

Identification of the viscoelastic properties in magnetic resonance elastography by coupling a finite element model and a gradient method

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Background: Finite element (FE)-based inversion methods allow for accurate reconstruction of the biomechanical properties in Magnetic Resonance Elastography (MRE) [1-3]. Thanks to the possibility of accounting for complex mechanical properties, such approaches offer major perspectives for quantitative, biomechanical applications of MRE.

Aims: The objective of this study is to investigate an automatic differentiation-based gradient method of a dedicated biomechanical model for the investigation of viscoelastic properties in MRE. The proposed approach focuses on the accurate characterization of viscoelastic properties using a FE description of wave propagation.

Methods: The first step consisted in developing a realistic numerical model of harmonic shear wave propagation with a limited amount of computational power and memory. Based on the first-order shear deformation theory (FSDT) for moderately thick viscoelastic heterogeneous structures, a 2D finite element formalism has been developed and compared to analytical formulations of wave propagation, to a numerical 3D model from a commercial FE software, and to experimental MRE data. As a first step, the proposed FE model mimics experimental cylindrical wave propagations obtained with the protocol described by [4]. At this time, the proposed model focuses on a known local source for the waves that has to be applied through the whole thickness of the model. The model is then differentiated using an Automatic Differentiation (AD) tool to compute an accurate gradient-based data assimilation approach and to solve the inverse problem. The method is applied for the identification of elasticity and viscosity: (i) in a 3D FE phantom generated using a commercial software (Comsol Multiphysics) ($|G^*| = 5\text{kPa}$, $\tan(\delta) = 0.1218$) with a soft viscoelastic inclusion ($|G^*| = 2.5\text{kPa}$, $\tan(\delta) = 0.2231$, $\phi = 40\text{mm}$); (ii) in an experimental 8% gelatin phantom with a soft inclusion ($\phi = 40\text{mm}$), in which cylindrical shear waves ($f_0 = 100\text{Hz}$) were generated from a vibrating needle and encoded in the slice direction using a spoiled gradient echo sequence with motion-sensitizing gradients (1.5T *Magnetom Aera Siemens*; $T_E/T_R = 7\text{ms}/10\text{ms}$; slice thickness = 10mm; matrix = 128x128; FOV = 350mmx350mm; 1 slice) [4]. The identification process is applied on the phase image regridded in 16x16 in a 118mmx118mm region of interest. The mechanical properties obtained with the proposed method are compared to measurements using rotational rheometry for both the phantom and the inclusion.

Results: This study shows that the proposed FSTD FE model allows simulating cylindrical, harmonic shear wave propagation in 2D in viscoelastic media at significantly reduced computer costs. Shear wave patterns from the numerical (**Figure 1.a**) and experimental phantoms (**Figure 2.a**) are represented next to the shear wave patterns simulated by the proposed 2D FE model using the optimal viscoelastic parameters (**Figures 1.b** and **2.b**, respectively).

Conclusions: These preliminary results illustrate the feasibility of the proposed approach. Viscoelastic parameters could be identified on a non-uniform phantom at low computational cost. Moreover, the AD-based gradient method offers the opportunity to account for complex mechanical properties, - such as anisotropy, hyperelasticity or porosity - by adapting the FEM accordingly. At this time, one of its major limitation is that the source of the waves has to be known and to be applied through the whole thickness of the model. The next step consists in optimizing the computational process to reduce further computer costs, allowing application of the method to images with higher resolution.

References: [1] Van Houten et al., *MRM*, 42(4):779-86, 1999. [2] Oberai et al., *Inverse Problems*, 19(2): 297-313, 2003. [3] Wang et al., *J Biomed Imaging*, 406854, Epub, 9, 6:1-6:9, 2009. [4] Corbin et al., *MRM*, 75(3): 1110-8, 2015.

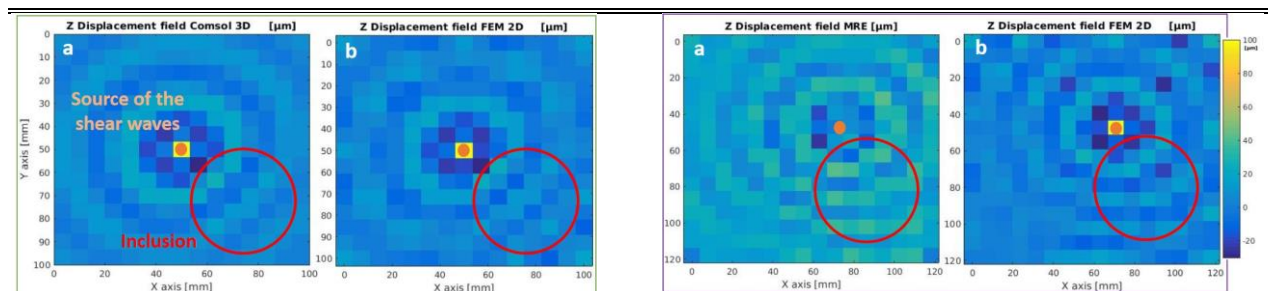


Figure 1: Wave pattern from 3D *Comsol* FE model (a) and from our 2D FE model with the identified mechanical parameters (b).

Figure 2: Wave pattern from experimental MRE (a) and from our 2D FE model with the identified mechanical parameters (b).