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Magnetic resonance elastography and diffusion-weighted imaging of the sol/gel phase transition in agarose

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Abstract

The dynamics of the sol/gel phase transition in agarose was analyzed with magnetic resonance elastography (MRE) and diffusion-weighted imaging, providing complementary information on a microstructural as well as on a macroscopic spatial scale. In thermal equilibrium, the diffusion coefficient of agarose is linearly correlated with temperature, independent of the sol/gel phase transition. In larger agarose samples, the transition from the sol to the gel state was characterized by a complex position and temperature dependency of both MRE shear wave patterns and apparent diffusion coefficients (ADC). The position dependency of the temperature was experimentally found to be qualitatively similar to the behavior of the ADC maps. The dynamics of the temperature could be described with a simplified model that described the heat exchange between sol and gel compartments. The experiments supported the approach to derive temperature maps from the ADC maps by a linear relationship. The spatially resolved dynamics of the temperature maps were therefore employed to determine the elasticities. For this reason, experimental MRE data were simulated using a model of coupled harmonic oscillators. The calculated images agreed well with the experimentally observed MRE wave patterns.

Keywords: Magnetic resonance elastography; Diffusion-weighted imaging; Sol/gel phase transition; Agarose; Modulus of elasticity

1. Introduction

Magnetic resonance elastography (MRE) has been established to study in vivo the spatial distribution of the elasticity characteristics of different tissues such as mamma, muscle, and brain [1–7]. Recently, it was demonstrated that MRE can be used for the spatially resolved monitoring of the dynamics of phase transitions in thermoreversible gels [8]. Since the dynamics of the sol/gel phase transition are determined by the assemblage of complex 3-D macromolecular networks, elasticity maps can reveal the distribution and the degree of the linkage that is established between supramolecular chains in dependency of local temperatures and of the growing macromolecular network.

MRE data are accumulated in terms of phase contrast wave images showing patterns of mechanical waves [9]. These wave images need to be reconstructed for obtaining elasticity maps displaying the particular elasticity contrast. Several approaches have been reported to reconstruct MRE wave images [2,10–18]. In forward-reconstruction techniques, wave images are calculated and matched to the experiment in order to prevent inversion artifacts due to boundaries, amplitude nulls, and noisy data. Such techniques require start data for the elasticity to reconstruct in iterative procedures stepwise-refined elasticity maps until simulated and experimental data match. In [11], MRE wave images were calculated analytically employing a model of coupled harmonic oscillators (CHO) that are displaced under forced excitation.

As in most fit routines, the start values in the CHO method have to be chosen to allow the solution to

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