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● *Original Contribution*

IN VIVO TIME HARMONIC ELASTOGRAPHY OF THE HUMAN HEART

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Abstract—Time harmonic elastography is introduced as a modality for assessing myocardial elasticity changes during the cardiac cycle. It is based on external stimulation and real-time analysis of 30-Hz harmonic shear waves in axial direction of a parasternal line of sight through the lateral heart wall. In 20 healthy volunteers, the externally induced waves showed smaller amplitudes during systole (76.0 ± 30.8 μm) and higher amplitudes during diastole (126.7 ± 52.1 μm). This periodic wave amplitude alteration preceded ventricular contraction and dilation by about 100 ms. The amplitude ratio of 1.75 ± 0.49 indicates a relative change in myocardial shear elasticity on the order of 14 ± 11. These results well agree with observations made by cardiac magnetic resonance elastography for a similar displacement component and region of the heart. The proposed method provides reproducible elastodynamic information on the heart in real-time and may help in diagnosing myocardial relaxation abnormalities in the future. (E-mail: ingolf.sack@charite.de) © **2011 World Federation for Ultrasound in Medicine & Biology.**

Key Words: **Myocardial shear modulus, Continuous harmonic waves, Shear wave energy flux, Ultrasound elastography, MR elastography, Isovolumetric times, Cardiac contraction, Cardiac relaxation, Real-time strain estimation.**

INTRODUCTION

The heart's capability to circulate blood through the cardiovascular system is directly related to the periodic alteration of myocardial elasticity. Contraction and relaxation of the heart is primarily effected by the alteration of the myocardial shear modulus, which thus represents the physical quantity behind pressure generation inside the ventricle. Direct measurement of the myocardial shear modulus may, thus, help in assessing myocardial dysfunction and relaxation abnormalities (Zile et al. 2004; Aurigemma et al. 2006).

Elastography enables the noninvasive measurement of mechanical parameters of *in vivo* soft tissue (Ophir et al. 1991) with emerging clinical applications from breast tissue characterization to cardiology (see [Wells and Liang 2011] and references therein). There are several approaches to elastography of the heart and the cardiovascular system. Various researchers exploited intrinsic activation of myocardium (Konofagou et al. 2002; Varghese et al. 2003; Kanai, 2005; Lee et al. 2011) or arteries (Maurice et al. 2008; Schaar et al. 2005; Vappou et al. 2010). Other approaches rely on extrinsic activation by modulating the ultrasonic radiation force (Hsu et al. 2007; Bouchard et al. 2009; Pislaru et al. 2009; Nenadic et al. 2011; Dumont et al. 2011) or sending time harmonic shear waves through the chest (Elgeti et al. 2008; Sack et al. 2009). The resulting strain fields can be determined using ultrasound (Ophir et al. 1991; Parker et al. 1990) or magnetic resonance imaging (MRI) (Plewes et al. 1995; Muthupillai and Ehman, 1996). While medical ultrasound is rather inexpensive, robust and capable of strain estimation in real-time, phase-contrast MRI has the advantage of being intrinsically sensitive to motion in three dimensions, which is particularly useful for elastography. However, cardiac MR elastography (MRE) suffers from long scanning times since images are reconstructed from lines acquired in synchrony with the electrocardiogram (ECG) over multiple heart beats (Rump et al. 2007; Sack et al. 2009;

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