A MULTISCALE POROMICRODYNAMICS APPROACH TO WAVE PROPAGATION AND ATTENUATION IN BONE

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Introduction

Ultrasonics is an important diagnostic tool for bone diseases, as it allows for a non-invasive investigation of the bone tissue composition and structure through its elastic properties. For solid media, the relation between wave velocity and elastic properties only depends on the solid mass density; it becomes however much more complex for fluid-filled porous media. In order to shed some light on this open issue, we here develop a multiscale poromicrodynamics approach valid across the great variety of different bone tissues.

Methods

The wave propagation problem tackled herein comprises three sets of equations: (i) the equation of motion with inertial term is derived at the macroscopic scale for harmonic waves; (ii) The poroelastic constitutive law of bone is derived from extending the six-scale micromechanics model of [Fritsch, 2009], towards the consideration of eigenstresses representing pore pressures in the vascular and lacunar pores (see Figure 1) and of pore fluid compressibility [Hellmich, 2009].

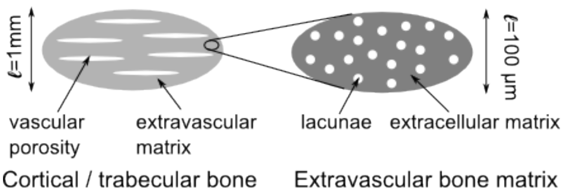

Figure 1: Hierarchical representation of the vascular and lacunar porosities in bone tissue (2D sketch of fully 3D representation).

(iii) Finally, Darcy's law governs the fluid flow in the vascular pore space, while the lacunae are considered as undrained. Namely, the characteristic loading time in ultrasonically-tested bones is several orders of magnitudes smaller than the characteristic response time of the lacunae. Combination of these three sets of equations yields the dispersion relation, from which attenuation coefficients and frequency-dependent wave velocities are derived [Coussy, 1995].

Results

Given a theory-predicted slow wave attenuation length ranging from only 10^{-5} m in cortical bone to 10^{3} m in trabecular bone, 2.25 MHz acoustical signals transmit (low-porosity) cortical bone only in the form of fast waves, agreeing very well with experimental data of [McCarthy, 1990] (see Figure 2), while both fast and slow waves transmit large-porosity trabecular bone [Hosokawa, 1997].

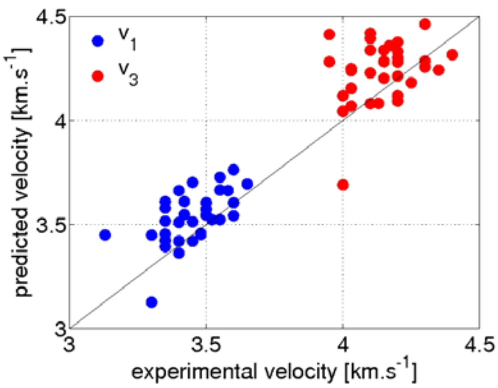

Figure 2: Predicted vs. experimental fast wave velocities in longitudinal (3) and transverse (1) directions

Discussion

Multiscale poromicrodynamics appears as appropriate tool for predicting fast and slow wave propagation in bone tissues, and provides essential information on how to correctly interpret experimental data from ultrasound protocols at different frequencies.

References

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