through the sample are reconstructed to get 3D data. Grey values in slices correspond to linear attenuation coefficient of material.



**Figure 2:** Scheme of X-ray computed tomography setup. **Figure 3:** CT device GE phoenix L240.

CT scan of an object visualizes its inner structure. It is possible to get a slice through an object in arbitrary direction. Based on different X-ray attenuation, and therefore different grey levels of various structures in CT data, it is possible to segment and further analyze these structures. Apart from visualization, analyses such as pore analysis, wall thickness analysis, and dimensional measurements can be carried out.

## Results

### Pore3D

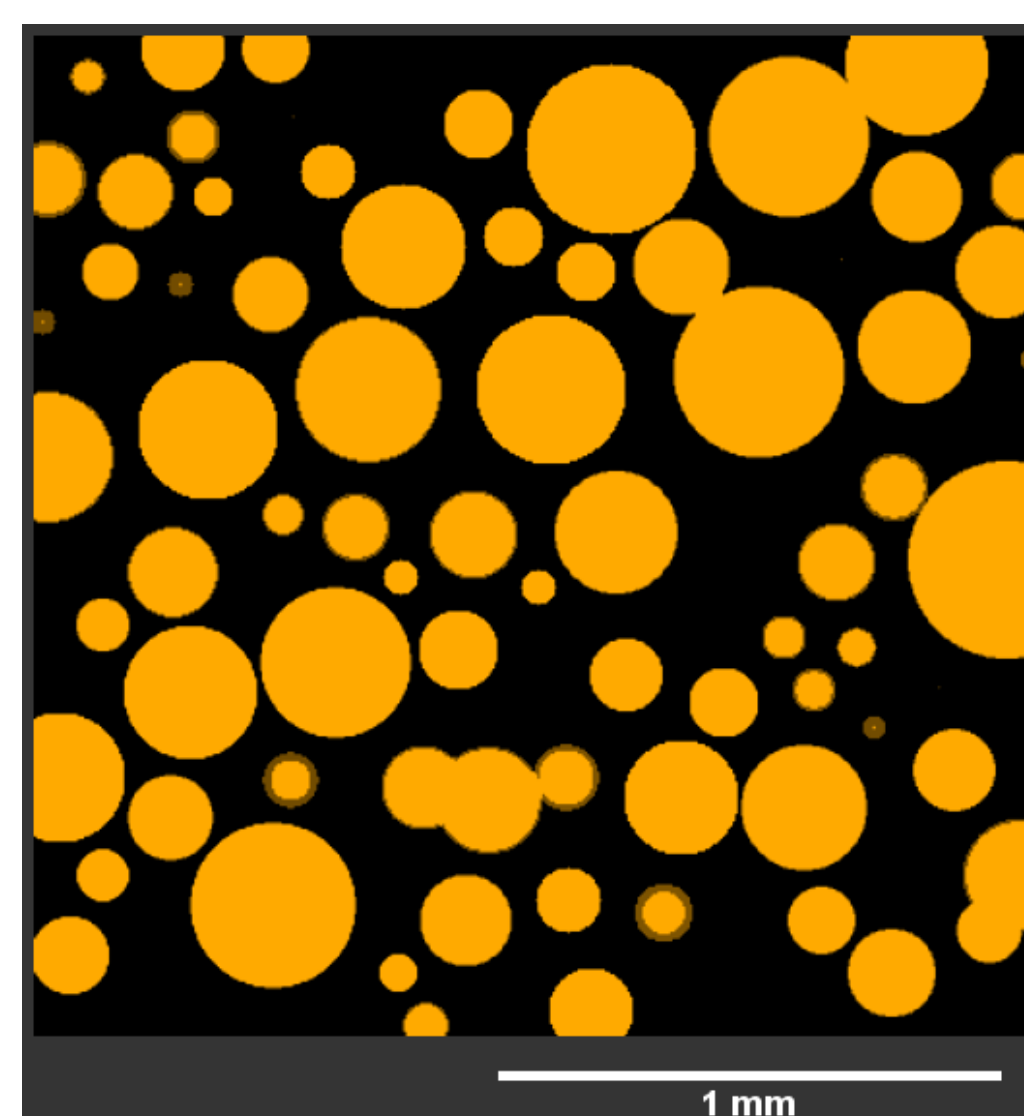
**Type of software:** open source for commercial IDL.

**Version:** Pore 3D 1.0 [1], IDL 7.0.

**Result:** Sizes and list of pores and joins between them ("throats"). Skeleton visualizing connectivity of the pore space. Pore and throats space are available as a binary mask, which can be opened and visualized in VGStudio MAX.

