MR Elastography of the Heart: Initial Feasibility

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Introduction:

Numerous investigators have suggested that myocardial stiffness is a clinically important variable which is highly correlated with disease type and extent [1-3]. However existing methods for measuring myocardial stiffness are extremely limited as they are either indirect or require sectioning the heart. A non-invasive MR imaging technique, called MR elastography (MRE), has been developed to accurately measure the shear stiffness of tissue when the organ of interest is at rest [4,5]. To account for cardiac motion, MRE will require some form of gated data acquisition. However, because MRE depends on induction of microscopic shear waves and precise timing of the imaging sequence with those waves, it is unclear what effect gating might have on MRE derived stiffness measurements. The purpose of this work is to evaluate the technical feasibility of performing MRE of a heart phantom undergoing periodic volumetric and pressure changes.

Methods:

Phantom: A spherical phantom of internal diameter of 104 mm and thickness of 12 mm (figure 1(a)) was constructed from a silicone rubber composite (Wirosil, BEGO, Germany) to simulate the left ventricle of the heart. A balloon connected to a closed circuit flow pump (Shelley Medical Imaging Technologies, Ontario, Canada) was inserted into the center of the sphere and inflated with water to atmospheric pressure. The flow pump provided a computer controlled method of periodicity varying the pressure within the sphere. An in-line pressure transducer (Omega Engineering Inc.) was used to record the line pressure. The pulse plethysmograph of the MR scanner (1.5T, GE Health Care, Waukesha, WI) was placed on the line between the flow pump and spherical phantom. Shear waves were induced by direct contact between an electromechanical driver and the base of the phantom. The phantom was then placed within a birdcage transmit/receive RF head coil.

Gated MRE: A gradient echo MRE pulse sequence was modified to perform gated MRE experiments. For each MRE experiment, the MRE sequence acquired k-space views at a predetermined time delay between the detection of a trigger and initiation of the imaging sequence. MRE parameters included TE/TR = 23/750 msec, k_x/k_y = 256x64, FOV = 140mm, shear wave freq. = 200Hz.

Static Pressure Gated MRE: An ECG simulator was used to test the gated MRE sequence under two separate conditions. (i) For a fixed ECG rate of 80 bpm the static pressure within the phantom was varied from 70 to 161 mm water. (ii) For a constant, static pressure of 77mm water the ECG rate was varied from 40 to 100 bpm.

Pulsatile Pressure Gated MRE: The flow phantom was programmed to deliver a sinusoidal pressure waveform with a maxim flow of 15ml/sec, producing a minimum and maximum pressure of 62 mm and 90 mm of water into within the phantom respectively. Triggering was performed on the pulse plethysmograph waveform. Gated MRE data at a single delay time of 12 msec were then acquired.

Shear Stiffness: For each MRE experiment, the wavelength of the shear wave was measured using a local frequency estimation algorithm [6] and the shear stiffness was calculated using the relationship $\mu=\rho f^2 \lambda^2$, where, μ, ρ, ƒ and λ are the shear stiffness, density, driving frequency and wavelength of propagating waves, respectively.

Results:

Figure 1(b) describes the linear relationship between shear stiffness and hydrostatic pressure inside the phantom at a fixed heart rate of 80 bpm. This result was consistent with the previously described 2D non-gated phase contrast imaging technique [7]. At variable heart rates (40-110 bpm) and a static pressure of 77 mm water, the stiffness remained unchanged at 30.21 ± 7.7kPa (+ 1 SD) with the gated pulse sequence (figure 1(c)). Figure 1(d) Gated MRE phase-contrast image of the shear wave displacement within the phantom at a fixed trigger delay (pressure point) time indicating the presence of the shear wave within the wall. The corresponding stiffness map is shown in figure 1(e). The mean value of stiffness in 1(d) averaged over the entire wall of the phantom is 17 ± 11kPa (+ 1 SD).

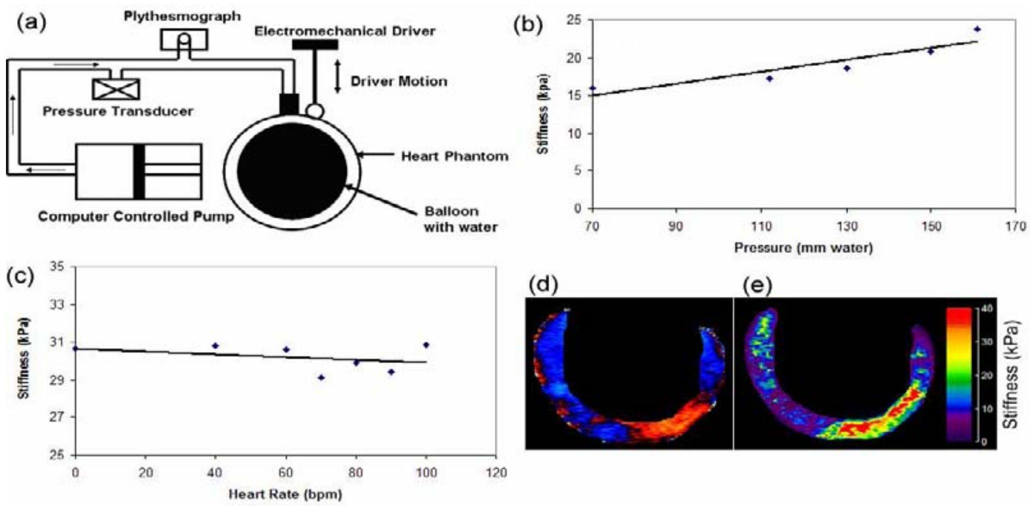

***Figure 1: (a)** Experimental setup showing the mechanical driver directly coupled to the top of the spherical phantom as well as the connection to the flow system, pressure transducer, and plythesmograph. **(b)** Gated MRE derived shear stiffness as a function of pressure. **(c)** Gated MRE derived shear stiffness versus heart rate. **(d)** Phase-difference image showing shear wave propagation under pulsatile pressure conditions. **(e)** Shear stiffness map derived from (d).*

Discussion:

We have demonstrated that in a stationary phantom at a static pressure, a stiffness value can be obtained using a gated MRE pulse sequence. At a static pressure, the stiffness value is not affected by the frequency of the gated acquisition ("heart rate"). This suggests that in spite of the precise timing required for MRE, gated MRE acquisitions are feasible. Further, when a pulsatile pressure waveform is introduced into the phantom, pressure at a given point in this cycle can be quantitated suggesting the feasibility of performing cardiac MRE.

References:

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