CONSTRUCTION AND MANUFACTURING OF AN MRI-READY EXPERIMENTAL SETUP WITH A PHANTOM HEART MODEL

Moritz Wiegand (1,2), Tim Bierewirtz (1,2), Lukas Obermeier (1,2), Leonid Goubergrits (1,2,3) and Katharina Vellguth (1,2)

1. Institute of Computerassisted Cardiovascular Medicine, Deutsches Herzzentrum der Charité, Germany; 2 Charité, Germany; 3. Einstein Center Digital Future, Germany

Introduction

CFD simulations using patient-specific geometries are a promising tool for diagnostics and treatment planning of heart diseases. To validate these simulations, 3D flow field measurement is necessary. This data can be obtained with a time-resolved phase contrast MRI using 3D velocity encoding. A verification study of the in silico computed intracardiac blood flow with a 4D-flow MRI was lately performed by Obermeier et al. [1]. However, the image quality of a human subject may be impaired by movements, irregular heart frequency and low dwell times in the MRI. To obtain data without these disturbances, we developed an MRI-ready experimental beating left heart phantom.

Methods

The phantom model is fabricated metal free to exclude interference with its magnetic field. A backup tank around the phantom model ensures leakage free operating.

The phantom model is made in the end-systolic shape and planted into a fluid filled, 3D-printed geometry of the LV in end-diastolic shape, which is connected to an MRI-compatible pump Shelly Medical Imaging Technologies, London, Canada). Therewith, the pressure around the flexible phantom can be changed to achieve physiological movement and thus recreating realistic hemodynamics in the ventricle.

The heart geometry of the phantom model was taken from the MRI-data of subject 3 from Obermeier et al. [1] and adapted, using the CAD software SOLIDWORKS® 2023 (Dassault Systemes Deutschland GmbH, Stuttgart, Germany).

The LV phantom is made from polyvinyl alcohol (PVA) based hydrogel (10% PVA, 10% glycerol, 80% water), cast into 3D-printed molds and hardened through three freezing-thawing cycles lasting 24 hours each. The PVA based hydrogel was chosen due to its elastic and robust behavior ensuring a changeable ventricular volume during the heart cycle. As it is made of similar substances as the blood mimicking fluid (60% water and 40% glycerol), the frequency shift between the materials inside the MRI can be kept to a minimum.

Both aortic and mitral valve were thermoformed from a 1 mm thick polyurethane film. They were manufactured in an almost closed state to ensure a correct shape and proper closing. Threads, acting as chordae tendineae were added and anchored in the ventricular tissue to avoid severe regurgitation.

Results

First measurements were performed in a MAGNETOM Cima.X 3T MRI (Siemans Healthineers AG, Germany). The first acquired images show a high image quality, that is often not achievable in human subjects.

Figure 1: Cross-sectional view of the phantom model. 2D cine MRI image.

Discussion

The phantom model fulfils the requirements of MRI-compatibility, cyclic movement of the ventricle and to a broad extend the functionality of the aortic and mitral valve. However, there is room for improvement, to create a more realistic setup and thus including the influence of the complexity of the LV and valves geometry and motion. For example, the mitral valve has a stenosis, and the movement of the flexible ventricle is currently mostly in longitudinal direction. Improvements on the mentioned functionalities and other minor fixes will be addressed prior to further measurements, which are planned to be performed in future.

References

1. Obermeier et al., Verification Study of in Silico Computed Intracardiac Blood Flow With 4D Flow MRI, IEEE Transactions on Biomedical Engineering, 10.1109/TBME.2024.3381212 , 2024

Acknowledgements

We thank Dr. rer. nat. S. Schmitter and D. H. Dillinger for active support and expertise during the measurements at the Physikalisch Technische Bundesanstalt This work was supported by the German Research Foundation (DFG) as part of the SPP2311 under Grant No. 465178743.