Pulsatile Flow Phantom for MR-guided Focused Ultrasound (MRgFUS) Vascular Thrombolysis and Occlusion

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Target Audience:
The target audience of this work is researchers and clinicians interested in stroke phantoms, focused ultrasound sonothrombolysis and vascular imaging.

Purpose:
For paediatric stroke patients, standard adult-based tPA treatment has significant side effects where up to 10% will develop secondary bleeds that can lead to death. [1] Other surgical-based interventions often leave patients with neurological impairment and negative impact on their cognitive development. MRgFUS provides a non-invasive technique to focus ultrasound energy for targeted thermal ablation or cavitation-based effects for both thrombolysis treatment and creation of occlusions. Prior work has shown that it can successful lyse vascular clots. [2] While it would be beneficial to utilize an animal model to perform studies, a MR-compatible flow phantom provides a more cost-effective method whereby allowing easier changes to the setup and optimization of acoustic parameters before *in-vivo* testing. The purpose is to develop a pulsatile MR-compatible flow phantom that can be used to study clot formation and lysis. We hypothesize that a MRI-compatible flow phantom can be built to simulate a variety of pulsatile vascular flows to study clot formation and lysis while providing access for MRgFUS treatment of the flow target while not creating artifacts on the image quality.

Methods:
The requirements for the flow phantom include: 1. MRI compatibility – where the magnetic metals and loops are not created to distort the image, 2. Flow and pulsatility – where the phantom is capable of pushing fluid at pressure and flow rates that mimic the human heart cycle, 3. Minimizing fluid volume – the system would circulate animal blood for clot formation and lysis. Previous in-house flow phantoms used electric motors and steels parts requiring several meters of tubing to circulate the fluid and making it costly to use animal blood. Lorenz *et al* designed a system with a ventricular assist device (VAD) to generate pressure to circulate fluid in a separate circuit where the results were positive but the inclusion of the VAD and clinical pump control device made it expensive. [3] For this issue, we have developed a low cost diaphragm pump coupled to an agar imaging model. The major materials used for the pump include: neoprene diaphragm, custom made dome chamber, brass weights, T900X pressure controller, PX-181B pressure transducer, RK-32825 flow sensor and National Instruments NI-6008 USB data acquisition system. (See figure 1 (a) and (b)). A Matlab interface was designed to measure the pressure and flow rates and to control the systolic pressure, systolic length and pulse rate. To maintain the systolic pressure, a PID controller was used to track the maximum pressure.

Results:
A dual circuit flow phantom was created using non-ferrous components where there is an internal circuit that contains the blood flow and an external driving circuit that provides pulsatile driving pressure. An opening was made in the phantom to provide an acoustic access to the target area. For initial testing, an agar phantom was made and placed in to the acoustic window. Using a PID controller, the system can hold a constant diastolic pressure, peak at a given systole and main the high pressure within 10% of desired value. When compared to 60 beats per minutes to the actual heart cycle, the system can match the rising edge and peaks while the falling edge does not match. (See figure 2) From an imaging perspective, the flow phantom was scanned using T1-weighted and T2-weighted sequences where the agar model did not show any imaging artifacts. Using arterial spin labeling, the pulsatile flow contrast was increased and easily seen against the background. (See figure 3)

Discussion:
For the mismatch of the falling edge of the pulse flow, it believed that either static friction of the piston system or the effect of the check valves is creating some spikes and changes in performance. To address this problem, greater work is being done to investigate the control scheme and to optimize the controller. The Matlab interface to controller provides a simple method to tune and alter this control scheme. Additional sensors are installed on the system (flow and temperature) but they have not been incorporated. Even though there is a mis-match in the falling edge pulse, imaging and system testing showed the pulsatile flow phantom design met the 3 design criteria. Data shows that the pump is functioning as expecting and there are no imaging artifacts but more work is required on controller development.

Conclusions:
A MRI-compatible flow phantom has been design and tested on a Philips Achieva 3T MRI which had positive imaging results (no imaging artifacts) and pumping functionality. With this design, *in-vitro* MRgFUS testing can be easily done to perform clot lysis and vascular occlusions. With additional work done to improve the control scheme, the system can be used as a model for pulsatile flow for various scenarios.

References:
[1] Recommendations for tPA thrombolysis in children, ISTH. (2002)
[2] A. Burgress, *et al.*, PLoS One; 7(8). (2012)
[3] R. Lorenz, *et al.*, Mag. Res. In Med, pp. 258-268. (2012)

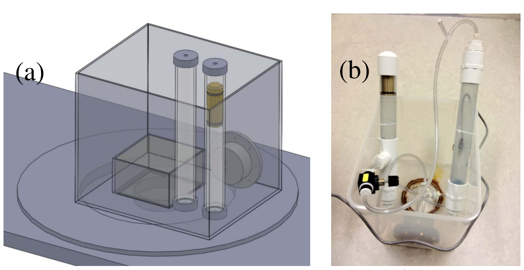

Fig. 1: (a) CAD model (b) Physical assembly

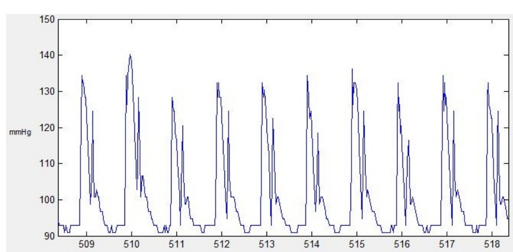

Fig. 2: Pressure profile

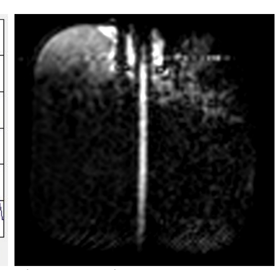
Fig. 3: MR image