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How Can a Numerical Model Help the Understanding of In-Vitro Ultrasound Stimulation of Bone Cells?

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ABSTRACT

The first clinical observations of the effects of Ultrasound stimulation of Bone Regeneration (USBR) were reported in early 1950s (Corradi et. al. 1953). Since then, USBR has gained enormous attractions in the scientific community owing its acceptability to the numerous promising experiments and publications on the subject. In 1994, the U.S. Food and Drug Administration's confirmation added more credibility to the approach and provoked the industry to invest in development and commercialization of para/medical devices like e.g. Exogen®; however, the underlying multiphysical processes are yet poorly understood (Padilla et. al. 2014) due to variety of parameters including complexity of the bone structure and characteristics of ultrasound waves. It is believed that the US stimulation at tissue scale exerts a mechanical stimuli on bone cells (osteocytes which are known to function as bone mechanosensors) which in turn react biologically in form of bone regeneration. Since the osteocytes are immersed in fluid inside lacuno-canalicular network (LCN), it is hypothesized that the fluid shear stress can be the mechanical stimuli. A first step is to understand how the bone cells react to US stimulation. Numerous in-vitro studies have been published in literature, but, due to variety of experimental setups, most of them fail to assess effects of setup configurations and wave characteristics simultaneously. Therefore, developing a numerical model representing the experimental setup in order to design and optimize the geometrical positioning of different elements and the ultrasound parameters seems inevitable. It also provides the opportunity to investigate wells' interactions which have been widely ignored so far and quantify precisely the US dose delivered to the cells. The mentioned approach not only helps the design process, but also presents a better insight to the results found. Moreover, time and cost management will be significantly improved. Figure 1. shows a simplified schematic representation of a common experimental setup where a transducer is located inside a water tank under a cell culture well made of polystyrene. For now, the content of well (cells and their nourishment) is represented by a layer of water which has an interface with well and air. For the sake of simplicity, the numerical model on the right side hand is only developed on a half-symmetric model (enclosed by dashed-dotted rectangle on left) in COMSOL Multiphysics®. The image thoroughly demonstrates the distribution of pressure and mechanical stress induced by pressure.

Keywords: *Ultrasound Stimulation, Bone Regeneration, FEM, COMSOL*
References: Corradi et al., Archivio di ortopedia, 1953. Padilla et al., Ultrasonics, 2014.

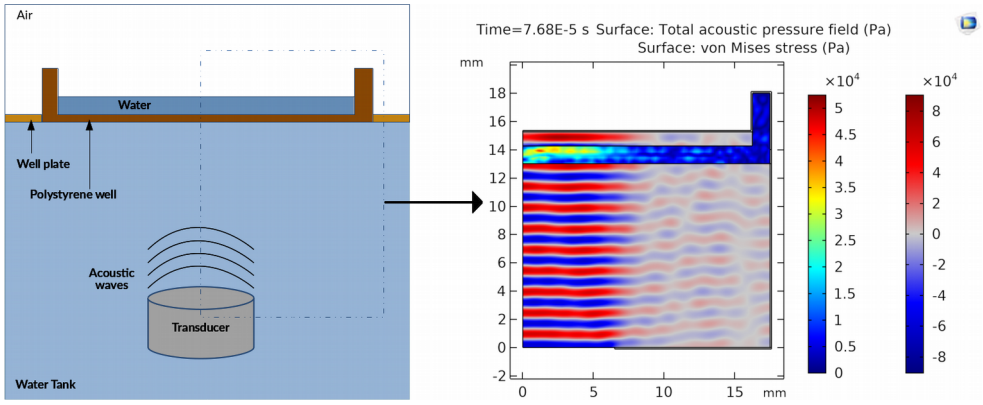

Figure 1. (Left) Schematic of an experimental setup; (Right) Pressure and mechanical stress distribution