COMPUTATIONAL FLUID DYNAMICS OF POROUS STRUCTURES: THEORETICAL, EXPERIMENTAL AND NATURAL MODELS

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INTRODUCTION

Synthetic porous foams are being used to investigate the infiltration properties of bone cements. The objective is to improve safety of minimally invasive spinal surgery applications (vertebro/kyphoplasty). In this study, computational fluid dynamic analysis (CFD) was performed to compare the fluid flow behaviour of synthetic foams and of natural human vertebral bone.

OBJECTIVES

The aim of our study is to characterize and compare the cement fluid flow through synthetic and real vertebral bone to determinate a possible dependence between CFD properties with microarquitecture parameters.

MATERIALS AND METHODS

Synthetic high (*WF*) and low (*BF*) porosity foams (Sawbones©, Pacific Research Laboratories, Inc) were scanned by μ-CT (eXplore Locus, GE Healthcare; 80KVp, 0.5 mA, 46 μm of maximum resolution). DICOM images were imported to Simpleware© (version 4.0). Automated tools were applied for noise reduction, smoothing and segmentation. 2D sections (30x30 mm) of different slices were exported to Comsol Multiphysics© for computation. Similarly, the ESA human L3 vertebra was used for comparison purposes (Fig. 1,2). Navier-Stokes Newtonian and incompressible application mode was used to model bone cement flow through porous media. The starting computation conditions were: cement density of 2.2 g/cm^3; viscosity of 2 Pa·s; inlet velocity of 0,02 m/s; and pressure at the outlet of 0 Pa. The ImageJ software and the plug-in BoneJ were used to obtain typical histomorphometric indices of both, the foams and the ESA vertebra.

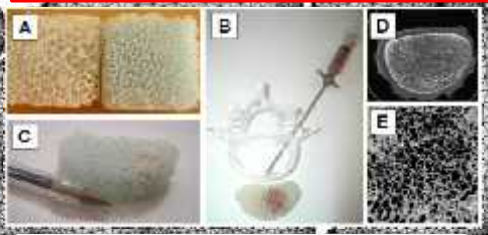

Figure 1. A. Synthetic polyurethane open cell rigid foams; B and C. Bone cement injected into synthetic foam; D and E. μ-CT and 3D reconstruction of a ROI sample of human lumbar vertebral body.

RESULTS

Table 1 shows the histomorphometric and the computational fluid flow indices obtained. The results indicate that synthetic and natural bone structures show histomorphometric coincidences. However, their fluid flow behaviour and consequently the pressure needed to maintain it was significantly different (Fig.2).

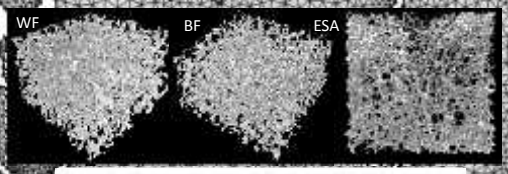

Figure 2. 3D reconstruction of foam and ESA bone samples.

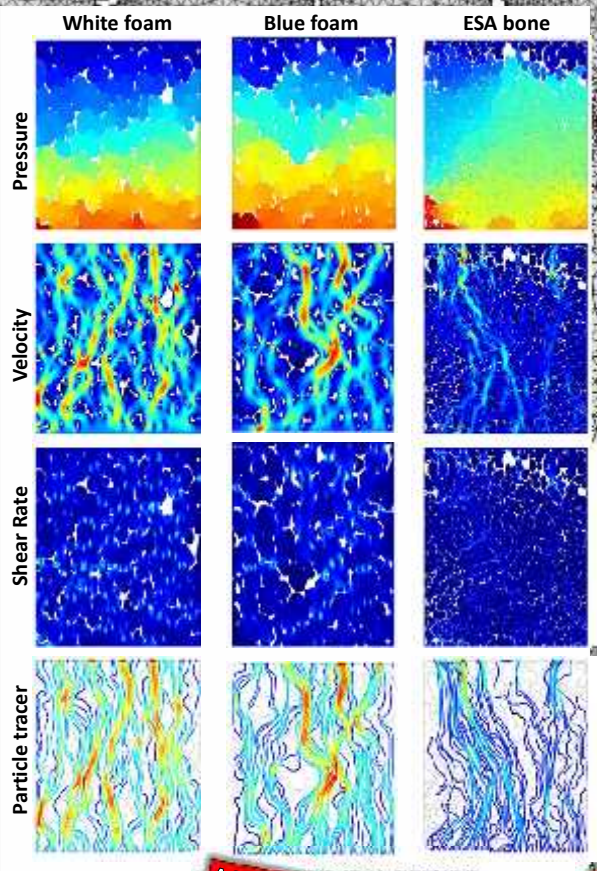

Figure 3. Pressure (Pa), Velocity (m/s), Shear rate (1/s) and particle tracing plot in white, blue and vertebral bone sample.

Index	WF	BF	ESA Bone
BV/TV (%)	4,7 (±0,3)	5,6 (±0,2)	9,4(±0,8)
Pressure (Pa)	2911(±78)	3418(±313)	41959 (±7833)
Permeability (m^2)	1,97E-07 (±1,30E-08)	1,76E-07 (±2,27E-08)	1,46E-08 (±2,28E-09)
Tortuosity	1,08 (±0,01)	1,12(±0,03)	1,13(±0,01)
Particle retained	2,4%	1,2%	23,6%
Average Velocity (m/s)	0,0117 (±0,0001)	0,0121 (±0,0001)	0,0217 (±0,0144)
Average Shear Rate (1/s)	17,1(±0,2)	17,4(±0,5)	53,3(±1,8)
Average Vorticity, 1/s	13,3(±0,0)	13,3(±0,2)	42,0(±1,5)
Tb.Th («m)	375 (±8)	381 (±8)	185 (±5)
Tb.Sp (mm)	1,17 (±0,04)	1,05 (±0,03)	0,97 (±0,04)
DA	0,35 (±0,05)	0,38 (±0,05)	0,914
Frac.D	1,37 (±0,02)	1,40 (±0,01)	1,75 (±0,02)

Table 1. Histomorphometric and computational fluid flow indices.

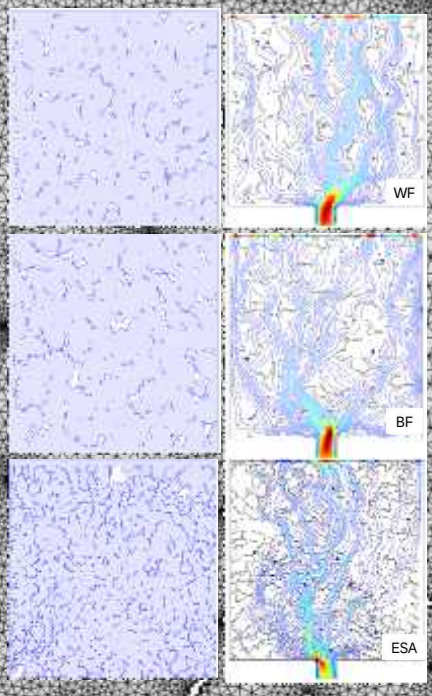

Figure 4. Tracing and retained particles.

CONCLUSIONS

It is concluded that synthetic foams do not perfectly match the microarquitecture of human vertebra. For this reason care should be taken to interpret future bone cement infiltration studies.

ACKNOWLEDGEMENTS

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