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Non-Destructive Quantitative 3D Analysis of Structural, Flow and Mechanical properties of Porous Scaffolds

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INTRODUCTION: Bioactive glass scaffolds have been produced with open macropores with a high degree of interconnectivity and large apertures for tissue engineering (TE) applications. The size of the porosity, and more importantly the interconnecting apertures, is critical to the success of 3D cell seeding and the survivability and growth of the new tissue. Non-destructive X-ray micro-tomography (XMT) and novel 3D image analysis have been used to quantify the pore networks. Fig 1 compares 3D XMT images of a scaffold and human trabecular bone. XMT data was input into a control volume model to predict the flow rate of culture medium through the scaffolds, which can be used for the design of optimised bioreactors for *in vitro* growth.

MATERIAL & METHODS: Glass Foaming: Bioactive glass scaffolds of composition 70 mol% SiO_2, 30 mol% CaO were made with 92% porosity using the sol-gel method with different final sintering temperatures (T_s); 600, 800, 1000°C [1].

XMT Scanning: One scaffold was scanned and sintered repeatedly so that the change in a specific pore network with temperature could be observed. Foams were cut into cuboids and scanned using a commercial XMT unit (Phoenix systems). Two different resolution scans were performed (high: 9.5-12.5 µm; low: 17.5-22.5 µm).

Analysing 3D Data: Quantification of the pore network, i.e., pore and aperture sizes, was achieved by thresholding and applying a dilatation algorithm to create a distance map of the image, which was then fed into a watershed algorithm [2]. Pore and aperture distributions for samples were plotted. Simulations were done on the recon-structed data to calculate flow and mechanical properties. Accuracy of the results was checked using manual measurements of individual pores and mercury porosimetry (MIP).

RESULTS & DISCUSSION: Pore size and aperture size distributions were obtained using the novel 3D image processing techniques. The modal pore diameter (D_{mode}) and modal aperture (A_{mode}) sizes decreased as T_s increased (Table 1). The % porosity also decreased. A_{mode} was greater than 100 µm for all the samples, as required for TE applications. The A_{mode} found from mercury porosimetry (MIP) was 100 µm or higher, but lower than the values obtained from 3D image analysis - MIP calculates the equivalent aperture diameter from flow analysis of mercury, rather than aperture length. Scaffold compressive strength increased, as T_s increased to 800°C, but aperture sizes were still suitable for TE.

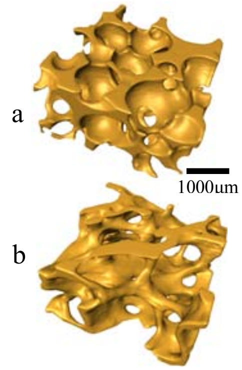

Fig 1. 3D image of (a) a scaffold and (b) human trabecular bone

Fig. 2 shows predicted fluid flow through a scaffold. Apertures were found to dictate flow properties. Table 1 shows mean value of the perme-ability tensor ($\overline{K}_{comp}$), which correlate to the MIP results.

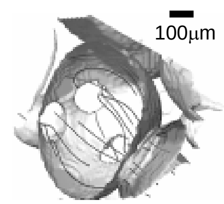

Fig. 2. Modeled flow shown in a scaffold pore using streak lines

Table 1. Characterisation of one scaffold heated to different T_s.

T_s [°C]	% Porosity	D_{mode} (3D) [µm]	A_{mode} (3D) [µm]	A_{mode} (Hg) [µm]	$\overline{K}_{comp}$
600	92.0	689	287	153	918
800	85.0	567	227	97	638
1000	84.5	537	228	119	721

Finite element modeling successfully predicted compressive strength of the scaffolds (data not shown).

CONCLUSIONS: XMT and novel image analysis allowed non-destructive 3D characterization of bioactive glass scaffolds and prediction of flow as a function of the pore network. These techniques are applicable to many types of scaffold material.

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