A perfusion phantom with distinct vascular territories

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Introduction

Perfusion phantoms that simulate elements of the vascular system of have been used to provide a controlled environment for optimisation of ASL sequences. For example, flow phantoms have been used to measure the inversion efficiency in continuous ASL (CASL)[4,7] and micro-vasculature phantoms that mimic the capillary bed for perfusion measurements[1,3,5]. Presented is a perfusion phantom which models the entire feeding vasculature of a human head: the carotid arteries, smaller branching arteries and the capillary bed. Two distinct vascular territories are present, allowing the phantom to be used in vessel selective labelling sequences, and both bulk blood flow and perfusion can be measured.

Phantom Design and Construction

The phantom consisted of two separate inflow sections, each with a 'carotid' artery, branching arteries and perfusion chamber. Prior to branching there was a large chamber for inversion efficiency measurements. Dimensions were: 'carotid' tubes – 85mm long, 7mm inner diameter (ID); measurement chamber – 40mm long, 20mm diameter; branching – 30 tubes, each 2mm ID, running 45mm into the perfusion chamber, capped at the ends and with 0.5mm holes every 2.5mm for water to pass through. Dimensions of the perfusion chamber were 34×80×50mm, and each was filled with 1mm diameter glass beads to simulate the capillary bed. All dimensions were based on measurements made of a 24 year old male volunteer. Water returned via multiple 0.5mm holes in the central partition between the two perfusion chambers, feeding a return pipe. The phantom was designed as two solid sections (main and lid) using computer aided design (CAD) software (Autodesk Inventor 2011), as shown in figure 1, and manufactured by selective laser sintering (SLS) of nylon. Epoxy resin was used to seal the lid and to watertight the outer. The phantom was placed in a close-fitting watertight plastic container filled with copper sulphate doped distilled water and 6.25mm ID plastic tubing was used to connect inflow and return tubes (see figure 2.). Pulsatile flow was provided by a peristaltic pump (502S, Watson Marlow, Cornwall, UK), giving a maximum flow rate of 600ml/min.

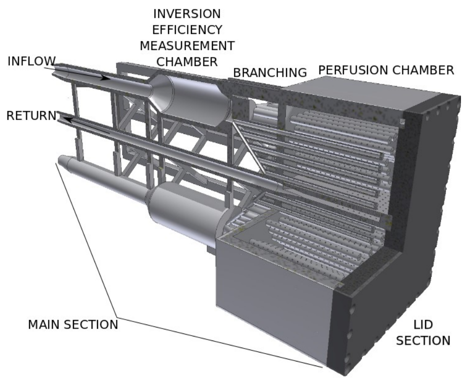

Figure 1: Phantom Design

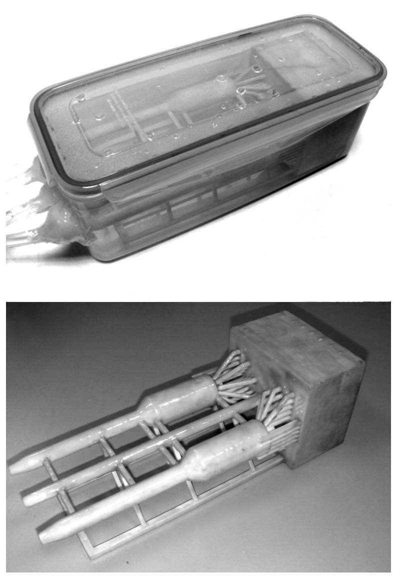

Figure 2: Finished Phantom

ASL Measurements

Images were acquired on a 3T Siemens Tim Trio scanner (Erlangen, Germany). A 3D time of flight (TOF) Angiogram was acquired of the entire phantom: TE=3.87ms, TR=20ms, α=20°, 3.75mm slice thickness, FOV=174×163×236mm, image matrix 256×240×64. Perfusion images of the perfusion chamber were obtained from a FAIR[2] PASL sequence, and separate labelling coil CASL[4] sequence, both with a 3D-GRASE[6] acquisition. CASL labelling was provided by two circular surface coils positioned on either side of the phantom, interfaced to a low power two channel in-house built transmitter system. Imaging parameters for both sequences were TE=14.9ms, TR=4350ms, FOV=240×145×60mm, 64×36×12 image matrix, 30 averages, 6/8 partial fourier and 2× GRAPPA accelerated. A TI of 2500ms was used in the PASL sequence, for the CASL sequence a labelling gradient of 3.5mT, duration of 3500ms and post labelling delay of 500ms was used. Images were enlarged by a factor of three using a bicubic filter in Matlab (The Mathworks Inc.).

Results

Figure 3. shows the two centre transverse slices of the perfusion chamber from the TOF angiogram(i), and images from the PASL(ii.), and CASL(iii.) sequences. Both the TOF and perfusion images show that the flow and perfusion rate is highest in the centre of each perfusion chamber, due to phantom geometry the centre tubes have a reduced flow resistance and hence higher flow rate. Both the PASL and CASL images have high SNR. The uneven labelling seen in Figure 3.iii. is due to sub-optimal labelling parameters resulting in a reduction in labelling efficiency for some of the pulsed flow cycle.

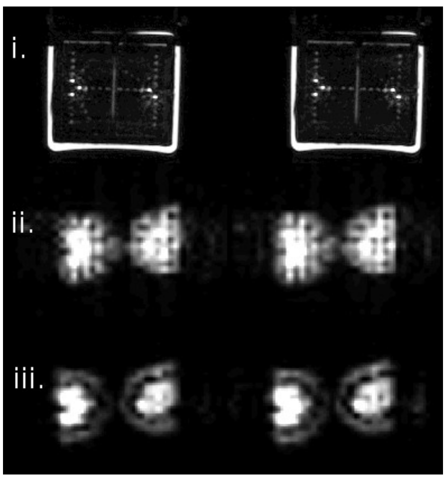

Figure 3: MRI Images

Discussion and conclusion

The perfusion phantom presented exhibits desirable qualities for developing both labelling and acquisition methods for ASL. It has a high perfusion rate yielding high SNR, permits the inversion efficiency to be measured in the 20mm diameter pipe sections, and has distinct, perfusion territories with spatially varying perfusion rates, facilitating vessel selective sequences to be tested. By using CAD software and rapid prototyping, phantoms can be made inexpensively (under £200) with dimensions adapted to a specific anatomy, or many identical phantoms can be made, for example for quality assurance in multi-centre ASL studies.

References: 1. Esparza-Coss E, et al., *Magn. Reson. Imag.*, 28 4:607 – 612, 2010. 2. Kim SG, MRM 34 3:293–301, 1995. 3. Lee GR, et al., in *Proc. ISMRM 10*, 2002. 4. Mildner T, et al., MRM 49 5:791–795, 2003. 5. Noguchi T, et al., *Magn. Reson. in Med. Sci.*, 6 2:91–97, 2007. 6. Oshio K, et al., MRM 20 2:344–349, 1991. 7. Werner R, et al., MRM 53 5:1006–1012, 2005.