

Waveform Optimized (Easy to Build) Pulsatile Flow Phantom of the Common Carotid Artery

C. Diwoy¹, C. Binter¹, J. K. Strasser¹, and R. Stollberger¹

¹Institute of Medical Engineering, Graz University of Technology, Graz, Austria

Introduction

Macroscopic blood flow is both an essential parameter for the description of the cardiovascular system [1] and an important source of different artefacts in MRI [2]. A phantom, which simulates the pulsatile flow within major arteries, is therefore highly valuable for optimization of MRI sequences for different applications. For general purpose we developed a phantom which simulates the flow within the common carotid artery followed by a simple vessel system within a water filled representation of the human head. Attention was paid on the exact reproduction of the flow profile without the need of expensive components. The system consists on a standard peristaltic pump, two passive valves, one electromagnetic valve and a simple electronic circuit. The performance of the flow phantom is presented by comparing the velocity-profile to in-vivo phase contrast images.

Material and Methods

Phantom setup: A peristaltic pump is used to build up high pressure within a silicon tube of 8mm inner diameter, 2mm wall thickness and a length of 1m during the phase of the closed magnetic valve (section 1 within Fig. 1a). After a time period of 600ms the valve is opened for the duration of 166ms. This timing is realized by the circuit given in Fig. 1b. To dam up the water not only allows much higher ejection velocities, but also produces pulse shapes which fit better the physiological flow behaviour caused by the left ventricle of the heart.

A main design guideline for the construction was that all electronic devices had to be placed outside of the RF-shielding in order to avoid artefacts caused by the pump and switching the magnetic valve. This circumstance forced us to choose a 6m long supply tube to the phantom (section 2 within Fig. 1a). To preserve the pulse shape produced by the magnetic valve it was essential to choose a tube with small compliance. In our setup we have chosen PVC tubing with 8mm inner diameter. The tubing of the return path (section 3 within Fig. 1a) however must be able to respond on a fast increase of the flow without resistance which otherwise would cause a broadening of the pulse profile. Therefore a soft silicone tube as in section 1 is used. On the other side, a tube with a high compliance can cause a halt or even a return flow, if the magnetic valve is closed. The reason for that is the mass inertia of the filling which causes a depression at the beginning of the high compliance tubing after closing the valve. Therefore we used two non-return valves, one directly at the phantom and one at the end of the return path. Finally the phantom itself consist on a water filled, head shaped tank whereas a small vessel system made out of silicone tubes of different size is appended to the common carotid artery (7mm inner diameter, 1mm wall thickness).

Imaging: Scans were performed on a 3T clinical system using a 12Ch head coil on the phantom and on a 22-year-old healthy volunteer. A MIP of the vascular system of the phantom was acquired with a 3D-GRE sequence: resolution 1x1x1.5 mm, FOV 270mm, TR/TE 3.5/20ms, FA 20; In-vivo and phantom phase-contrast velocity images: velocity-encoding through plane, aliasing velocity ± 150 cm/s, resolution 0.8x0.8x5 mm, FOV 160mm, TR/TE 71/5.4ms, FA 10, images/cardiac cycle 37. Post-processing was done in Matlab (The MathWorks, Natick, MA). The pulse profile over time was calculated out of the phase-contrast images taking a 3x3 pixel ROI in the middle of the common carotid artery. Pulse profile over the carotids cross-section is presented at the velocity peak value.

