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Wide-range dynamic magnetic resonance elastography

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ABSTRACT

Tissue mechanical parameters have been shown to be highly sensitive to disease by elastography. Magnetic resonance elastography (MRE) in the human body relies on the low-dynamic range of tissue mechanics < 100 Hz. In contrast, MRE suited for investigations of mice or small tissue samples requires vibration frequencies 10–20 times higher than those used in human MRE. The dispersion of the complex shear modulus (G^*) prevents direct comparison of elastography data at different frequency bands and, consequently, frequency-independent viscoelastic models that fit to G^* over a wide dynamic range have to be employed. This study presents data of G^* of samples of agarose gel, liver, brain, and muscle measured by high-resolution MRE in a 7T-animal scanner at 200–800 Hz vibration frequency. Material constants μ and α according to the springpot model and related to shear elasticity and slope of the G^*-dispersion were determined. Both μ and α of calf brain and bovine liver were found to be similar, while a sample of fibrotic human liver (METAVIR score of 3) displayed about fifteen times higher shear elasticity, similar to μ of bovine muscle measured in muscle fiber direction. α was the highest in fibrotic liver, followed by normal brain and liver, while muscle had the lowest α-values of all biological samples investigated in this study. As expected, the least G^*-dispersion was seen in soft gel. The proposed technique of wide-range dynamic MRE can provide baseline data for both human MRE and high-dynamic MRE for better understanding tissue mechanics of different tissue structures.

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1. Introduction

Shear viscoelastic properties are sensitive to the microstructural constitution and physiological state of biological tissues. Changes in the mechanical properties of living tissue can indicate disease progression as in liver fibrosis (Ziol et al., 2005; Yin et al., 2007; Huwart et al., 2007), physiological processes such as normal aging of cerebral tissue (Sack et al., 2009), or the establishment of myosin cross-links with muscle contraction (Hoyt et al., 2008; Gennisson et al., 2010). Researchers today use elastography to gain insights into the relationship between disease and tissue mechanics. Elastography combines mechanical stimulation of tissue by shear waves or by static compression with medical ultrasound or magnetic resonance imaging (Ophir et al., 1991; Muthupillai et al., 1995). Shear-wave-based ultrasound elastography has been used to measure viscoelasticity of skeletal muscle and liver by means of the dispersion of the wave propagation speed within a frequency range 80–800 Hz (Hoyt et al., 2008; Deffieux et al., 2009; Gennisson et al., 2010). In contrast, multifrequency magnetic resonance elastography (MRE) relies on the inversion of complex shear wave images after Fourier decomposition of time-harmonic vibrations (Klatt et al., 2007). This strategy directly yields the dispersion of the complex shear modulus, G^*, which has been analyzed in liver (Asbach et al., 2008, 2010), brain (Sack et al., 2009; Wuerfel et al., 2010), and skeletal muscle (Klatt et al., 2010b) in a frequency range between 25 and 62.5 Hz. The dynamic range of MRE can be extended by invasive tests (Vappou et al., 2007) or in vivo mouse MRE, where the range of frequencies is between 200 and 1200 Hz due to a smaller field of view and higher gradient strengths (Othman et al., 2005; Atay et al., 2008; Salameh et al., 2009). However, few elastography data have been reported on the dynamics of the complex shear modulus in this frequency range, and their comparison to the low-dynamic range applicable to humans is still vague. This "missing link" between high-dynamic MRE and human MRE might be resolved by applying identical models of the viscoelastic behavior of tissue in order to deduce comparable (frequency-independent) material constants. Therefore this study aims to investigate the complex modulus dispersion of tissue samples in a 7T animal MRI scanner over a wide dynamic range. Three types of biological tissue are investigated: bovine skeletal muscle, bovine liver, and calf brain.

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