CHARACTERISATION AND THREE-DIMENSIONAL RECONSTRUCTION OF SYNTHETIC BONE MODEL FOAMS

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INTRODUCTION

Synthetic open-cell foams (Sawbones©) are being used to model vertebra cement injection experiments. However, these foams lack from a reliable microstructure characterisation.

OBJECTIVES

- ❑ To characterize the Sawbones© foams histomorphometricaly.
- ❑ To obtain the 3D virtual models of Sawbones© foams.

MATERIALS AND METHODS

Sawbones© foams

- Polyurethane open cell rigid foams (white and blue foams, WF and BF; ρ_{WF}=0.09 g/cm^3 and ρ_{BF}=0.12 g/cm^3).
- Cell structure 95% open; cell sizes 1.5 to 2.5 mm; compressive strength C_{WF}=6.2 MPa and C_{BF}=18.6 MPa.

Scanning electron microscopy (SEM)

- SEM was used to reveal both the micro architectural features and the composite nature of the foams.
- SEM images were treated with *ImageJ* (version 1.44p) to estimate the trabecular thickness (Tb.Th), the trabecular separation (Tb.Sp) and the cell size of the foams.

Micro-computed tomography («-CT)

- Maximum resolution of 46 μm (i.e. physical distance between successive images).
- DICOM image files were treated with *ImageJ*, converted to 8-bit grayscale, binarised with *threshold* and softened with *smooth* software commands.
- The 3D virtual models were built, after proper set scale, with *ImageJ*.

Parametric characterization

- *BoneJ*, a plugin for *ImageJ*, was used to analyze the bone-like geometry of the foams. The selected indices were the bone-volume to total-volume ratio (BV/TV), the trabecular thickness (Tb.Th), the trabecular plateness (Tb.Pt), the connectivity density (Conn.D), the degree of anisotropy (DA) and the fractal dimension (Frac.D).
- The statistic data control was performed on 10 subsets of 50 consecutive images to minimize the computation time (data: mean ±std deviation).

RESULTS

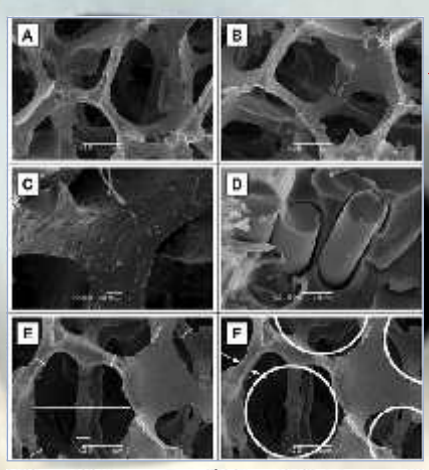

Fig. 1. SEM pictures obtained for both foams, BF (see A, D, E and F) and WF (see B and C). The open cell structure is formed by an interconnected network of rod and plate like units (see A and B); the composite nature of the foam is also revealed (see C and D). Methods to approximate values for Tb.Th and Tb.Sp are also shown (see E and F).

- ❑ Sawbones© foams (WF and BF), while having different porosity, had similar histomorphometric indices.
- ❑ The microstructure of Sawbones© foams was similar to trabecular bone.
- ❑ Sawbones© foams had similar histomorphometric indices than human vertebra (see Table1).

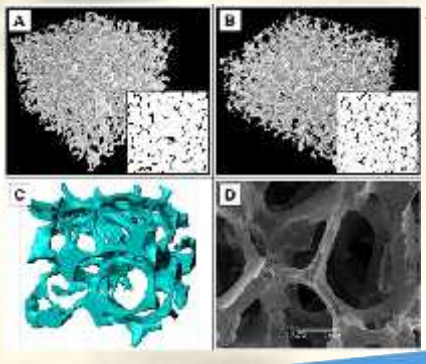

Fig. 2. A) 3D reconstruction of WF obtained from the «-CT images. B) Similar reconstruction as before but for the BF. C) Detail of a region-of-interest of the virtual model showing the trabecular-like structure. D) Trabecular structure of the real model foam.

Table 1. Structural indices obtained for the Sawbones© foams versus published human vertebral data.

Index	WF[1]	BF[1]	WF[2]	BF[2]	HV-L2/L4[3]	HV-L1[4]	HV-L3[5]	HV-L2[6]
BV/TV (%)	4.7 (±0.3)	5.6 (±0,2)	7.9	10.6	8.3/8.7	6.1-10	9-18	10.3
Tb.Th («m)	375 (±8)	381 (±8)	319	378	122/139	98-122	80-130	103
Tb.N (mm^{-1}) [a]	0.65 (±0,02)	0.70 (±0,02)	-	-	1.1/1.0[g]	0.60-0.71[g]	1.0-1.9[g]	1.47
Tb.N (mm^{-1}) [b]	0.123 (±0.006)	0.147 (±0.006)	0.249	0.280	-	-	-	-
Tb.Sp (mm) [a]	1.17 (±0.04)	1.05 (±0.03)	-	-	0.792/0.854[h]	1.31-1.57[h]	0.45-0.90[h]	0.58[g]
Tb.Sp (mm) [b]	7.8 (±0.4)	6.4 (±0.3)	3.70	3.20	-	-	-	-
Tb.Pt [c]	0.49 (±0.04)	0.55 (±0.02)	-	-	-	-	-	-
Tb.Pt [d]	0.30 (±0.02)	0.32 (±0.02)	-	-	-	-	-	-
Conn.D (mm^{-3})	0.12 (±0.02)	0.19 (±0.02)	-	-	-	2.44-4.98	-	3.29
DA	0.35 (±0.05)	0.38 (±0.05)	0.10[g]	0.13[g]	0.30[g]/0.34[g]	-	-	0.39[g]
Frac.D [e]	1,37 (±0,02)	1,40 (±0,01)	-	-	-	-	-	-
Frac.D [f]	2,236 (±0,005)	2,240 (±0,009)	-	-	-	-	-	2.06[f]

[1] WF/BF: white/blue foam (Sawbones©, Refs. 505/507); present study. [2] WF/BF: white/blue foam (Sawbones©); Johnson et al. [3] HV-L2/L4: human vertebra L2 and L4; Hildebrand et al. [4] HV-L1: human vertebra L1; Kinney et al. [5] HV-L3: human vertebra L3; Cvijanovic et al. [6] HV-L2: human vertebra L2; Sone et al.

[a] Cylindrical rod model. [b] Parallel plate model. [c] Spheroid axis ratio eV2/eV1. [d] Spheroid axis ratio eV3/eV1. [e] Fractal dimension in 2D. [f] Fractal dimension in 3D. [g] Calculated value obtained from other data reported by the authors. [h] Mixed structure with prevalence of the rod model.

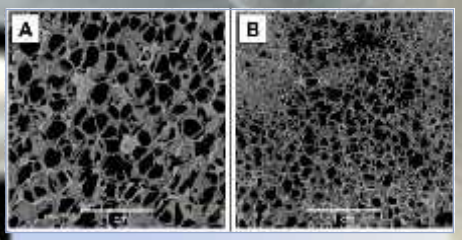

Fig. 3. A) 3D virtual reconstruction of a limited number of slices for the BF. The isotropic but mixed rod and plate-like structure is revealed. B) Image obtained for the human vertebra ESA29-99-L3; the structure is more compact than that in A.

CONCLUSIONS

The microstructure of Sawbones© foams is similar to that of trabecular bone. These foams are a good option to study in vitro the infiltration behaviour of bone cements and the like.

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