A 5D motion phantom for simulating simultaneous cardiac and respiratory motions

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INTRODUCTION

Sudden cardiac death caused by ventricular tachycardia (VT) results in >150,000 deaths/year in U.S. Noninvasive Cardiac Radio-Ablation (NCRA) was recently reported as a novel alternative treatment to treat VT refractory to antiarrhythmogenic drugs and catheter ablation. Heart and respiratory motions can significantly affect the accuracy of multi-modality image fusion used for target definition in treatment planning and jeopardize the precision of image-guided target localization and radiation delivery. Heart motion is very difficult to evaluate because of the simultaneous respiratory motion and the lack of ground truth. A physical motion phantom is useful by providing the ground truth for testing different imaging systems and protocols. In this study, a heart motion phantom was designed to simulate the simultaneous cardiac and respiratory motion .

AIM

Accurate imaging of the heart and its motion is an important part of image-guided cardiac radiotherapy. A physical phantom that simulated the motion of the heart is needed to provide simultaneous cardiac and respiratory motions to support motion-compensated 4DCT and 4DMR studies and allows end-to-end radiation dosimetry testing of NCRA.

METHOD

The heart motion phantom with multiple components was constructed. Two double-layered balloons were filled with ~350 ml water to simulate the blood flow. Each balloon was narrowed in its upper middle by a rubber band to separate upper and lower chambers simulating the dynamics of blood-flow between atrium and ventricle. Two such balloons wrapped by an air bag and packed in a container simulated four chambers of a heart. The air bag, inflated and deflated at 1 Hz by an air pump, squeezed the lower chambers rhythmically to create heart beating and blood-flow between atria and ventricles. The balloon and air bag assembly was placed on the motion platform which provided respiratory motion in superior-inferior at 0.25 Hz. Both the respiratory and cardiac cycle frequencies are adjustable.

RESULTS

The heart phantom was built by: 1st Using double layer two latex balloons (1 and 2 in Fig 1) and fill them with water/ dosed liquid; 2nd Tying a rubber band (7) on the upper middle of each balloon to form a tube-like region that creates two segmented but still connected chamber to simulate the atrium (1A and 2A) and ventricle (1V and 2V); 3rd Wrapping a thick balloon air bag (3) around the ventricle area and place the water balloons and airbag in a low-wall container that only restrain the ventricle area; and 4th Linking the air bag to an air pump. The filled water flowed from the ventricle to the atrium when the air bag was inflated and went back to the ventricle when deflated; 5th placing the above phantom parts in a bigger container (6) and placing it on a motor-driven platform (8 in Fig 2) that moved in the superior -inferior direction. Landmarks were placed on the water balloons, air bag, and the containers for the image tracking.

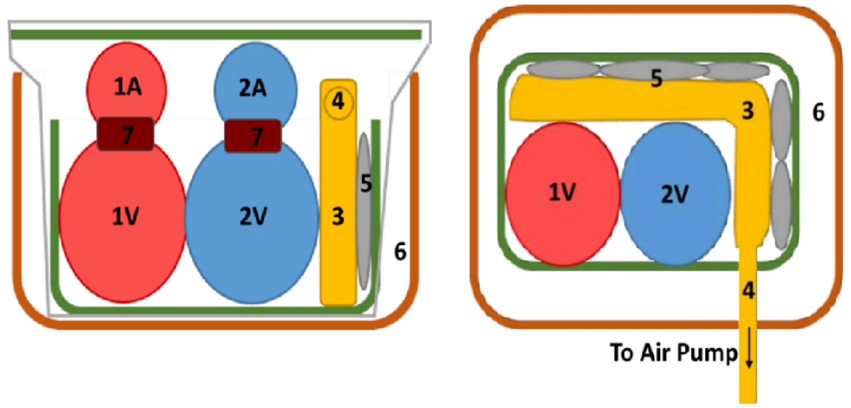

Fig 1: Design of the heart motion phantom (left: axial, right: coronal view). The red (1A and 1V) and blue (2A and 2V) water balloons simulate the left and right part of the heart. The dark red (7) is the rubber band that segments the atrium and ventricle. The yellow is the air bag (3) and the connective tube (4). The gray area is the padding (5), and the rectangles (6) are the container on the motion platform.

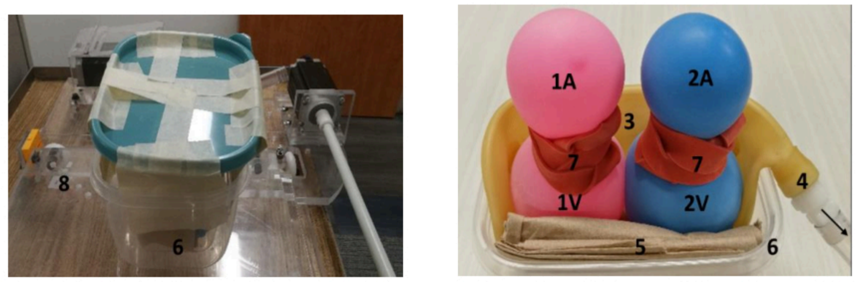

Fig 2: The physical phantom. Left: The two water filled balloons are shown with the yellow air bag (Semi-finished phantom after step 3) Right: the finished phantom is shown in the container on the motor platform (the link to the air-pump is not visible in this figure.) Number of each component is consistent with Fig.1

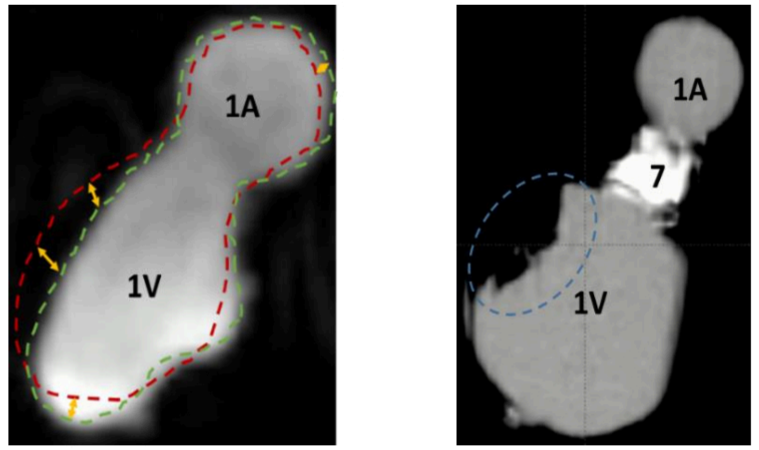

Fig 3. An example of a 2D MRI (left) and CT (right) scan. Only cardiac motion was applied during MRI because the motion platform is currently not MRI-compatible. The contours of the heart phantom (red and green) in different motion phases are shown by the dotted lines.

Both cardiac motion and respiratory motion are applied in the ungated helical CT scan (right). The motion artifacts (e.g. The area within the blue circle) are simulated clearly in this dataset.

CONCLUSIONS

A 5D motion phantom supporting simultaneous cardiac and respiratory motions was constructed. It will be useful for imaging, motion-management and dosimetry research studies for NCRA.

CONTACT INFORMATION

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