**Usage:** Requires knowledge of basic programming.

**Figures:** Pores are marked with orange, throats with green and skeleton with blue.



### VGStudio MAX

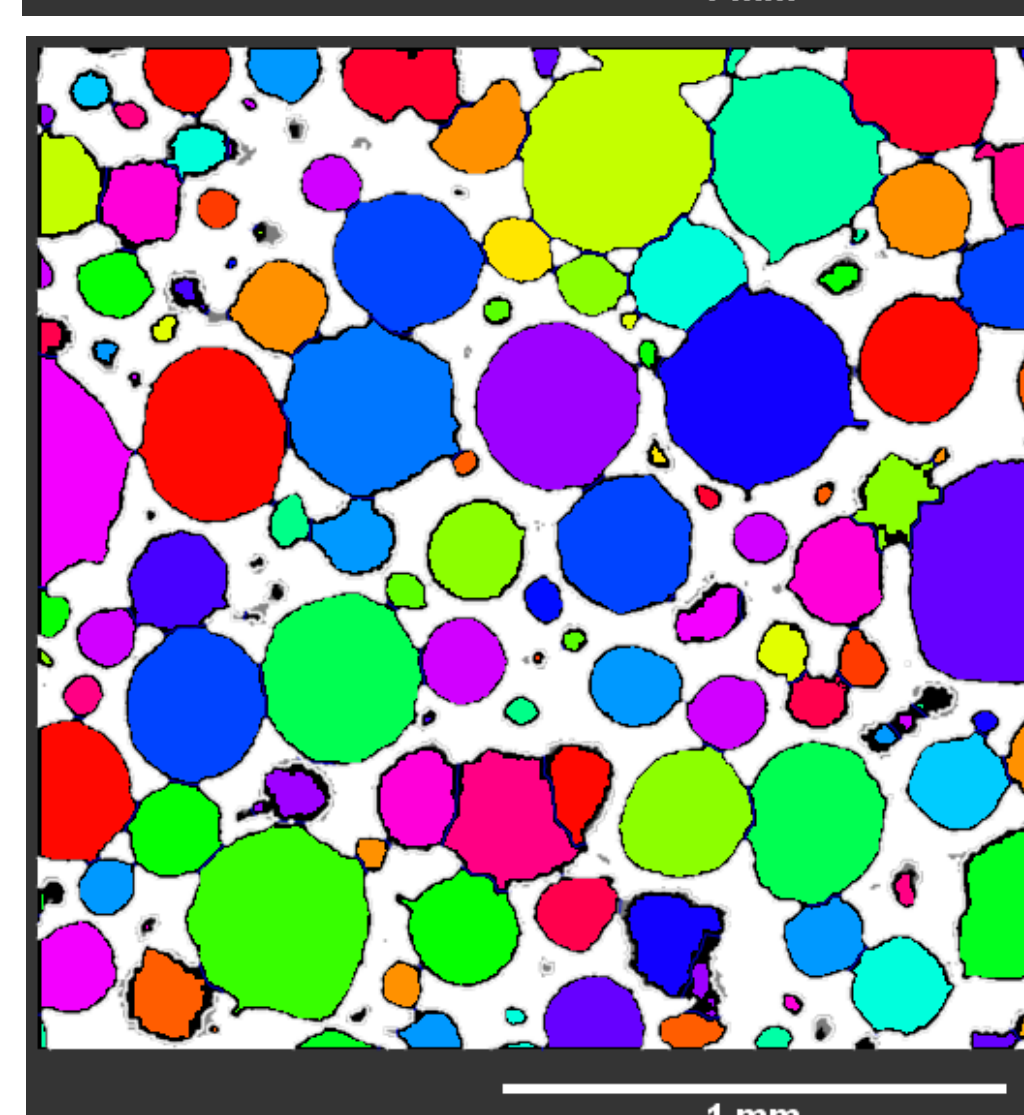
**Type of software:** commercial programme.

**Version:** 3.0. [2]

**Result:** Volume, list and advanced statistics of pores and contact surfaces between them ("Faces"). Thickness map of the material matrix (Strut thickness). 3D renders of analysis are available.

