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ScienceDirect
Acta Biomaterialia xxx (2006) xxx–xxx
Acta BIOMATERIALIA
www.actamat-journals.com

Three-dimensional analysis of shear wave propagation observed by *in vivo* magnetic resonance elastography of the brain ☆

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Received 2 March 2006; received in revised form 29 August 2006; accepted 29 August 2006

Abstract

Dynamic magnetic resonance elastography (MRE) is a non-invasive method for the quantitative determination of the mechanical properties of soft tissues *in vivo*. In MRE, shear waves are generated in the tissue and visualized using phase-sensitive MR imaging methods. The resulting two-dimensional (2-D) wave images can reveal in-plane elastic properties when possible geometrical biases of the wave patterns are taken into account. In this study, 3-D MRE experiments of *in vivo* human brain are analyzed to gain knowledge about the direction of wave propagation and to deduce in-plane elastic properties. The direction of wave propagation was determined using a new algorithm which identifies minimal wave velocities along rays from the surface into the brain. It was possible to quantify biases of the elastic parameters due to projections onto coronal, sagittal and transversal image planes in 2-D MRE. It was found that the in-plane shear modulus is increasingly overestimated when the image slice is displaced from narrow slabs of 2–5 cm through the center of the brain. The mean shear modulus of the brain was deduced from 4-D wave data with about 3.5 kPa. Using the proposed slice positions in 2-D MRE, this shear modulus can be reproduced with an acceptable error within a fraction of the full 3-D examination time.

Keywords: Magnetic resonance elastography; Brain; 3-D analysis; Direction of shear wave propagation; Shear modulus

1. Introduction

For centuries, palpation has been used as the primary test for pathological tissue change. The sensitivity of the method is based on the mechanical resistance of soft tissue to compression and shear deformations, which varies in orders of magnitude throughout the human body. However, manual palpation is a subjective method limited to soft tissues in the vicinity of the body surface. Therefore, dynamic magnetic resonance elastography (MRE) was developed as a non-invasive method for quantitatively measuring the viscoelastic properties of human soft tissue *in vivo* [1–10]. In contrast to static MRE, where static or quasi-static tissue deformations are applied, dynamic MRE is based on the application of low-frequency acoustic waves penetrating the tissue of interest. Short dynamic excitation pulses are used in transient dynamic MRE, whereas steady-state dynamic MRE – the subject of this study – uses several motion cycles or continuous excitations. The tissue motion is magnetically encoded in the MR phase signal by synchronously oscillating gradients. The wave images display a phase-difference contrast that is sensitive to deflections smaller than 1 μm. In dynamic MRE, if the direction of wave propagation lies in the image plane and boundary effects and viscosity are negligible, the wavelength of the observed wave patterns is related to the elasticity of the tissue.

Comparisons of dynamic MRE with independent shear modulus-determining methods have shown that MRE provides correct quantities in tissue phantoms [1,11–13].

☆ This work was presented in parts at the First International Conference on Mechanics of Biomaterials & Tissues.

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1742-7061/$ - see front matter
doi:10.1016/j.actbio.2006.08.007