Design, Implementation, Application and Evaluation of a MR Compatible Left Ventricle Model

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INTRODUCTION Quantification of cardiac magnetic resonance (CMR) measurements plays a key role in clinical diagnoses. The development and validation of MR sequences require a high degree of reproducibility including phantom experiments that mimic *in vivo*. Static phantoms providing dedicated MR parameters such as T_1, T_2, T_2* facilitate the development and validation of imaging techniques tailored for parametric mapping of static organs. Cardiac examinations present the extra challenge of ventricular motion, respiratory motion and blood flow, which can significantly compromise image quality and hence might have detrimental effects on the reproducibility of quantitative mapping. For all these reasons, this study is aiming at the design, implementation, application and evaluation of a comprehensive left ventricle model. The model is designed to resemble motion patterns and flow dynamics of a beating heart, as well as signal characteristics and relaxation times of myocardial tissue.

METHODS A mold (Fig.1) was designed in a 3D computer aided design (CAD) program (Inventor, Autodesk GmbH, Munich, Germany) and spawned by a 3D-plotter (Stratasys, Eden Prairie, USA) based on the geometric approximation of a paraboloid. The optimum mixture ratio of low viscose and high elastic silicones (HE Creartec trend-design GmbH, Weiler, Germany) was evaluated to match myocardial T_1 and T_2 relaxation times. A silicone mixture with increased water content imitating edema (elevated T_2) was focally injected after filling the mold but before hardening. The relaxation times T_1 and T_2 of the solidified composition were quantified using a Look-Locker inversion recovery ($TR>5xT_1$) and a multi-echo spin-echo sequence ($TR>5xT_1$) using a 3T MRI (Verio, Siemens Healthcare, Erlangen). The drive comprised of a gear supported stepper motor, which was controlled by an interface programmed with Labview (National Instruments, Austin, Texas). Hardware devices, i.e. a flow meter (B.I.O-TECH e.K., Vilshofen, Germany), emergency stops, a trigger switch were connected to a CompactRIO FPGA (National Instruments, Austin, Texas) via an I/O Box. A piston pump was used to produce pulsatile flow of a water/glycerol mixture, which exhibits the viscosity of human blood. Flow paradigms with different stroke volumes were applied to the pump system and validated on a 3T MR scanner (Siemens Healthcare, Erlangen, Germany) using a phase contrast technique (TE/TR=3.2ms/11.4ms; 50 cardiac phases). Background phase was measured in the pipe without flow to rule out systematic phase bias.

RESULTS The wall thickness of the model was designed to be 10mm in systole and 6.5mm in diastole. The relaxation times T_1 (950ms) and T_2 (59ms) of the ventricle were of the order of physiological values of myocardium at 3T. The segment with the increased water content imitating myocardial edema exhibited an elevated T_2 value of 64ms, which is equivalent to an 8.5% increase. FLASH cine images (diastole and systole) demonstrate that the signal intensity is sufficient for MR imaging (Fig. 1b). End-systolic volume was measured to be 55ml, which represents an average left ventricle [1]. End-diastolic volume depended on the driven stroke volume. Background phase bias was measured to yield only 0.3±0.6ml. The flow profiles provided by the ventricular model were found to agree well with phase contrast measurements (Figure 2a). The volumes provided by the pump were slightly lower (77ml vs. 72ml and 31ml vs. 27ml, Figure 2b).

DISCUSSION AND CONCLUSIONS We developed an artificial ventricle with physiological relaxation times T_1 and T_2, which is driven by a pump system. The material shows uniform signal intensity (Fig. 1b). This setup facilitated the generation of arbitrary flow profiles with peak flow rates of up to 300ml/s and supports synchronization with the scanner. The extension of the model using valves (bioprosthesis) is planned to enable a realistic inflow/outflow system. The 3D-CAD program used for the design of the model offers the opportunity to design even more sophisticated ventricles. Consequently, we anticipate to include pathologies like wall-motion abnormalities, localized thinning and hypertrophies into the model.

