Assessment of heart function by cardiac MR elastography: Comparison to left ventricular pressure measurements

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Background:

Today multiple cardiac imaging modalities can provide excellent information of the heart's morphology and tissue structure in a high temporal resolution. However, as these modalities cannot measure forces, insight into the initiation of morphological changes of the heart, i.e. the contraction and the relaxation of the myocardium, is limited. Essential information of the heart's elasticity and contractility in the clinical setting still requires catheterization for a direct measurement of pressure in the chamber of interest (1). Recently cardiac MR elastography was introduced as a noninvasive means for detecting relative changes in myocardial elasticity during the heart cycle (2, 3). This method employs low-frequency shear waves induced into the heart by an external harmonic vibrator and measures the wave amplitude variation (WAV), which is a result of the alteration of myocardial stiffness (2).

Problem

A linear elasticity model combined with the assumption of constant wave intensity can be employed to calculate stiffness ratios from WAV-MRE data. In (2) it was further proposed to use WAV-MRE as a noninvasive measure of pressure changes in the left ventricle (LV). Although the MRE-derived cardiac work agreed well with literature data no direct comparison between LV-pressure and MRE has been provided.

Objective

The aim of this study is to investigate the correlation between LV-pressure and cardiac MRE-signal without applying any geometric model or elastodynamic assumptions. MRE is applied to three minipigs displaying individual variations of heart rate, systolic and diastolic pressure and pressure gradients. Tip manometers mounted on catheters were used to directly acquire LV-pressure functions over time.

MATERIAL AND METHODS:

Cardiac MRE was applied to three minipigs (LEWE) using 48.6-Hz shear vibrations and an encoding fraction of 4 wave images per vibration cycle in a 1.5 T scanner (Siemens Sonata). A remote mechanical driver was used to vibrate the left lateral chest of the animals by 48 Hz. An ECG-triggered, motion sensitized, spoiled gradient echo sequence was run to acquire the wave images with a frame rate of 193 Hz. (repetition time, TR: 5.18 ms, echo time, TE: 3.1 ms, flip angle, α: 15°, length of the motion encoding gradient, MEG: 2 ms, MEG-amplitude: 33, 25 and 21 mT/m along the direction of read-out, phase encoding and slice-selection, respectively, FOV: 200x400 mm, slice thickness: 6 mm in a short axis-view, Matrix size: 64 x 128). Invasive pressure-time functions were measured by left ventricular catheterization and tip-manometers (model PC-380, Millar Systems, Houston, Texas).

MRE-Data analysis was performed as described in (3). The LV-boundaries were manually segmented during systole. Additionally, regions of contracting tissue were extracted by correlation of the wave amplitude time function with a logical function which was one for all time points during diastole and otherwise zero.

RESULTS:

The figure shows the time dependence of both MRE wave amplitudes $U(t)$ and invasively measured LV-pressure. It is clearly visible that $U(t)$ alternates in synchrony to the pressure inside the left ventricle providing a strong indication about the validity of the correlation of LV-pressure and MRE-wave amplitudes as proposed in (2). The maximum ratio of wave amplitudes during diastole and systole were measured with 2.03 (0.08), 2.22 (0.10), and 2.55 (0.21) (standard deviation given in brackets). A linear elastic model reveals corresponding elasticity ratios of 16.8 (0.7), 24.1 (1.1), and 42.0 (3.4). The respective LV-manometer pressure differences between diastole and systole were 60, 65, and 73 mmHg. It was not possible to derive ratios of invasively measured LV-pressure during systole and diastole since small diastolic pressure values are susceptible to large experimental errors in catheter experiments.

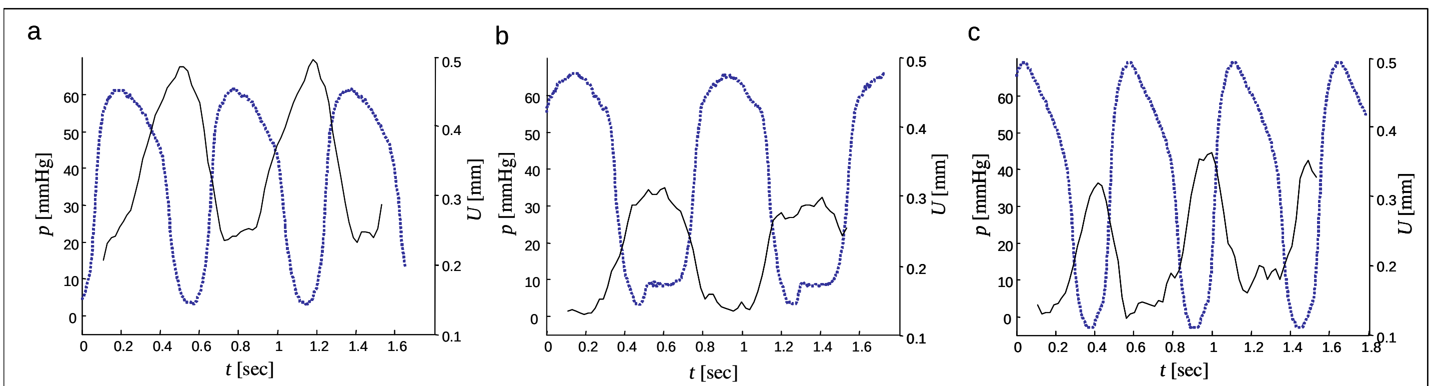

Fig: Variation of wave amplitudes observed by MRE (U, solid grey lines) compared to the invasively measured LV- pressure (dotted blue lines) in three pigs (a, b, and c, corresponding to study numbers 1,2 and 3). Shear wave amplitudes increase during diastole reversely to the LV-pressure, which is in accordance to the model of constant wave intensity given in (2) and (3). The investigated animals displayed different heart rates and pressure levels giving rise to different relative wave amplitude changes and amplitude offsets in MRE

SUMMARY AND CONCLUSION:

The mechanical stimulus of the heart by low-frequency shear vibrations provides a new contrast in MRI which is sensitive to myocardial elasticity changes. Cardiac MRE correlates well to the invasively observed alteration of LV-pressure during the cardiac phases. The results underscore the sensitivity of WAV-MRE to the LV-pressure dynamics. Individual variations of LV-pressure differences could be reproduced by MRE.

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