**Usage:** Easy usage, although choice of right parameters in analysis settings might be difficult.

**Figures:** Pores are marked with random colours for pores visualization. Faces are marked with blue colour.



### MAVI

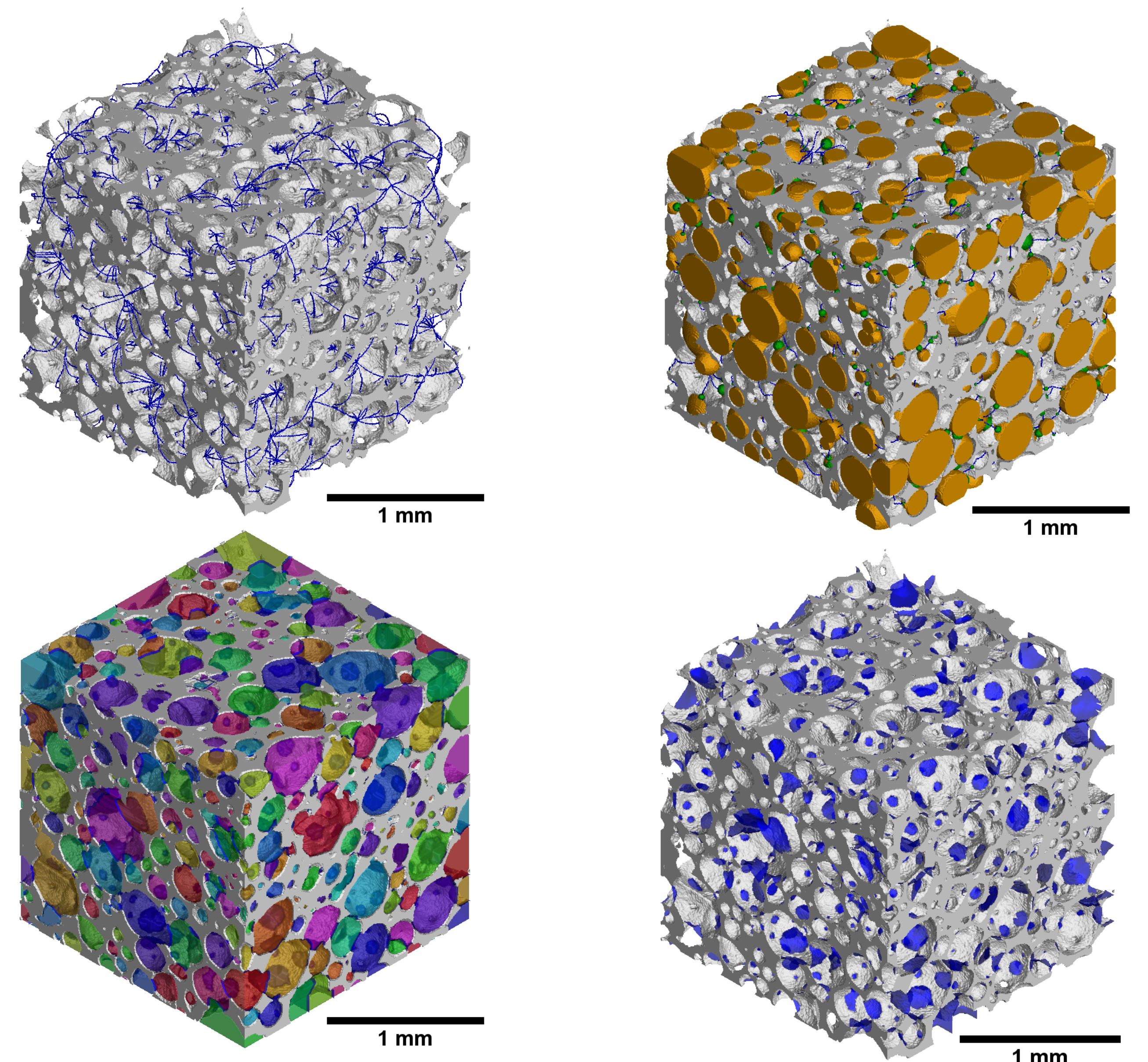
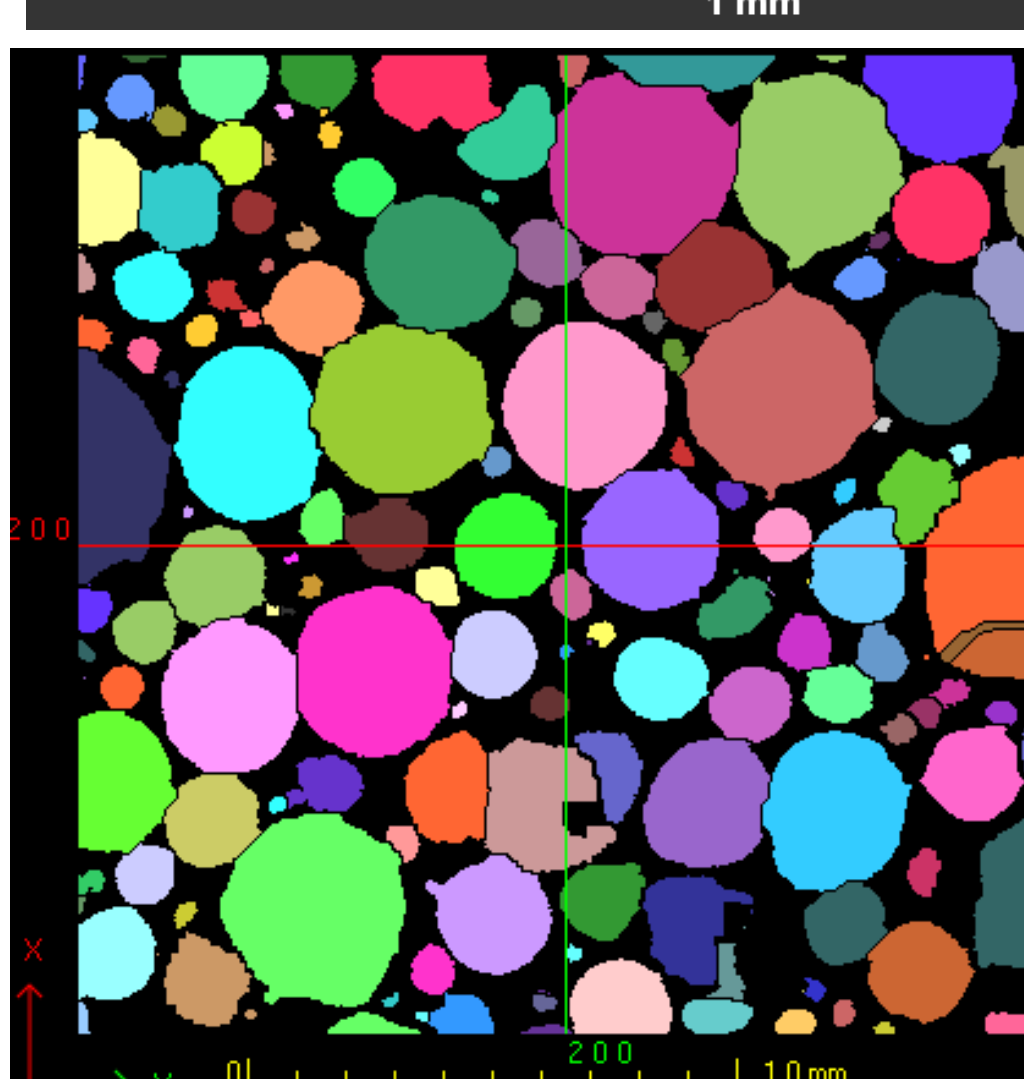
**Type of software:** commercial programme.

