Analysis of in vivo myocardial oscillations using high temporal resolution cine MR elastography

J. Rump[1], T. Elgeti[1], S. Papazoglou[1], D. Klatt[1], U. Hamhaber[2], J. Braun[2], and I. Sack[1]

[1]Department of Radiology, Charité Berlin, Berlin, Germany, [2]Institute of Medical Informatics, Charité, Berlin, Berlin, Germany

Introduction: In vivo measurement of myocardial elasticity (heart stiffness) may play a key role in diagnosis and assessment of myocardial dysfunctions as well as for testing the viability of myocardium after infarction [1-3]. MR elastography (MRE) [4] is a technique to measure elastic parameters of living soft tissue that is based on phase sensitive MRI and externally induced shear waves.

Problem: External shear wave excitation of the heart requires the use of low vibration frequencies in order to compensate for the mechanical shielding and the viscosity of the wave-transmitting tissue. Therefore, shear wavelengths in the myocardium are too large for reconstructing elastic parameters by wave inversion.

Objective: Time resolved detection and analysis of external oscillations in the myocardium is proposed in order to derive an estimate of the evolution of the elasticity during the cardiac cycle. Therefore, a cine FLASH-MRE sequence was developed for capturing shear vibrations in the interventricular septum (IVP) with high temporal resolution comparable to echocardiography (5.8 ms). For data analysis a sliding-window Fourier transform was applied yielding wave amplitudes in all spatial directions.

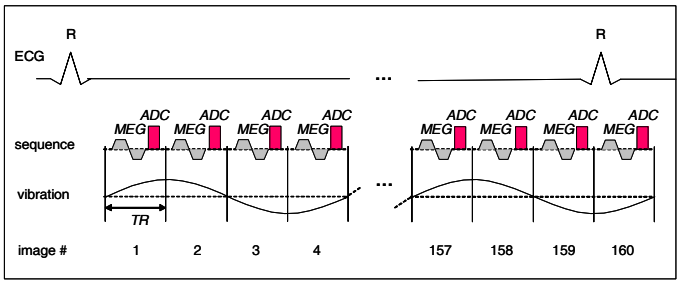

Fig.1: Timing of motion encoding in cine FLASH-MRE relative to the induced vibration. The polarity of the MEG was toggled in consecutive experiments

Methods: Cine FLASH-MRE (TR = 5.8 ms) incorporating a single-cycle motion encoding gradient (MEG) of 2.5 ms was run on a 1.5 T scanner (Siemens Sonata, Erlangen, Germany). Single *k*-space lines of 160 images were acquired within one heartbeat (fig.1). A matrix size of 128x64 combined with GRAPPA (acceleration factor two) yielded a total measure time of 32 heartbeats which were achieved during breath hold. The image slice (thickness: 5mm) was aligned with the IVS. Shear vibrations were induced by a remote loudspeaker that was coupled to the chest of the volunteer using a carbon fiber rod (fig.2). Wave excitation frequency was 43.3 Hz (4xTR). Six experiments were run with positive and negative MEG-polarity along the directions of slice selection, phase encoding and frequency encoding. Phase difference data were averaged over the IVS and subjected to a temporal 1D Fourier analysis using a sliding Gauss-window of 32xTR width. Signal intensities in the Fourier space were picked at vibration frequency.

Results: Fig.3 demonstrates the sampling of the external motion by the phase signal in the IVS. Four sampling points support one vibration cycle corresponding to the applied frequency of 4xTR. Without vibration no frequency component in the range of the excitation frequency is seen. This is quantified in fig.4, where the reference experiments displays almost zero deflection amplitude (< 2 µm). The largest deflection amplitude was found along the through-plane direction. The principal in-plane deflection was almost perpendicular to the long axis of the heart running from the apex to the aortic valve (fig.3). Amplitude variations in all three wave components are visible in fig.4.

