Evaluation of a Heart Phantom for Cardiac MR Elastography: A Feasibility Study

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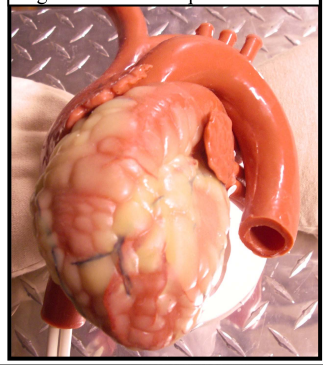
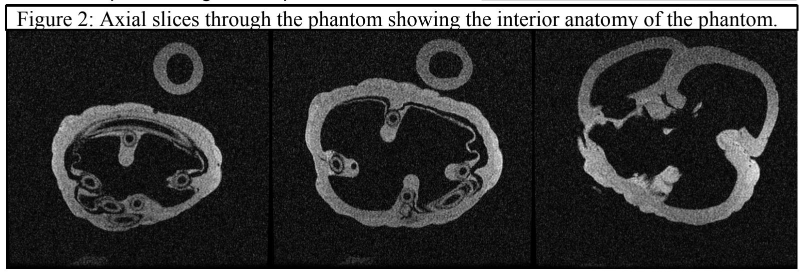
Introduction: Normal cardiac function is dependent on the mechanical properties of the myocardium such as the myocardial stiffness [1]. Myocardial stiffness is known to be a highly significant diagnostic and prognostic metric for myocardial infarctions. MR elastography (MRE) is a phase-contrast MR technique for measuring the stiffness of tissue in vivo [2]. Recent studies of pigs have shown that MRE can assess regional differences in stiffness between infarcted and remote, noninfarcted myocardium [3]. However, clinical applications of cardiac MRE (CMRE) face significant challenges, including optimal driver design to produce motion in the heart, pulse sequence requirements to acquire 3D images with high SNR and resolution in a reasonable amount of time, and accurate 3D inversion algorithms for quantifying myocardial stiffness that can help with the diagnosis of various diseases of the heart. Some of the challenges for imaging and analyzing wave propagation in the heart are that the myocardial wall is thin and the complex geometry of the heart and the resulting boundary effects demand complex 3D inversions to obtain meaningful stiffness maps. Recent studies with a spherical shell model of the heart demonstrated potential as a basic model for the left ventricle [4]. However, what is needed is a geometrically correct heart phantom with thin myocardial walls that can also beat at realistic heart rates to mimic the heart so that techniques that are developed and tested for CMRE in phantom studies are meaningful when applied to the heart. In this study, a commercially available, geometrically correct heart phantom was evaluated for CMRE. The purpose of this work was to evaluate the heart phantom as a practical tool to help develop 3D CMRE acquisition and processing techniques.

Figure 1: The heart phantom.



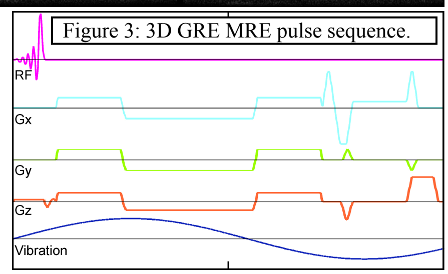
Methods: All experiments were performed with a 1.5-T whole-body scanner (Signa EXCITE, GE Healthcare, Milwaukee, WI). The "silicone beating heart" phantom (Fig. 1) was obtained from The Chamberlain Group, Maryland for CMRE evaluation. Various combinations of drivers, imaging coils, frequencies of vibration, and MRE imaging sequences were explored, including 2D multislice (MS) GRE, spin-echo (SE), and SE-EPI and 3D GRE. For purposes of evaluating the choice of imaging and experimental methods, the phantom was imaged while not beating.

Figure 2: Axial slices through the phantom showing the interior anatomy of the phantom.



