Direct elastography of in vivo human heart

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Background: Heart function is determined by the alteration of myocardial elasticity during the heart cycle. Consequently, measurement of myocardial elasticity may support the diagnosis of cardiac dysfunction related to myocardial contraction and relaxation abnormalities. Measurement of elastic parameters requires the mechanical stimulation of tissue which is performed in dynamic MR elastography (MRE) by harmonic vibrations of the body in the low acoustic range of a few tens of Hz.
Problem: MRE of the heart relies on motion encoding gradients which prolong TE and thus inherently reduce image quality and temporal resolution [1,2,3]. Furthermore, spin-phase contrast methods suffer from susceptibility artefacts and phase wraps.
Objective: Direct elastography is introduced for measuring externally induced oscillatory wall deformations in the human heart. For this purpose, vibrations of the myocardium can be traced over time in magnitude images for deducing elasticity-based functional parameters.

Methods: Experiments were run in 1.5 T scanner (Siemens, Erlangen, Germany). An extended piston driver placed on the anterior chest wall was used to stimulate the heart by 22.8 Hz acoustic oscillations (Fig.1). The oscillations were synchronized to a balanced steady-state imaging sequence so that one vibration period matched exactly 12 x TR with TR = 3.65 ms. A total of 360 separate images were acquired during an interval of approximately 1.5 cardiac cycles (1.31 seconds = TR x 360). During this interval a single phase-encoding step was performed for each image. Acquisition of all k-space data for each image required 176 x 1.31 seconds (matrix size: 176 x 256, 1.56 mm² in-plane resolution, 5 mm slice thickness). During each of the 1.31-second intervals of data acquisition, the volunteers held their breath in expiration, followed by a short period of 2.5 seconds of free breathing (one inhalation and one exhalation) before the next k-line acquisition started (Fig.2). Total measure time was 11.2 min. For data processing two profiles x_1 and x_2 were drawn along the anterior-inferior axis and the septal-lateral axis of the heart and oscillations of the anterior ventricular wall visible in x_1-t and x_2-t plots were automatically segmented by a threshold-tracing algorithm (Fig.3).

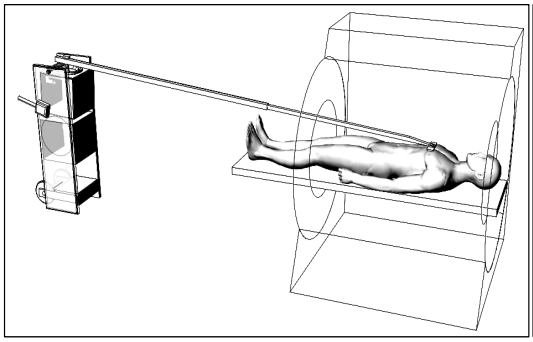

Fig.1: Vibration generator (left) is connected to the patient's chest via extended piston transducer

