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Simulation and analysis of magnetic resonance elastography wave images using coupled harmonic oscillators and Gaussian local frequency estimation

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Abstract

New methods for simulating and analyzing Magnetic Resonance Elastography (MRE) images are introduced. To simulate a two-dimensional shear wave pattern, the wave equation is solved for a field of coupled harmonic oscillators with spatially varying coupling and damping coefficients in the presence of an external force. The spatial distribution of the coupling and the damping constants are derived from an MR image of the investigated object. To validate the simulation as well as to derive the elasticity modules from experimental MRE images, the wave patterns are analyzed using a Local Frequency Estimation (LFE) algorithm based on Gauss filter functions with variable bandwidths.

The algorithms are tested using an Agar gel phantom with spatially varying elasticity constants. Simulated wave patterns and LFE results show a high agreement with experimental data. Furthermore, brain images with estimated elasticities for gray and white matter as well as for exemplary tumor tissue are used to simulate experimental MRE data. The calculations show that already small distributions of pathologically changed brain tissue should be detectable by MRE even within the limit of relatively low shear wave excitation frequency around 0.2 kHz. © 2001 Elsevier Science Inc. All rights reserved.

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1. Introduction

It is well known from clinical experience that manual palpation is an important procedure for diagnosing changes in elastic properties of tissue. Especially in mammography, palpation often leads to the localization of tumors. The stiffness of pathologic tissue can vary tremendously from surrounding normal tissue [1,2]. However, manual palpation is clearly restricted to manually accessible regions of the human body and suffers from a reduced spatial resolution. Usually only surface-near, large and stiff tumors may be detected. The last few years have witnessed an enormous interest (i) in developing novel techniques for mapping the biomechanical properties of tissue with increased spatial resolution in two and three dimensions, (ii) in extending these techniques to regions that are manually inaccessible, and (iii) in providing a quantitative estimate of the elastic properties of different unaffected and pathologically transformed tissues.

Elastic tissue properties such as increased stiffness are physically designated as elastic moduli that describe the resistance of the material to deformations.

For an imaging of local contrast according to the elastic moduli, various stress-preparation methods have been applied in combination with X-ray, ultrasound, or magnetic resonance [3–11]. Dynamic magnetic resonance elastography (MRE) offers one of the most promising techniques for in-vivo elasticity measurements [8,12]. The feasibility of MR elastography for the detection of breast tumor has been impressibly demonstrated recently [13–15]. Furthermore, preliminary results of in-vivo MRE studies of the human body have been published for skeletal muscles [16] and the brain [17,18].

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