Investigating the performance of Shear Wave Elastography for cardiac stiffness assessment through Finite Element simulations

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Shear Wave Elastography is a non-invasive ultrasound technique for stiffness quantification, clinically proven successful for breast cancer and liver fibrosis diagnosis. It induces a vibration source inside the tissue by appropriate focusing of acoustic energy. This generates shear waves (SW's) with their propagation speed linked to the tissue stiffness. However, cardiac application of this technique is challenging, as the ventricular geometry and anisotropic tissue generate complex wave phenomena, causing issues for current tissue characterization algorithms. To study these complex SW phenomena in the heart, we used a combined experimental and numerical approach in a left ventricular model.

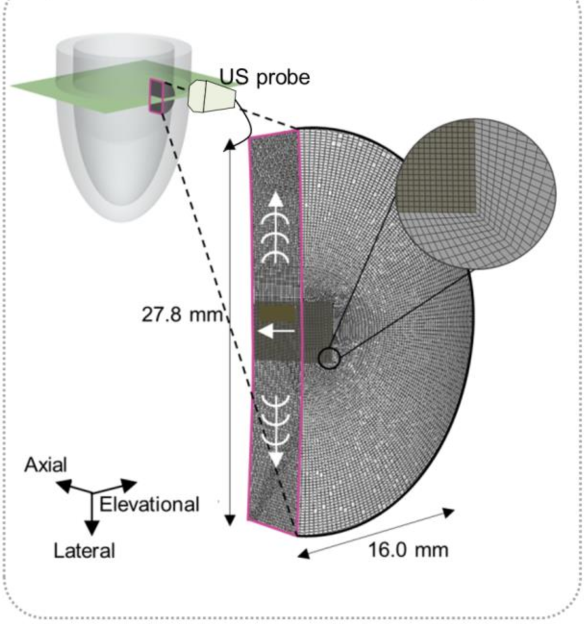
For the experiments, a ventricular phantom was created using a 10% polyvinyl alcohol solution (fig. A). SW's were excited in this phantom using a focused high-intensity ultrasonic beam, creating an acoustic radiation force, cfr. fig. B1. The phantom's stiffness was determined via uniaxial tensile tests.

For the simulations, fig. A illustrates the corresponding numerical model created in the finite element software Abaqus. The acoustic force from the experiment was computed in an ultrasound simulator (Field II) and imposed as a volume force in Abaqus (cfr. fig. B2). An elastic material law was derived from the mechanical testing.

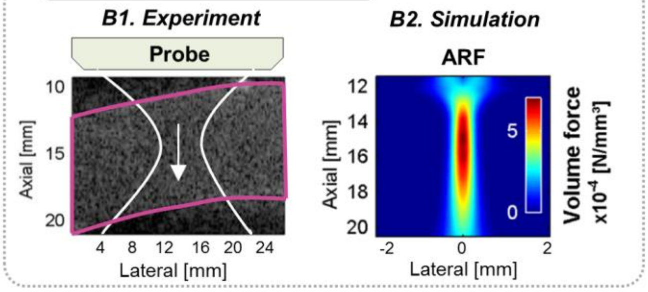
The modeled SW propagation (fig. C2) corresponds qualitatively well with the experiment (fig. C1), especially when modeling following features: (i) the water surrounding the phantom and (ii) the surface radiation force at the phantom-water transition present when exciting SW's. Both model and experiment show SW dispersion, i.e. the wave front arising from the downward push (red zone in B2) has split in two (cfr. arrows in fig.C1-2).

When assessing tissue stiffness with algorithms for non-dispersive wave regimes, the shear modulus was 16.5 kPa, i.e. 32.1% lower than the mechanically tested value of 24.3 kPa. This can be improved using an algorithm taking into account dispersion: 26.2 kPa (+ 7.8%). However, as both methods show a significant deviation from the ground truth stiffness, we will look for additional insights into the complex SW physics via modeling to ultimately improve these tissue characterization techniques.

A. Experimental & numerical set-up

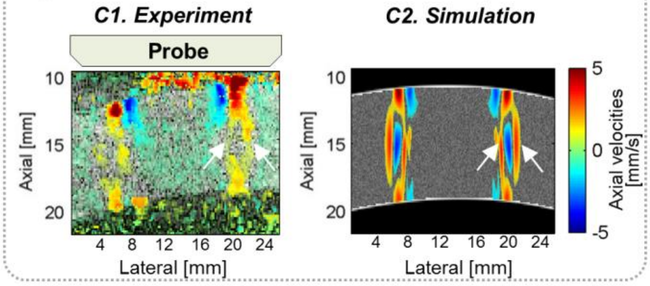


B. Shear wave excitation



B1. Experiment *B2. Simulation*

C. Shear wave propagation (t=1.8 ms)



C1. Experiment *C2. Simulation*