FULL PAPER

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MR Elastography of the Liver and the Spleen Using a Piezoelectric Driver, Single-Shot Wave-Field Acquisition, and Multifrequency Dual Parameter Reconstruction

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Purpose: Viscoelastic properties of the liver are sensitive to fibrosis. This study proposes several modifications to existing magnetic resonance elastography (MRE) techniques to improve the accuracy of abdominal MRE.
Methods: The proposed method comprises the following steps: (i) wave generation by a nonmagnetic, piezoelectric driver suitable for integration into the patient table, (ii) fast single-shot 3D wave-field acquisition at four drive frequencies between 30 and 60 Hz, and (iii) single-step postprocessing by a novel multifrequency dual parameter inversion of the wave equation. The method is tested in phantoms, healthy volunteers, and patients with portal hypertension and ascites.
Results: Spatial maps of magnitude and phase of the complex shear modulus were acquired within 6–8 min. These maps are not subject to bias from inversion-related artifacts known from classic MRE. The spatially averaged modulus for healthy liver was 1.44 ± 0.23 kPa with $\phi = 0.492 \pm 0.064$. Both parameters were significantly higher in the spleen (2.29 ± 0.97 kPa, $P = 0.015$ and 0.749 ± 0.144, $P = 6.58 \cdot 10^{-5}$, respectively).
Conclusion: The proposed method provides abdominal images of viscoelasticity in a short time with spatial resolution comparable to conventional MR images and improved quality without being compromised by ascites. The new setup allows for the integration of abdominal MRE into the clinical workflow. **Magn Reson Med 000:000–000, 2013. © 2013 Wiley Periodicals, Inc.**

Key words: 3D multifrequency MRE; least-squares inversion; piezoelectric driver; shear waves; complex shear modulus; loss tangent; liver; portal hypertension

INTRODUCTION

Hepatic fibrosis is associated with significantly elevated liver stiffness. Therefore, elastography based on ultrasound (1,2) or magnetic resonance imaging (3,4) has been established during the last decade as a noninvasive marker of liver fibrosis.

In elastography, the tissue is mechanically excited by static compression, focused acoustic radiation, or gentle vibrations in the low frequency range below 100 Hz (5–7). The latter type of stimulation is exploited in magnetic resonance elastography (MRE), which relies on the evaluation of shear wave fields in two or three dimensions (8–10). With its capability of capturing any component of the wave field within arbitrarily angulated imaging planes or in 3D slabs, MRE is currently the most precise elastography technique for staging hepatic fibrosis (11). Furthermore, the mechanical properties of the spleen attainable by an MRE scan of the liver have been proven sensitive to hepatic portal hypertension and can thus provide additional diagnostic information (12).

However, only a few sites worldwide have established MRE of the liver as a routine clinical procedure. One major limitation of clinical MRE is the current driver technology, which relies on Lorentz coils (13) or loudspeakers (14,15), imposing either field distortions, which limit the applicability of fast echo-planar-imaging (EPI) sequences, or requiring rods and tubes for the transmission of vibrations from distant wave sources to the liver (10,14). Interference-free, nonmagnetic drivers have been proposed in the past, however, without being optimized and tested for applications in abdominal MRE (16,17).

A further obstacle is that spatial maps of viscoelastic parameters still lack consistency. These so-called elastograms (18–24) are regularly limited by severe artifacts due to wave nodes or low amplitudes, resulting in unreliable regions within the liver because no elastic deformation can be achieved. Such uncertain regions have to be identified and masked to avoid biased stiffness estimates.

To overcome these limitations, we here introduce a setup and protocol which incorporates a semidistant driver placed at the end of the patient table, fast 3D EPI-based acquisition of vibration fields at multiple drive frequencies, and a single-step inversion algorithm of multifrequency 3D wave-field data. While the driver and the imaging sequence are novel in the application to the liver and to the spleen, we will introduce an inversion algorithm that is of general interest in multifrequency MRE. Our aim is an improved spatial resolution of abdominal MRE given by reduced inversion errors and less regions suffering from uncertain viscoelasticity values. This, combined with short examination times and improved driver handling, aids the further advancement of abdominal MRE towards a precise clinical modality for staging hepatic

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