

A TWO-CHAMBER MULTI-MODAL (MR/ULTRASOUND) CARDIAC PHANTOM FOR NORMAL AND PATHOLOGIC HEARTS

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Purpose: To manufacture a non-ferromagnetic, multimodal two chamber moving heart phantom with applications to cardiac MR, echocardiography and Doppler Ultrasound imaging.

Background: Different registration and pulse sequence techniques are widely available for MR and ultrasound imaging of the heart. Evaluation techniques on realistic phantoms are typically required. A controlled experimental phantom setup has been developed to simulate the anatomy and physiology of the heart. Phantoms are easier to handle and can be validated with marker or contrast pellets. To date, no MRI-compatible phantom has been developed in the literature to simulate a two-chamber human heart with multimodal capabilities.

Methods: In order to build the phantom, a cardiac computerized model taking into account the size of the left and right ventricles was designed and used to build an acrylic-based cardiac mold. Polyvinyl alcohol (PVA) was utilized to mimic the mechanical and acoustical tissue properties of the heart. It has been shown that PVA can simulate the ultrasound attenuation and texture in the heart in addition to T1/ T2 properties in MR studies. PVA is more robust to stress with regard to the traditional gelatin-based phantoms and can have a wide range of Young moduli and elasticity based on chemical reactions [1]. A 10% solution of PVA plus 1% enamel paint was used as the basic material. The enamel paint acts as an ultrasound scatterer as well as the color of the heart. The PVA solution was stirred and heated up to 90 deg. C until it became clear. It is important to continue heating until the powder is fully dissolved. This process can vary from 0.5 to 3 hours. Overheating the solution leads to faster dissolution of the powder but degrades the chemical structure of the molecules. Practically, it is better to discard the final superficial thick layer of the solution in order to decrease inhomogeneity. Subsequently, the solution was gradually cooled down from 80 deg. C to room temperature. Subsequently, it was poured into the cardiac mold and gradually exposed to a temperature of -20 deg. C until it froze. The mold and the solution were kept in that temperature for 24 hours. At that time the molecules in the PVA solution were cross linked with each other in order to make a tougher material called cryogel. Finally, the mold and the frozen gel were gradually exposed to the room temperature in order to avoid any additional inhomogeneity in the chemical process of the cryogel. At this point, the normal heart phantom has passed one freeze-thaw cycle.

An additional model consisting of the left and right ventricles but with a segmental thin wall in the LV was used to build an additional mold for a pathologically scarred heart. The thinner wall was designed to mimic an aneurysmal, dyskinetic wall. Three PVA-based inclusions were separately made as a circle; slab and cube using nine, six and three freeze-thaw cycles respectively. Each freeze-thaw cycle decreases the elasticity of the heart mimicking scarred myocardium. The attenuation of the PVA and speed of sound increase after each freeze-thaw cycle [1]. The cylindrical, slab like and cube like objects were placed in the mold in different American Heart Association cardiac segments. Subsequently, the PVA solution was added to fill the rest of the space in the mold. After one freeze-thaw cycle, the abnormal heart consisted of a background of normal texture with one freeze-thaw cycle plus three infarct-mimicking inclusions having 10, 7 and 4 freeze-thaw cycles. According to the literature, the speed of sound in PVA is 1527, 1540, 1545, and 1550 m/s and ultrasound attenuation is 0.4, 0.52, 0.57, and 0.59 db/cm for 1, 4, 7 and 10 freeze-thaw cycles. Additionally, T1/T2 is 980/820, 690/605, 540/500, and 520/480 ms for 1, 4, 7 and 10 freeze-thaw cycles [1]. The mediastinal space that mimics the great vessels was manufactured by a third mold using a single freeze-thaw cycle. Finally, two latex balloons were placed in the ventricles to dilate and contract the phantom and a mechanical piston was used as the actuator. The piston was attached to the balloons using two long connector tubes so the piston could stay out of the MR tunnel. The volume and pressure of each ventricle could be adjusted by using two valves controlling the flow to each ventricle. Balloons simulated the ventricular motion by repetitive backward and forward motion of the piston. A solution of 50% water and 50% glycerol was used to mimic the blood. The heart phantom was placed in the mediastinal space and the mediastinum phantom was placed in a container.

Results: Image acquisition was performed using different echocardiographic views on a Philips iE33 workstation. 2D, 3D and TDI images could be acquired and analyzed for evaluation studies. MRI images were collected using a 1.5 T Philips Achieva scanner. Six 3D images were acquired at different inflation pressures using 3D T1 weighted FFE, TE/TR 5/25 ms, FA 30°, slice thickness 3 mm, spatial resolution 0.625×0.625×1.5 mm, 3D FOV 224×224×189 mm, and number of slices 63. An additional volumetric 3D image was acquired using balanced FFE, TE/TR 1/3 ms, FA 60°, spatial resolution 1.70×1.70×11.35 mm, 3D FOV 176×176×272 mm, and number of slices 24.

Conclusion: A biventricular PVA based heart phantom was manufactured that mimics cardiac shape, elasticity, MR and ultrasound properties. Pathologic conditions were simulated in an additional phantom. The biventricular structure is able to simulate the asymmetric RV and LV motion. All the classical echocardiography views can be captured in this phantom. Additionally, since the heart phantom is positioned in a mediastinal phantom, it is possible to acquire trans-esophageal echo images.

References: [1] Surry KJM, Austin HJB, Fenster A, Peters TM. "Poly (vinyl alcohol) cryogel phantoms for use in ultrasound and MR imaging." Phys Med Biol., vol. 49, pp. 5529-5546, Dec 2004.

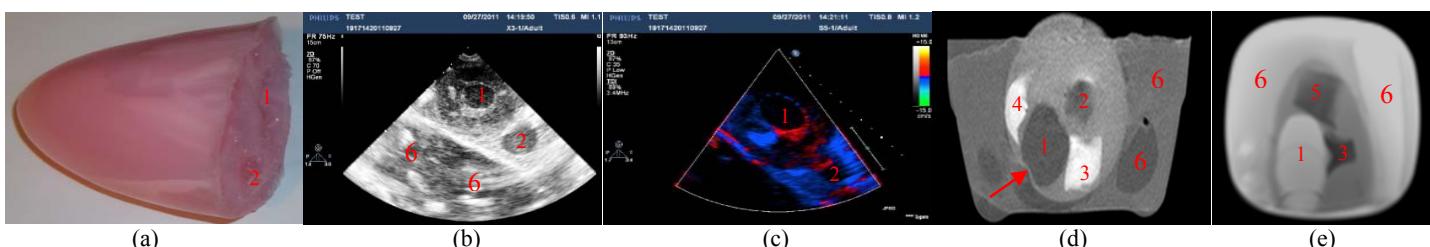


Figure 1. (a) A picture of the two-chamber model (b) B-mode echocardiography image (c) TDI (Tissue Doppler Imaging) image of the moving phantom during balloon inflation, (d) A static slice of the phantom using T1 weighted FFE, The arrow points to the aneurysm (the thin ventricular wall) (e) A static slice of the phantom using balanced FFE (1: LV, 2: RV, 3: cylindrical inclusion, 4: slab-like inclusion, 5: cube like inclusion, 6: mediastinum and mediastinal structures)