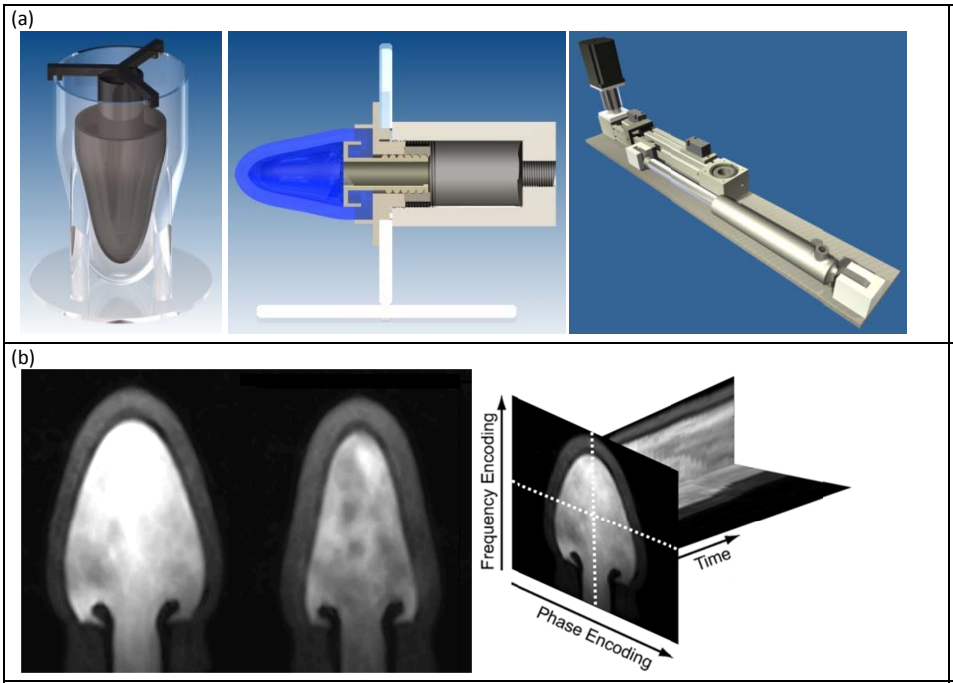

Figure 1: (a, from left to right) 3D rendering (Inventor, Autodesk GmbH, Munich, Germany) of the mold, the artificial left ventricle in a dedicated holder, pump system comprising of a gear supported stepper motor, a linear axis and a piston. The drive was controlled via a Labview interface.
(b, from left to right) Flash cine image of the artificial ventricle acquired in end-diastole and end-systole, projections over one cardiac cycle derived from the horizontal and vertical profiles across the ventricle marked as dotted lines.

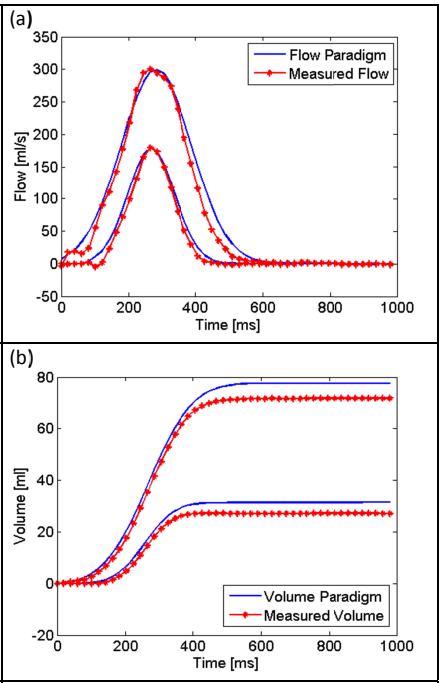

Figure2: (a) Flow paradigm and measured flow for two stroke volumes revealing good agreement.
(b) Volume curves and measurement revealed a minor difference (5ml and 4ml respectively) between paradigm and measurement.

[1] Schlosser, et. al. Am J Roentgenol. 2005;184(3):765-773.