A Left Ventricular Motion Phantom for Cardiac MRI

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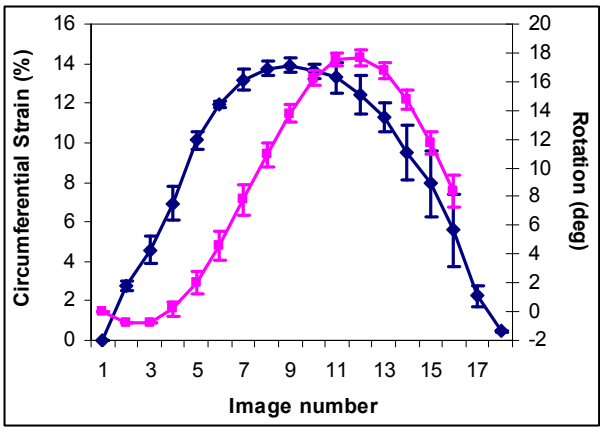
Purpose: To design and build a low-cost, non-ferromagnetic left ventricular (LV) motion phantom for use with cardiac MRI that is able to produce physiologically realistic LV wall thickening and rotation.

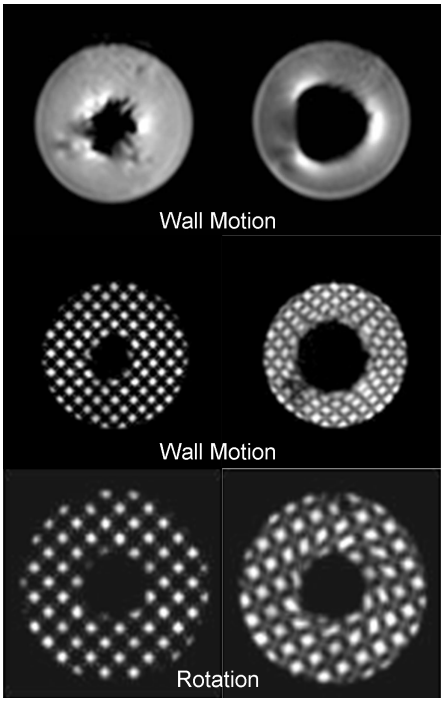
Background: New pulse sequences for cardiovascular MRI are constantly in development. An essential step in the development process is validation in the presence of cardiac motion. Thus, MRI-compatible dynamic motion phantoms that mimic the LV motion patterns could be of substantial benefit. However, there are two distinct components of LV motion: wall thickening and rotation. To date, no MRI-compatible motion phantom has succeeded in duplicating both of these motions.

Design and Construction: Wall motion and rotation are modeled using separate phantoms housed within a common enclosure. The wall motion phantom is pneumatic, driven by a custom non-ferromagnetic air pump (shown at right) that cyclically fills and empties a latex balloon situated within the cylindrical gel "myocardium". In the rotation phantom, the gel "myocardium" lies between two concentric polycarbonate cylinders. The inner cylinder is fixed and the outer cylinder rotates through a user-specified angular rotation using a manually operated rotary cam mechanism. Each phantom supplies a 5V TTL signal to the scanner to simulate the R-wave trigger from a patient's ECG. The wall motion phantom is triggered at minimum gel thickness; the rotation phantom is triggered at the beginning of each rotation cycle.

Image Acquisition: Images were acquired at 3T (Achieva, Philips, Best, NL) using a 2-element circular receive coil. The wall motion phantom was imaged using a GRE cine sequence: TR/TE 3.8/1.6ms, α 15°, turbo factor 19, FOV 150x150mm, matrix 128x89, 7mm thickness. Both phantoms were imaged using a grid-tagged GRE-EPI cine sequence: TR/TE 8.9/4.6ms, α 10°, turbo factor 9, FOV 150x150mm, 128x97 matrix, EPI factor 3. All acquisitions (cine and tagged) were repeated (n=3 or 4) to evaluate reproducibility. Tagged images were analyzed using HARP software (Diagnosoft).

Results: Representative images are shown below right for the wall motion (top, middle) and rotation (bottom) phantoms, at rest (left) and at maximum deformation (right). Note that the wall motion phantom deforms the gel in a "reverse systole" pattern. Results were reproducible, with average endocardial strain and rotation shown in the figure below left. The standard deviation between acquisitions ranged from 0% to 1.7% for circumferential strain and from 0° to 1.1° for rotation, with the larger values found later in the cycle, when tag lines were fading.





Discussion: Two separate dynamic motion phantoms have been designed and built that mimic the known cyclic motion patterns of the human LV. The rotation phantom mimics the rotation of the LV apex, which typically rotates by 15°-20° during systole. The wall motion phantom can generate varying degrees of wall thickening. The ability to alter both maximal rotation and wall motion enables the user to model either healthy or diseased LVs. The phantoms are easy to assemble and can be set up in <10 minutes. In addition, they are constructed entirely of non-ferromagnetic materials, except for the small amount of wiring associated with the trigger circuit. Susceptibility artifacts were observed at the air-gel interface of the wall motion phantom; we are currently experimenting with liquid-filled balloons for use in future studies. In conclusion, these phantoms could be of benefit when developing new cardiac MRI techniques and could potentially reduce costs associated with human and/or animal subjects during early development.