

Hydraulic conductivity estimation using magnetic resonance elastography

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Introduction:

Mechanical property estimation of *in vivo* tissue offers opportunities for detecting and diagnosing disease. One common technique is magnetic resonance elastography¹ (MRE) which converts measurements of tissue deformation into an image of material property distributions (most often shear modulus) by applying a mechanical model that describes the tissue's response to the induced motion – most commonly under linear elastic or viscoelastic assumptions. In biphasic tissues such as brain parenchyma, a poroelastic material model may be needed to separate the response of the solid tissue matrix from the penetrating interstitial fluid. While a poroelastic model has been shown to estimate shear modulus and pore-pressure², hydrodynamic parameters like hydraulic conductivity (*hc*) could also provide new clinical information. Defined as the rate at which fluid penetrates through pores, *hc* could delineate tumors (where perfusion is much lower), detect increases in intracranial pressure in diseases such as hydrocephalus or insults associated with traumatic brain injury, or elucidate mechanisms of drug delivery. Here, we present our initial results from an image reconstruction algorithm which estimates the spatial distribution of *hc* from simulated and experimental MRE motion data.

Methods:

Our original MR poroelastography (MRPE) subzone-based image reconstruction algorithm^{2,3} was modified to estimate the *hc* parameter. Initial simulations were performed on 1-inclusion and 3-inclusion poroelastic phantoms. The 3-inclusion simulation (see Figure 1) was similar in size and was actuated at the same frequencies as our typical experimental phantom blocks. The left inclusion was assigned contrast in shear modulus and *hc* with the background, the middle inclusion had only shear modulus contrast, whereas the right inclusion had only *hc* contrast. Differing contrast levels, initial estimates, regularization parameters, and amounts of measurement noise were used to evaluate the overall robustness of estimating *hc* from the synthetic data. Data from an actual gelatin inclusion-in-tofu background phantom were also reconstructed – where gelatin is expected to have a lower *hc* than tofu.

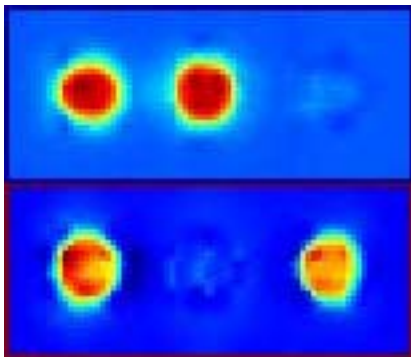


Figure 1: Reconstructed images of a simulated 3-inclusion phantom. Top image shows shear modulus and bottom image shows hydraulic conductivity (*hc*). Left inclusion had contrast in both shear and *hc*, middle inclusion in shear only and right inclusion in *hc* only.

Results:

The MRPE algorithm reconstructed the simulated phantoms with high accuracy for both shear modulus and *hc* (Figure 1). The shear modulus estimation reaches the correct solution in fewer iterations than *hc*, is more robust to measurement noise and requires less regularization. For example, *hc* was robust to 3% Gaussian noise and shear modulus was robust to 5% noise. Initial images recovered from experimental data acquired on a gelatin-in-tofu phantom showed correct spatial delineation of the gelatin inclusion and similar shear modulus contrast but more modest levels of contrast in *hc* than expected.

Conclusions:

Hydraulic conductivity is a potentially new mechanical property of biphasic tissue that may have application in tumor delineation, ICP detection, and drug delivery. MR poroelastography is an avenue for noninvasive *hc* estimation *in vivo*. Current results show that estimation of this parameter is possible in simulations representative of typical experimental conditions. Initial gelatin-in-tofu phantom experimental results showed some contrast in *hc* relative to shear modulus, but the differences between the background and inclusion were less than anticipated and further algorithmic development and evaluation is warranted. For example, the reconstruction process may require higher regularization or different degrees of spatial parameterization of *hc* relative to the shear modulus.

References:

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