Visualizing the viscoelastic behavior of soft tissues

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Introduction: Magnetic resonance elastography (MRE) is an emerging imaging modality that derives intrinsic tissue mechanical property images from MR measured induced internal tissue displacements based on the premise that soft tissues exhibit linear isotropic elastic behavior. Although these assumptions have proven to be a good approximation for some tissues it is inappropriate for tissues (such as the breast) that exhibit considerable viscoelastic tendencies. Consequently, an enhanced inverse image reconstruction technique has been developed based on a viscoelastic formulation of shear wave propagation. In this paper, we report the results of experiments conducted on gelatin phantoms and volunteer breast cancer patients.

Method: The governing partial differential equations (PDEs) that describes the propagation of shear waves in a linear isotropic viscoelastic medium is given by $\nabla \bullet \mu \nabla \bar{\mathbf{u}} + \nabla(\lambda + \mu)\nabla \bullet \bar{\mathbf{u}} = (iw\alpha - \rho w^2)\bar{\mathbf{u}}$, where $\bar{\mathbf{u}}$ is the spatially varying complex-valued displacement vector **u**, μ and λ are Lamé constant, α is the damping coefficient and ρ is the density of the medium, which in this study was assumed to be equivalent of water (≈ 1000 kg/m^3). Information regarding shear wave propagation obtained by employing contrast enhanced MRI is generally in the form of phase and harmonic amplitude maps. However, this information was transformed to frequency domain Viz. $\mathbf{u}(x,y,z,t) = \mathrm{Re}\left\{\bar{\mathbf{u}}(x,y,z)e^{iwt}\right\}$to facilitate image reconstruction. The dominant mechanical parameters (i.e. shear modulus, μ, and the damping coefficient, α) were estimated from the complex-valued displacements by employing an overlapping subzone inversion strategy[1] that we have recently developed based on the equations of motions for a viscoelastic medium. Figure 1 shows representative example of contrast enhanced T2 weighted MR images, and shear modulus elastograms that was obtained from a breast cancer patient with a locally advanced malignancy. The tumor is visualized in the contrast enhanced MR images has a highly localized region of low intensity, which corresponds to an area of high shear modulus (mean shear modulus = 11 ± 2 kPa; shear modulus contrast ≈ 14.8 dB (5:1)) in the shear modulus elastogram. Figure 2 shows a montage of damping coefficient elastograms corresponding to the images shown in Fig. 1. The inclusion is not discernible in damping coefficient elastograms, which suggests that globally both tissue types (inclusion and surrounding tissues) exhibit similar viscoelastic behavior. It is apparent from the images shown in Fig. 1 and the damping coefficient images shown in Fig. 2 that there is a strong correlation between regions of high contrast uptakes and regions low damping (as well with regions of high shear modulus); however, not all regions with high contrast uptakes corresponds to regions of low damping. We believe that the regions were low damping correlates with areas of high shear modulus corresponds to areas where the fibrous encapsulation of the malignancy is intact. Further investigations are currently being conducted to corroborate this hypothesis. Preliminary phantom experiments have been conducted to assess the statistical accuracy of our improved image reconstruction technique. The discrepancy between the mean shear modulus computed from shear modulus elastograms and those estimated from independent rhelogical measurements decreased noticeably (typically by 5 %) when the shear modulus elastograms were reconstructed by taking proper account of the viscoelastic effect compared to when reconstructions were performed based on the assumption that viscous effects was negligible.

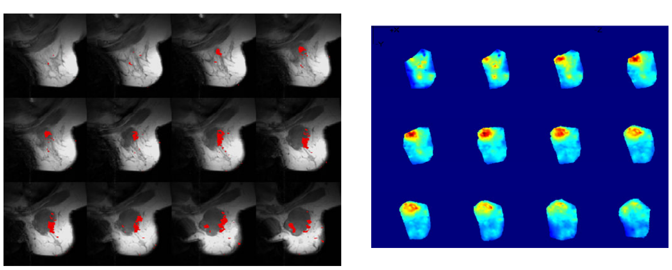

Figure 1 Montage of contrast enhanced T2 weighted MR images (left) and shear modulus elastograms (right) obtained from a patient with a locally advanced malignancy. The red arrows indicate areas of contrast enhancement.

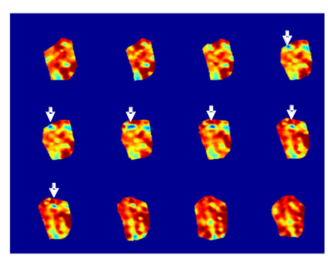

Figure 2 Montage of damping coefficient elastograms corresponding to the modulus elastograms and MR images shown in Fig. 1. Arrows denotes areas of increased damping coefficient.

Conclusions The preliminary results reported in this article demonstrates that taking proper account of viscoelastic effects in breast tissues will not only provide a new contrast mechanism that could aid the differential diagnosis of breast cancer but should also improve the statistical accuracy of shear modulus elastograms.

1. Van Houten, E.E., K.D. Paulsen, M.I. Miga, F.E. Kennedy, and J.B. Weaver, *An overlapping subzone technique for MR-based elastic property reconstruction.* Magn Reson Med, 1999. **42**(4): p. 779-86.