**Version:** 1.4.1. [3]

**Result:** Size and basic statistics of pores and contact surfaces between them ("Faces"). 3D renders of analysis are not available.

**Usage:** More complicated procedures for analysis, less user-friendly software.

**Figure:** Pores are marked with random colours for pores visualization.



Program	Number	Total volume of pores		Average pore volume
		mm <sup>3</sup>	%	mm <sup>3</sup>
VGStudio MAX	1946	5.6	70	0.0029
MAVI	2362	5.6	71	0.0024
Pore3D	917	3.7	46	0.0022

**Table 1:** Comparison of pore analysis of CT data of hydroxyapatite foam from different software (total volume of the examined sample was 8.00 mm<sup>3</sup>).

## Summary

Different softwares for pore analysis of CT data of hydroxyapatite foam were compared. VGStudio and MAVI work on similar principle (the pore space is divided into individual pores based on input parameters) and provide similar analysis results. Pore3D creates skeleton and fits maximal spheres at joints, therefore detects less number of pores. Distances between joints (throats) are visualized by spheres of the same size. In comparison with VGStudio MAX, MAVI offers additional filtering and various morphological operations to obtain more precise results, but in this version lacks some basic features like 3D rendering of result analysis. VGStudio MAX offers additional analyses and the best visualization of results.

All software show similar average pore volumes. Pore3D provides different pores number and volume than MAVI and VGStudio MAX, because it works on another principle. From this short comparison, the determination of porosity of the sample is not clearly defined and should be confirmed with another quantitative method.

## Acknowledgement

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## References

- [1] F. Brun, L. Mancini, P. Kasae, S. Favretto, D. Dreossi, G. Tromba. Pore3D: A software library for quantitative analysis of porous media. Nuclear Instruments and Methods in Physics Research A, vol. 615, nr. 3, pp. 326-332. 2010.
- [2] <https://www.volumegraphics.com/en/products/vgstudio-max.html>
- [3] <http://www.itwm.fraunhofer.de/en/departments/image-processing/microstructure-analysis/mavi.html>