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Tomoelastography by multifrequency wave number recovery from time-harmonic propagating shear waves☆

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ABSTRACT

Palpation is one of the most sensitive, effective diagnostic practices, motivating the quantitative and spatially resolved determination of soft tissue elasticity parameters by medical ultrasound or MRI. However, this so-called elastography often suffers from limited anatomical resolution due to noise and insufficient elastic deformation, currently precluding its use as a tomographic modality on its own. We here introduce an efficient way of processing wave images acquired by multifrequency magnetic resonance elastography (MMRE), which relies on wave number reconstruction at different harmonic frequencies followed by their amplitude-weighted averaging prior to inversion. This results in compound maps of wave speed, which reveal variations in tissue elasticity in a tomographic fashion, i.e. an unmasked, slice-wise display of anatomical details at pixel-wise resolution. The method is demonstrated using MMRE data from the literature including abdominal and pelvic organs such as the liver, spleen, uterus body and uterus cervix. Even in small regions with low wave amplitudes, such as *nucleus pulposus* and spinal cord, elastic parameters consistent with literature values were obtained. Overall, the proposed method provides a simple and noise-robust strategy of in-plane wave analysis of MMRE data, with a pixel-wise resolution producing superior detail to MRE direct inversion methods.

1. Introduction

Since the advent of elastography in the early 1990s, stiffness measurements of biological tissues have become routine diagnostic applications of sonography (Ophir et al., 1991; Parker et al., 1990) and magnetic resonance imaging (MRI) (Muthupillai et al., 1995; Plewes et al., 1995). Today, many, if not all, commercial ultrasound scanners have one or more elastography options (Cosgrove et al., 2013). Major MRI vendors also offer elastography as a tool for the noninvasive staging of liver fibrosis based on a standardized procedure approved by the US Food and Drug Administration (Venkatesh and Ehman, 2015). Many factors have contributed to the success of elastography, including quantitative measurements, non-invasive acquisitions, no need for contrast medium, and high sensitivity to multiscale tissue structures.

The standard output of elastography is an image of stiffness, elasticity or wave speed, which is known as an elastogram and mapped as a colored overlay onto a high-resolution anatomical image (Cosgrove et al., 2013; Venkatesh et al., 2013). In general, the resolution of the elastogram is lower than that of the underlying gray-scale sonographic or MR image due to noise and unknown boundary conditions in the elasticity reconstruction procedures (Doyley, 2012; Manduca et al., 2001). For example, stress accumulation at tissue interfaces, or wave nulls due to interfering propagating waves, or acoustic shading, often cause artifacts in the elastograms, necessitating masking in order to blank out areas of unreliable stiffness values. For this reason, the main clinical use of quantitative elastography is measuring the elasticity of entire organs or large Regions of Interest (ROIs).

Different approaches have been proposed to overcome limits in the resolution of anatomical details in elastography (Baghani et al., 2011; Honarvar et al., 2013; Manduca et al., 2003; McGarry et al., 2012). One promising method is multifrequency magnetic resonance elastography (MMRE), based on multifrequency dual elasto-visco (MDEV) inversion, in which several harmonic wave fields are acquired and averaged prior to inversion of the wave equation (Hirsch et al., 2014; Papazoglou et al., 2012). With use of this strategy, regions of low elastic strain and therefore low signal-to-noise-ratio (SNR) in one frequency are compensated for

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