Results: Figure 2 shows short-axis cross-sectional images from a high-resolution 3D GRE acquisition (FOV=120x120x102.4 mm, 256x256x128 matrix; TR/TE=6.9/1.6 ms; flip=10º) showing the interior structure of the phantom. The interior of the current phantom design differs from true cardiac anatomy, including the presence of a network of tubes used to provide realistic deformations of the beating heart and the lack of an interventricular septum. However, the overall shape and thickness of the ventricle wall is realistic, which is important for studying the effects of wave propagation in CMRE. Initial results with the 2D MS sequences indicated that SE-EPI offered the best opportunity for acquiring volumetric measurements of the vector displacement field throughout the phantom in a reasonable amount of time and with good SNR. The 3D GRE acquisition offered the best opportunity to acquire the high-resolution displacement data desired for exploring appropriate inversion algorithms for CMRE data. Figure 3 shows part of the 3D GRE MRE pulse sequence, which incorporates tetrahedral motion encoding and motion-encoding gradients smaller than the period of vibration to keep the TE and TR short. Figure 4 shows a long-axis view of the phantom acquired using the 3D GRE acquisition (FOV=160x160x100 mm, 80x80x100 matrix; TR/TE=12.5/9.6 ms; flip=10º), a 13-cm diameter birdcage coil, and 100-Hz vibrations delivered by a pneumatic driver system pushing the heart at its apex with the induced wave motion being clearly visible. Figure 5 shows a short-axis view acquired with 2D SE-EPI (FOV=200x200 mm, 96x96 matrix, 44 2.5-mm slices, TR/TE=660/34.7 ms) and 200-Hz vibrations.

Figure 3: 3D GRE MRE pulse sequence.



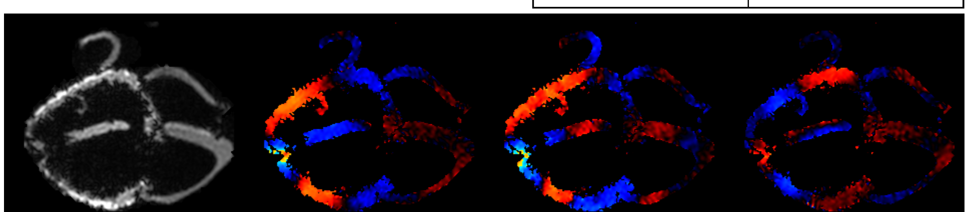


Figure 4: 3D GRE MRE acquisition showing the magnitude image and X, Y, and Z displacement images.

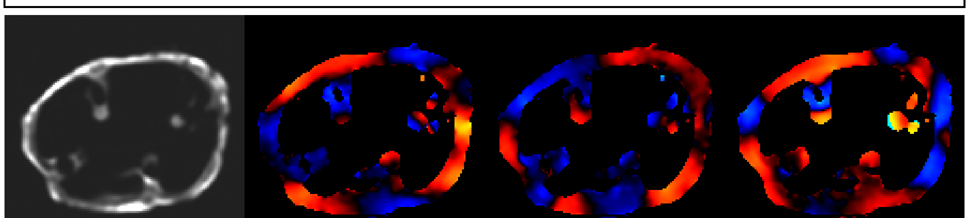


Figure 5: 2D SE-EPI MRE acquisition showing the magnitude image and X, Y, and Z displacement images.

Conclusion: We have presented preliminary volumetric MRE data on a commercially available heart phantom. These data demonstrate the benefits of this type of phantom for CMRE and provide motivation to further explore its use to address CMRE technical challenges to make it a more robust and clinically applicable diagnostic tool for evaluating myocardial stiffness.

References: **1.** Holmes JW, Ann Rev Biomed Engg 2005;7:223-253. **2.** Muthupillai R, et al, Science 1995;269:1854-1857. **3**. Kolipaka A, et al, Proc. Intl. Soc. Mag. Reson. Med. 2011;19,15. **4**. Kolipaka A, et al. Magn Reson Med. 2009;62(1),135-40.