Discussion and conclusion:

The experiments demonstrate that external wave excitation of the living human heart is well achievable. The excellent time resolution of the cine FLASH-MRI phase signal enables the measurement of wave amplitude variations over the cardiac cycle. The significance of the measured wave amplitude modulations is a subject of ongoing research. The magnitude of the vibration vector varies with less than 5%. This result indicates that either compression waves are captured or the range of shear-elasticity variations in the IVP is limited. In conclusion, the amplitude-based in vivo heart MRE might provide a valuable additional modality to detect cardiac dysfunction. In future, low frequency vibrations could accompany cardiac PC-MRI for screening the rigidity of the heart during the cardiac cycle. Therefore, the significance of time-resolved wave amplitudes in healthy as well as in diseased myocardium has to be cleared. Furthermore, respiratory gating will be important for applying the proposed technique to patients.

References:

[1] Sinkus R et al, ISMRM 2006, 77 ; [2] Rump J et al, ISMRM 2006, 149

[3] Kolipaka A et al, ISMRM 2006, 796

[4] Muthupillai R et al, Science 1995; 269: 1854-1857

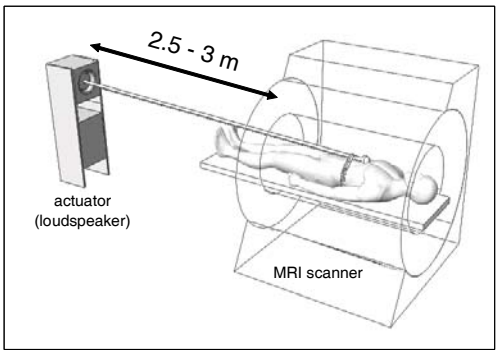

Fig.2: Sketch of the driver used for wave excitation.

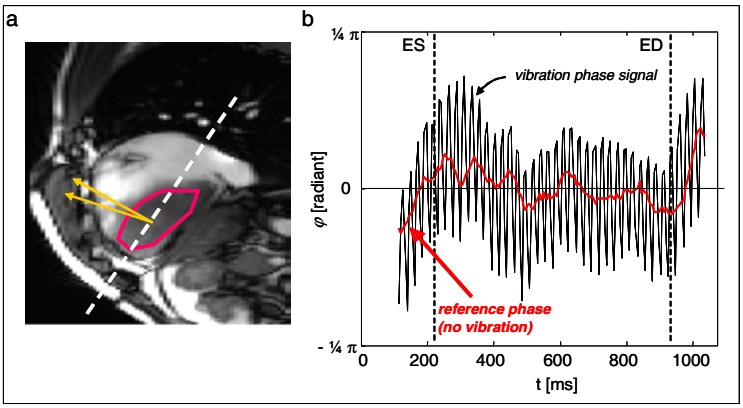

Fig. 3a: Magnitude image for the anatomical representation of the IVS. The region of interest is demarked by a red line. The dashed line shows the long axis of the heart from the apex to the aorta. The yellow arrows indicate variations in the direction of the principal axis of in-plane vibrations during the cardiac cycle **b:** Phase signal in phase encoding direction (left-right in **a**). ES and ED label the end of the systole and diastole.

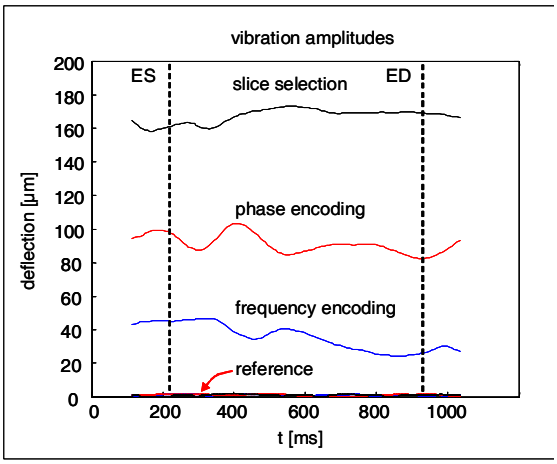

Fig.4: Amplitudes of the external oscillations along the cardiac cycle.