3D Finite Element Study of Multi-frequency Harmonic Shear Wave Elastography (HSWE) for Stiffness Contrast Quantification with Experimental Validation

Background, Motivation, and Objective

Shear Wave Elastography (SWE) is an imaging technique that uses acoustic radiation force (ARF) to generate localized vibrations within tissue. This allows for the estimation of the relative stiffness of the tissue based on the resulting displacement amplitude. HSWE is a novel approach that uses multi-frequency ARF to get displacements within tissue. Viscoelasticity, an important biomarker that constitutes the stiffness contrast of the tissue, can be assessed by generating the shear wave speed (group velocity, GV, and phase velocity, PV) from the resulting displacement. In this study, a 3D finite element model (FEM) is used to simulate the displacement of a medium with a stiffer inclusion. The resulting displacement, along with subsequent GV and PV maps, will be compared to those obtained from the conventional Pulse-SWE (PSWE) and a commercially available phantom (model 049A, CIRS, Norfolk, VA, USA).

Statement of Contribution/Methods

The simulation study involves the following steps – (1) Generating a 3D FEM in the LS-DYNA (Livermore Software Technology Corporation, CA, USA) by considering a spherical inclusion of diameter of 6.5 mm and Young's modulus (E) of 44 kPa embedded in a rectangular domain of softer (E=5.3 kPa) background tissue. To eliminate reflection from the end boundaries of the background, a 5 mm thick Perfectly Matched Layer is added at the boundaries. Since the model is symmetric in the elevation (y) direction, a half-symmetrical model is considered to reduce the computational time (refer to Fig.(a)). (2) Simulating the 2D pressure field of the ultrasound transducer in Field II and using it as a loading condition in the FEM along with its temporal variation. Because pushing and tracking cannot be done simultaneously with a single transducer, interleaved ARF is applied (see Fig. (b) in which one temporal cycle is shown). (3) Obtaining the temporally varying displacement from the FEM solution. (4) Computing the GV from the FE displacements using the cross-correlation-based time of flight method. (5) For the PV maps at the frequencies of the applied force, transforming the FE displacements to the Fourier space to obtain the spatial wavenumbers in both lateral and axial directions corresponding to the maximum Fourier Transformed magnitude over a 4 mm window surrounding a pixel.

Results/Discussion

The GV and PV maps corresponding to the considered HSWE are shown in Fig. (c) and (d) respectively. The HSWE results are compared to those of the PSWE method, which are considered as reference results (see Fig. (e)). The difference between the HSWE and PSWE methods is calculated and the mean and standard deviation are 6.6% and 8.6%, respectively. HSWE is therefore found to have similar performance as PSWE but with the added advantage of providing information on frequency-dependent mechanical properties at higher frequencies.