COMMUNICATION

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Vibration-Synchronized Magnetic Resonance Imaging for the Detection of Myocardial Elasticity Changes

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Vibration synchronized magnetic resonance imaging of harmonically oscillating tissue interfaces is proposed for cardiac magnetic resonance elastography. The new approach exploits cardiac triggered cine imaging synchronized with extrinsic harmonic stimulation (f = 22.83 Hz) to display oscillatory tissue deformations in magnitude images. Oscillations are analyzed by intensity threshold-based image processing to track wave amplitude variations over the cardiac cycle. In agreement to literature data, results in 10 volunteers showed that endocardial wave amplitudes during systole (0.13 ± 0.07 mm) were significantly lower than during diastole (0.34 ± 0.14 mm, $P < 0.001$). Wave amplitudes were found to decrease 117 ± 40 ms before myocardial contraction and to increase 75 ± 31 ms before myocardial relaxation. Vibration synchronized magnetic resonance imaging improves the temporal resolution of magnetic resonance elastography as it overcomes the use of extra motion encoding gradients, is less sensitive to susceptibility artifacts, and does not suffer from dynamic range constraints frequently encountered in phase-based magnetic resonance elastography. Magn Reson Med 000:000–000, 2012. © **2012 Wiley Periodicals, Inc.**

Key words: time harmonic vibrations; cardiac elastography; MRE; shear modulus; heart contraction; myocardial relaxation; shear waves

INTRODUCTION

Cardiac function is determined by the alteration of myocardial elasticity during the cardiac cycle. Therefore, measurement of myocardial elasticity may support the diagnosis and follow-up of cardiac contraction and relaxation abnormalities. Challenges for noninvasively mapping myocardial elasticity arise from the complex geometry of the heart, its periodic motion, structural anisotropy of the myocardium, and its pronounced viscoelastic and hyperelastic behavior (1). Various groups have tackled cardiac elasticity imaging by developing a variety of dedicated elastography methods (2–8). In general, elastography requires mechanical stimulation of tissue, measurement of the induced tissue response, and extraction of diagnostic parameters from the acquired data. Cardiac magnetic resonance elastography (MRE) uses low-frequency mechanical oscillations for stimulating the heart through the anterior chest wall (6,8–10). The flux of elastic waves through the heart is captured by cardiac motion-synchronized phase-contrast magnetic resonance imaging (MRI) techniques (11,12). Phase-contrast-based MRE has recently been used for measuring cardiac volume–pressure cycles (13,14), isovolumetric tension-relaxation times of the heart (15), and symptomatically reduced diastolic relaxation (16).

In general, the MRI phase signal can encode coherent particle shifts on the order of microns (17,18). This inherent sensitivity to motion combined with the capability to encode motion in arbitrary directions renders MRI suitable for flow quantification and elastography. While in flow quantification particle velocity is measured, MRE is designed to capture deflection of the oscillating shear wave field assuming time-harmonic motions. Normally, the amplitudes of externally induced harmonic oscillations inside the body are low, i.e., on the order of tens of microns. Particularly at high shear wave frequencies larger than 80 Hz, viscose damping dominates in vivo vibration patterns. On the other hand, shear waves penetrate the body without any major attenuation at drive frequencies below 25 Hz. In this case, deflection amplitudes approach the order of millimeters throughout the body without the use of an excessive oscillation stimulus. With this low-frequency regime, the externally induced motion is in the order of the in-plane resolution commonly used in clinical MRI. Consequently, oscillations become directly visible in the morphological contrast of an MR image. The oscillatory response of tissue morphology to external stimuli measured by standard MRI may provide elastodynamic information without phase image processing and wave inversion. Unlike conventional MRE, the proposed method does not require specially tailored phase-contrast techniques for encoding oscillatory motion by extra motion-encoding gradients (MEG). Instead, any MRI sequence synchronized to externally induced tissue vibrations can be used motivating henceforth the term vibration-synchronized MRI (vsMRI). As no MEG is required in vsMRI, echo time and repetition time (TR) can be shortened reducing signal relaxation, susceptibility artifacts and improving temporal resolution in cine steady-state MRE. This study demonstrates the feasibility of vsMRI and examines its applicability for cardiac MRE. For this purpose, a

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