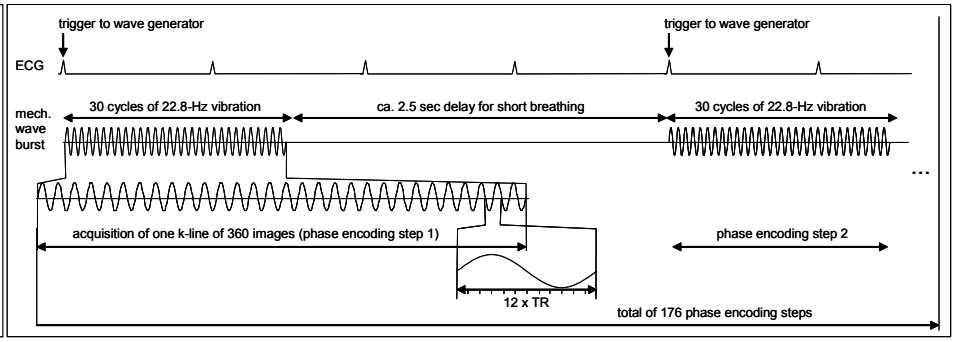

Fig.2: Synchronization of ECG, mechanical vibration and bSSFP-sequence TR

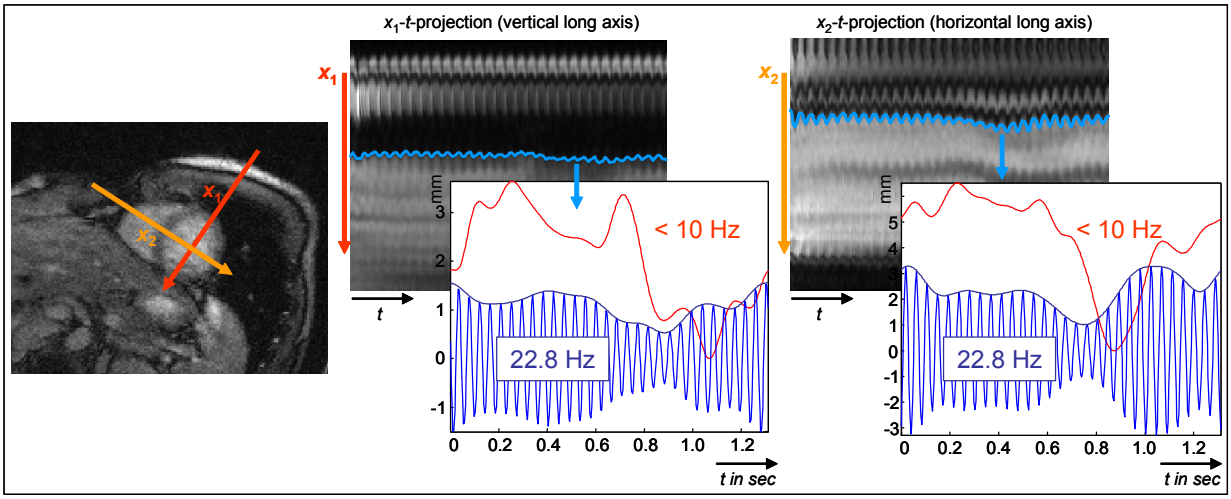

Fig.3: Profile-based data evaluation in direct elastography. Oscillations at 22.8 Hz represent the externally induced harmonic motion. Motion components < 10 Hz mainly reflect intrinsic heart motion.

Results: Principal findings are illustrated in figure 3: Vibrations induced by the external actuator are well visible in thoracic wall, subcutaneous fat, anterior wall of right- and left ventricle and the septum. Vibration amplitude of the heart was approximately 1.5 mm. Wave amplitudes varied over the cardiac cycle about factors of two to four from anterior-inferior profiles to septal-lateral profiles with smallest amplitudes during systole. The minimum of wave amplitudes occurred up to 200 ms ahead of the minimum of the ventricular diameter that is given by the minimum deflection of intrinsic motion components with frequencies below 10 Hz.

Discussion: Direct elastography relies on shear waves with amplitudes in the order of the in-plane resolution of vibration-synchronized MRI. As reported by cardiac MRE, shear wave amplitudes in the heart vary in synchrony to the cardiac cycle and can therewith reveal physiological [1] and symptomatic elasticity variations of the myocardium [4]. Compared to spin-phase sensitive MRE, direct elastography has an improved temporal resolution due to shorter echo times. Also, the proposed magnitude approach is less prone to image artifacts and reveals the mechanical response of highly resolved anatomical details. As a limitation, direct elastography requires image contrast between anatomical structures for resolving the phase propagation of the mechanical waves. Further progress can be made by applying 2D-correlation techniques for deducing the externally stimulated in-plane deformation of the heart. An extension of this work to (ultra)high fields is anticipated to make use of the enhanced signal-to-noise ratio, which bears the potential to resolve shear wave amplitudes with an improved spatial resolution.

Literature: [1] Sack I. MRM 2009, 61, 668-77; [2] Kolipaka A. MRM 2010, 64, 862-70 [3] Robert B. MRM 2009, 62, 1155-63 [4] Elgeti T. Invest.Radiol. 2010 45(12)