MR Compatible Heart Phantom for Medical Research

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Introduction

We propose a pneumatically driven heart phantom, which can be used for a wide variety of tests in medical research and has unique features like arbitrary and reproducible motion patterns for heartbeat and respiration, integrated customizable vasculature for interventional or flow measurements, and simulated ECG and respiratory trigger signals. The phantom's contrast properties allow for imaging using MRT, X-ray, or CT, which makes it especially suited for multi-modality experiments. The setup of the phantom is presented, and key parameters are evaluated, which demonstrate the feasibility of the phantom for MR image acquisition.

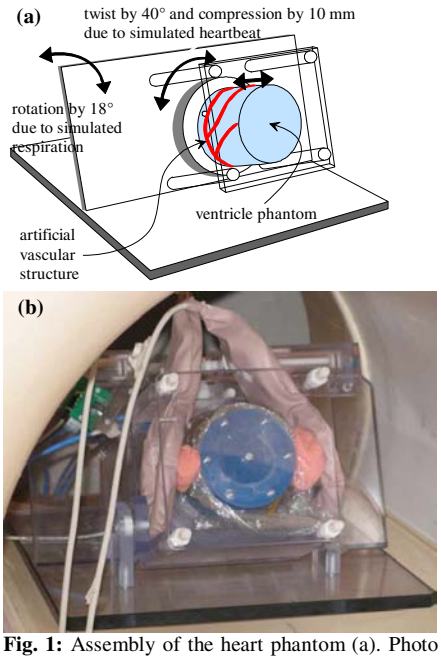

Fig. 1: Assembly of the heart phantom (a). Photo of the phantom and synergy coils while located in an MR scanner (b).

Materials and Methods

The phantom consists of a rigid plastic frame which mechanically deforms the attached elastic ventricle phantom (T1 ≈ 1000 ms and T2* ≈ 130 ms) using controlled pneumatics. Fig. 1 shows a sketch and a photo of the phantom. Motion parameters like amplitude and cycle length can be configured separately for heartbeat and respiration. Additionally, the contraction period and shape of the heartbeat can be adjusted, and pathological patterns like extra systoles or cycle deviations can basically be integrated. The maximum displacements of the ventricle phantom due to motion are 23 mm (heartbeat) and 21 mm (respiration). The vasculature of the ventricle phantom is realized with silicon tubes of an inner diameter 2-3 mm. The values for the displacements and the diameter of the vasculature are in approximate accordance with those found for human coronaries [1-3]. The geometrical properties of the vasculature can be customized to the desired level of complexity depending on the application to be simulated. The heart phantom is driven pneumatically and controlled by a computer located outside of the exam room. The computer also calculates an artificial ECG and provides a respiratory signal, which both can be used for gated imaging. The only connections from the heart phantom to the outside are 4 pneumatic tubes (2 for each type of motion) and 2 shielded electrical cables for the light barriers, which determine the position of the pneumatic pistons in the cylinders. In case of MR imaging, the electric cables are connected via a band-stop filter, which ensures electromagnetic decoupling of the signals from the MR exam room. To demonstrate the capabilities of the phantom for applications in research, the range of operation and the reproducibility of motion are determined. In addition, gated MR images were acquired exemplarily. All measurements were done in a shielded MR exam room. The range of operation refers to the minimum and maximum cycle length and is mainly limited by adhesion and mechanical inertia. It was determined by de- and increasing the cycle length, until the motion pattern became incomplete or incorrect which was indicated by the measured light barrier signals. The reproducibility in dependence on the heart rate and respiratory cycle length was also calculated by evaluation of the measured light barrier signals. Finally, 3D MR images of the ventricle phantom were acquired with an Intera 1.5T scanner (Philips Medical Systems, Best, The Netherlands) using two synergy coils, Fig. 1(b). For comparison, images were taken without and with ECG gating while the heartbeat motion was set to 60 bpm with no respiratory motion present. Fig. 2 shows maximum intensity projections of these images.

Results

The heart rate can be adjusted reliably between 40 bpm and 120 bpm, and the respiratory cycle may be varied between 2 s and 10 s. Within these ranges, the phantom was able to perform complete motion trajectories.

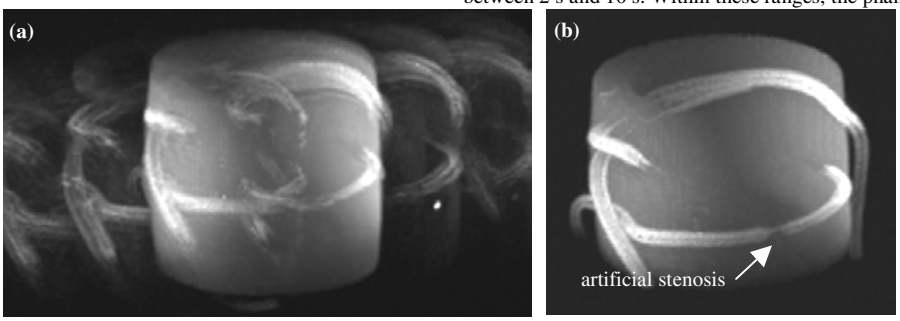

Fig. 2: Maximum intensity projections of the uncompensated (a) and gated (b) 3D MR images of the ventricle phantom during heartbeat. Without gating, motion artifacts limit the image quality. With gating, the ventricle phantom with its vasculature including a stenosis can be imaged in high resolution.

The reproducibility of the heartbeat and respiratory motion was evaluated by calculating the uncertainty of the position measurements using the light barriers. The uncertainty of the motion cycle length was in the order of 0.1 ms to 8 ms for both types of motion. The corresponding uncertainty of the motion amplitude was in the order of 1 % of the maximum amplitude for heartbeat and even below 0.5 % for respiration.

The acquired MR images were visually inspected and no motion induced artefacts could be detected after gating. Also, no B_0 inhomogeneity could be detected within the imaging volume of the ventricle phantom. Fig. 3 shows slice images of the acquired volumes.

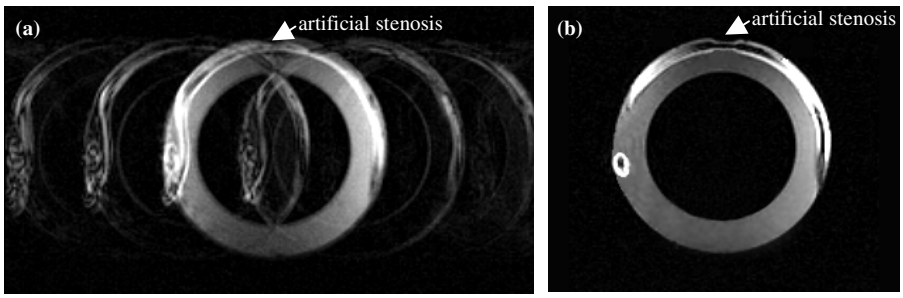

Fig 3: Slice image of the ventricle phantom during heartbeat with 60 bpm. In (a), no motion compensation was employed leading to significant artifacts. The stenosis cannot be identified clearly. In (b), gating was used for image acquisition. The phantom is imaged in high resolution, and the artificial stenosis can clearly be seen.

Discussion and Conclusions

A pneumatically driven MR compatible cardiac respiratory phantom is presented. The motion trajectories are performed with high reproducibility which allows for gated imaging using standard MR equipment. The assembly of the phantom enables the utilization of arbitrarily shaped ventricle phantoms and vasculature as well as configurable motion patterns to meet the needs of a wide variety of experiments.

Acknowledgements

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Literature

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