Results and Discussion

With the proposed simple setup we are able to simulate the physiological flow-velocity pulse shape of a 22-year-old healthy volunteer in the common carotid artery. Examining the impact of the used components on the velocity profile over time (Fig. 2 c, d), it is possible to create different, also pathologic, flow profiles too. We could sum up the parameters and their influence in the following way: The pump performance (rpm) determines the overall output, whereas the shape of the systolic peak is determined by the compliance and length of the tubing between the pump and the magnetic valve. The tubing to the phantom should be stiff enough otherwise it causes a broadening of the systolic part. The representation of the diastolic pulse shape is reached by choosing soft, high compliance tubing for the return path to take up the systolic wave without a major resistance. Additionally, non-return valves are attached to the return path in order to reduce a flow downtime which is caused by mass inertia of the artificial blood. It is important to note that our attached vessel-system does not affect the pulse shape if the overall vessel area after each ramification stays the same or grow bigger. In summary a flexible, cheap and easy to build up pulsatile-flow-phantom is presented which allows an in-vitro optimization of flow sensitive pulse sequences to the exact in-vivo flow conditions.

Reference

- [1] PJ Kilner et al., Flow measurement by magnetic resonance: a unique asset worth optimising, J Cardiovasc Magn Reson. 2007;9(4):723-8.
 [2] O Dietrich et al., Artifacts in 3-T MRI: physical background and reduction strategies. Eur J Radiol. 2008 Jan;65(1):29-35.

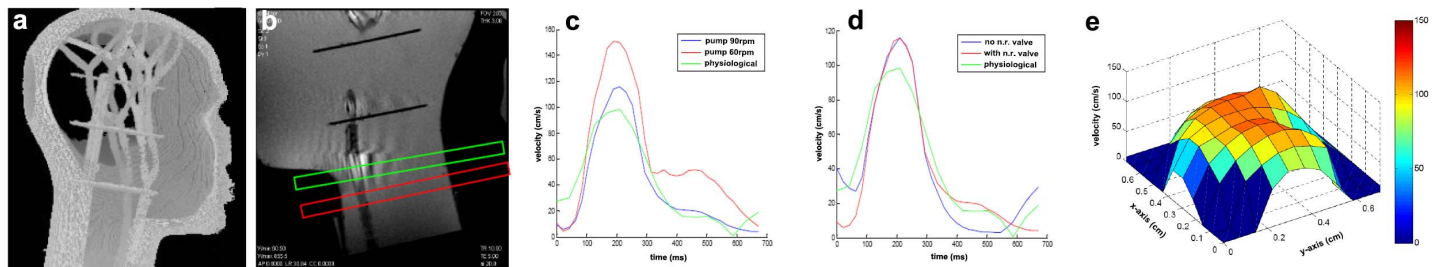


Fig. 2: MIP of the vessel system (a). Localizer and two different ROIs for the trough-plane phase-contrast images (b). Influence of different parameters on the pulse-velocity-shape (c, d). Whereas the curves present the physiological pulse shape (green), the phantom pulse shape with 60rpm (blue) and 90rpm (red) in (c) and without (blue) and with (red) non-return valve at the water tank for 60rpm in (d). Exemplary pulse velocity profile over the cross-section (d).

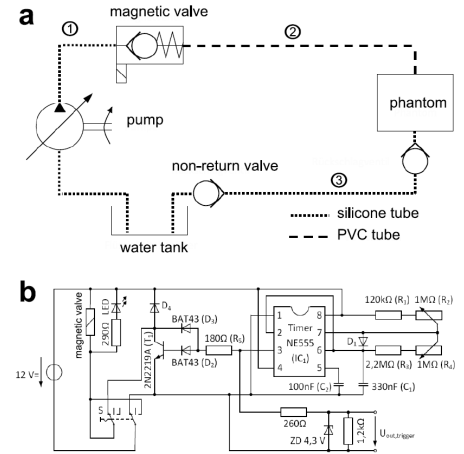


Fig. 1: (a) Diagram of the phantom. Length and compliance of tubing 1 affects maximum peak velocity (1m silicone, i.d./o.d 8/12mm). Path 2 has a small compliance to transmit pulse shape correctly (6m PVC, i.d. 8mm). Tubing 3 should minimize the resistance of the return path (6m silicone, i.d./o.d. 8/12mm). (b) Circuit used for timing of the magnetic valve.