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● *Original Contribution*

ISOVOLUMETRIC ELASTICITY ALTERATION IN THE HUMAN HEART DETECTED BY *IN VIVO* TIME-HARMONIC ELASTOGRAPHY

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Abstract—Time harmonic elastography (THE) has recently been introduced for measurement of the periodic alteration in myocardial shear modulus based on externally induced low-frequency acoustic vibrations produced by a loudspeaker. In this study, we propose further developments of cardiac THE toward a clinical modality including integration of the vibration source into the patient bed and automated parameter extraction from harmonic shear wave amplitudes, wall motion profiles and synchronized electrocardiographic records. This method has enabled us to evaluate the delay between wall motion and wave amplitude alteration for the measurement of isovolumetric times of elasticity alteration during contraction (τ_C) and relaxation (τ_R) in a group of 32 healthy volunteers. On average, the wave amplitudes changed between systole and diastole by a factor of 1.7 ± 0.3, with a τ_C of 137 ± 61 ms and a τ_R of 68 ± 73 ms, which agrees with results obtained with the more time-consuming and expensive cardiac magnetic resonance elastography. Furthermore, because of the high sampling rate, elasto-morphometric parameters such as transition times and the area of wave amplitude-cardiac motion cycles can be processed in an automated way for the future clinical detection of myocardial relaxation abnormalities. (E-mail: ingolf.sack@charite.de) © 2013 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Cardiac elastography, Time-harmonic shear waves, Heart, Shear modulus alteration, Isovolumetric times, Cardiac magnetic resonance elastography.**

INTRODUCTION

The periodic alteration in myocardial shear modulus is vital to blood circulation. Measurement of the shear modulus of the heart wall would provide the primary biomarker of myocardial activity and dysfunction (Glantz and Kernoff 1975; Zile et al. 2004). Myocardial tissue characterization by echocardiography combines acoustic parameters such as ultrasonic attenuation (O'Donnell et al. 1979), propagation speed (O'Brien et al. 1995) and integrated backscatter (D'Hooge et al. 2000; Wickline et al. 1985). However, these parameters are related to the propagation of pressure waves and, thus, are governed by the myocardial bulk modulus, which is, other than the shear modulus, not the primary mechanical constant altered by muscle contraction.

For this reason, various strategies of cardiac elastography have been pursued by medical ultrasound or magnetic resonance imaging (MRI) researchers to assess the alteration in myocardial elasticity during the heart cycle non-invasively. Basically three concepts of mechanical activation of *in vivo* heart muscle for elastographic examinations have been realized: intrinsic activation of the myocardium (Kanai 2005, 2009; Konofagou et al. 2002; Luo et al. 2007; Pernot et al. 2007); internal stimulation of shear waves based on focused ultrasound impulses (Bouchard et al. 2009, 2011; Couade et al. 2011; Hsu et al. 2007; Pernot et al. 2011); and externally induced shear waves from a time-harmonic vibration source (Elgeti et al. 2008, 2012; Kolipaka et al. 2010). The last concept, time-harmonic elastography (THE), has been tested in animals, healthy volunteers and patients using MRI (Elgeti et al. 2010a; Kolipaka et al. 2011; Sack et al. 2009) and ultrasound (Tzschatzsch et al. 2012). Time-harmonic shear waves in the low audible frequency range 25 to 30 Hz, for example, can readily be introduced into the chest without

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