Interaction of ultrasound with cortical bone as a two-level porous medium: a multiscale computational study

Bone is a complex biological tissue which remodels all along healing. Bone remodeling is the result of bone cells activation due to mechanical stresses. The osteocytes are thought to be the principal mechanosensory cells of bone. They are immersed in the lacuno-canalicular network (LCN) filled with interstitial fluid. There is theoretical and experimental evidence that osteocytes are stimulated via fluid flow generated shear stresses acting on osteocyte cell processes within canaliculi. Low Intensity Pulsed UltraSound (LIPUS) is a current clinical treatment to speed up or consolidate bone healing. But although it has been proven that LIPUS induces minimal thermal effects, debate is still opened to know how LIPUS mechanically stimulates bone regeneration.
The aim of this preliminary study is to numerically investigate LIPUS stimulation from a tissue-scale model to a cellular-scale model in order to make the connection between in vitro studies and clinical observations.
Two numerical models were developed with the commercial software Comsol Multiphysics. The first tissue-scale model (ModBone) simulates the interaction of the ultrasound (US) stimulation with the cortical bone. Cortical bone is considered as a two-level porous medium: the vascular pores full of fluid are reconstructed from RX images and the lacuno-canalicular porosity is taken into account assuming an anisotropic poroelastic extracellular matrix (ECM) (Cowin et al., 2009, Scheiner et al., 2015). The second model is the cellular-scale model (ModOst) including a 3D fluid-structure interaction model of one osteocyte immersed in the interstitial fluid of the LCN and embedded in the ECM.
The pressure gradient induced by US stimulation in ModBone is applied as boundary condition for the fluid in ModOst. The interstitial fluid shear stress magnitude applied on osteocytes is calculated in the two models and compared with shear stress levels cell activation recorded in litterature. (Weinbaum et al., 1994).
How ultrasounds interact with bone tissue and which mechanical stimulation is induced on osteocytes remain tricky questions. In this preliminary study, several points are still on going, among them: permeability value of the LCN, boundary conditions at the endosteum and periosteum, or the 3D reconstruction of vascular pore network.

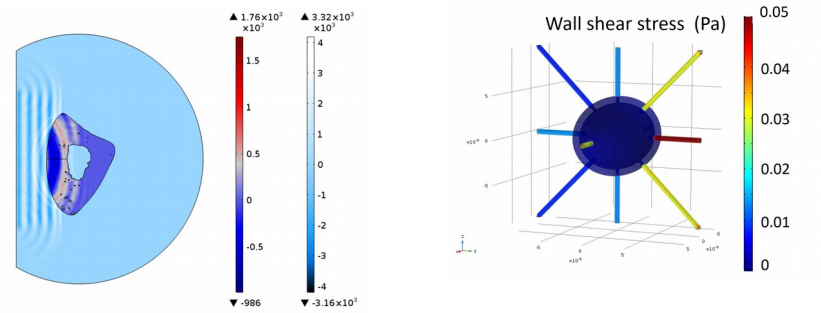

Figure: Acoustic pressure and interstitial fluid pressure at tissue scale and wall shear stress on osteocyte.

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