Design and Evaluation of an MR Compatible Pneumatic Non-rigid Moving Heart Phantom for Simulating Respiratory and Cardiac Motion

D. Stanton[1], N. Dobhal[1], M. Casanova[2], M. Hedjazi Moghari[2], A. Jain[1], R. Manzke[1], W. J. Manning[2], C. Hall[1], and R. Nezafat[2]
[1]Philips Research, Briarcliff Manor, NY, United States, [2]Dept. of Medicine (Cardiovascular Div.), Beth Israel Deaconess Medical Center, Harvard Medical Sch., Boston, MA, United States

Purpose: An anthropomorphic MR compatible non-rigid motion phantom, with the capability of simulating respiratory and cardiac motion, can significantly facilitate evaluation of various MR imaging sequences. In this abstract, we present major design components and initial evaluation of a non-rigid programmable motion phantom.

Phantom Specification:
Fig. 1 shows the constructed motion phantom. The heart model (Fig. 2) is cast in a complex mold using polyvinyl alcohol (PVA) material (with T_1/T_2 of 800/63 ms) simulating both ventricles. This anatomically accurate human heart replica can be animated to create simultaneous compression and torsion to mimic normal heart motion. Additionally the heart is deflected in elevation and translation to mimic deflection caused by respiratory breathing. The motions are programmable and synchronization waveform outputs are provided. The heart is located within a robust Plexiglas tank approximating the volume of a human torso. The tank is penetrated at each end by large o-ring sealed circular plug flanges to which a variety of devices may be attached. Additionally two large lateral Ultrasound window ports are provided which may also be used for a variety of experiments. The apex of the heart is fused with a cylindrical PVA element attached to the actuator responsible for the cardiac motion. The top part of the heart is also combined with a cylindrical PVA element fixing the heart to a sled. The sled is controlled by another actuator responsible for the rigid respiratory motion of the heart.

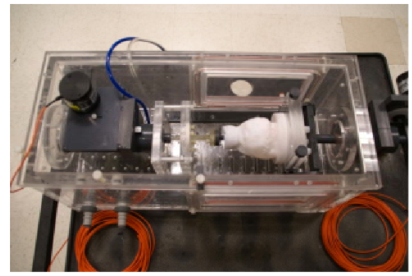

Fig.1: *The moving heart phantom inside the Plexiglas tank.*

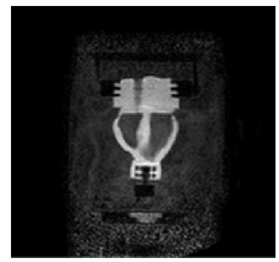

Fig.2: *real-time images of the heart phantom.*

<u>*Respiratory motion:*</u> To simulate the respiratory motion of the heart, the sled is moving on the rails designed at the bottom of the container, as shown in Fig.3. The sled moves along a ramp to create two dependent translations along superior-inferior (SI), and anterior-posterior (AP) with one degree of freedom. The control unit placed at the outside of the scanner controls air pressure of the actuator for moving the sled, based on the motion pattern predefined in the control unit. To have a feedback from the position of heart phantom, a rotary optical encoder returns the sled's positions through fiber optics to the control unit.

<u>*Cardiac motion:*</u> To replicate cardiac heart motion, another actuator is placed at the apex of the heart. This actuator provides a force leading to a screw/nut motion, i.e., compression and torsion of the heart phantom. A rotary encoder is used to measure the amount of actuator's displacements. The displacements are then fed back to the control unit through fiber optics for controlling the pattern of the cardiac motion (compression/torsion) based on the predefined electrocardiogram sequence saved in the control unit.

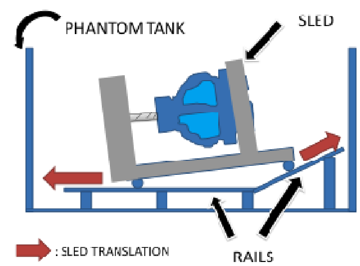

Fig.3: *Schematic diagram of the phantoms' cardiac and respiratory motions.*

<u>*Imaging protocol:*</u> The respiratory pattern of a healthy subject was measured continuously using a two-dimensional (2D) pencil-beam navigator (NAV), and tracking the edge of the right hemi-diaphragm (RHD) locations. Offline the RHD locations were programmed into the control unit for moving the heart phantom. The phantom was imaged using a 1.5T MR system (Achieva, Philips) with an ECG triggered, 3D axial, SSFP sequence with the following parameters: TR/TE = 5.0/2.0 ms; FOV = 300×300×112 mm^3; 1.3×1.3×1.5 mm^3; flip angle = 90º. A NAV was placed at the edge of the sled for gating the displacements of the phantom within 5mm gating window.

Results: Fig.4a depicts the place of the planed imaging plane and NAV location. Fig.4b shows the acquired NAV signal from the respiratory motion of the phantom. Fig.4c displays the prospective reconstruction of the heart phantom images.

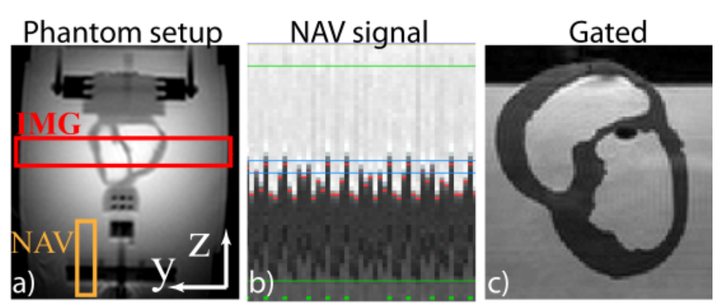

Fig.4: *A simulated respiratory navigator gated image acquisition using actual human hemi-diaphragm motion programmed into the phantom controller.*

Conclusions: We have designed and successfully evaluated a non-rigid MR-compatible motion phantom that can be programmed using a user-defined respiratory or cardiac motion. This system will facilitate development of various imaging sequences, motion compensation methods, and allows for realistic motion creation from human patients.

Acknowledgements: This study is supported by NIH R01EB008743.