A Standardization Phantom for Quantitative Perfusion with Arterial Spin Labeling

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Target Audience: Clinical and technical ASL researchers

Purpose: Arterial spin labeling (ASL) is a well established method for obtaining non-invasive perfusion images with MR[1]. Perfusion refers to the delivery of oxygen and nutrients to tissues by means of blood flow through an intricate vascular tree, including exchange of perfusate at the microvascular level. A limitation in the development and validation of perfusion imaging methods is the absence of a perfusion phantom that can be used for calibration and quality assurance (QA).. Some recent progress has been made in the development of phantoms for flow measurements with ASL[2,3], however a standardized phantom that appropriately simulates perfusion in the microvasculature remains elusive.

Materials and Methods: We utilized a two-chamber phantom design[2], constructed from a 50-mm diameter glass chromatography column. The first chamber was filled with 1-mm diameter acid-washed glass beads (Sigma-Aldrich, G1152), and the second chamber filled with a coarse synthetic fiber mesh (Fig. 1). The glass beads dispersed the labeled in-flowing perfusate, and provided a realistic transit time from the labeling plane to the mesh. The high packing density and magnetic susceptibility (Fig. 1) of the glass beads leads to complete signal loss. The fiber mesh provides a much higher water proton density and a lower susceptibility. The water-filled cavities within the mesh also provide a medium of exchange of the labeled and unlabeled perfusate. A Masterflex L/S programmable peristaltic pump (Cole-Parmer) was used to pump the perfusate through 5-mm inner-diameter neoprene tubing. The phantom perfusate consisted of a dilute solution of copper sulfate (~0.15 g/L $CuSO_4$ in saline), which was used to approximately match the T_1 of arterial blood at 3 T. The exterior of the column was packed between two gadolinium-doped saline bags (4 mL Gd-DTPA per 1L saline) to allow for center-frequency detection and shimming. ASL data were collected at 3 T (Siemens Tim Trio) with a conventional 1500-ms pseudo-continuous ASL (pCASL)[4] labeling train, followed by a single-slice SPGR (FLASH) readout. Ten label/control pairs were collected for two pump flow rates (350 mL/min and 450 mL/min) and six different post-label delay times (500-3000 ms at 500-ms increments). The T_1 of the perfusate and the approximate proton density of the mesh was determined using MP-RAGE with variable inversion time. Percent difference was measured from circular ROIs drawn in the percent difference images within the mesh. A Gaussian-based dispersion model was used to simulate the expected ΔM% for a range of transit times.

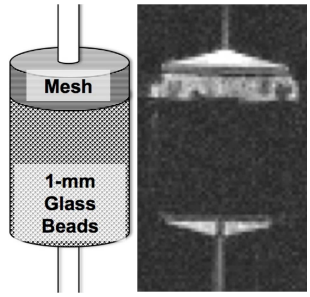

Fig. 1 – Two-chamber phantom schematic and FLASH image.

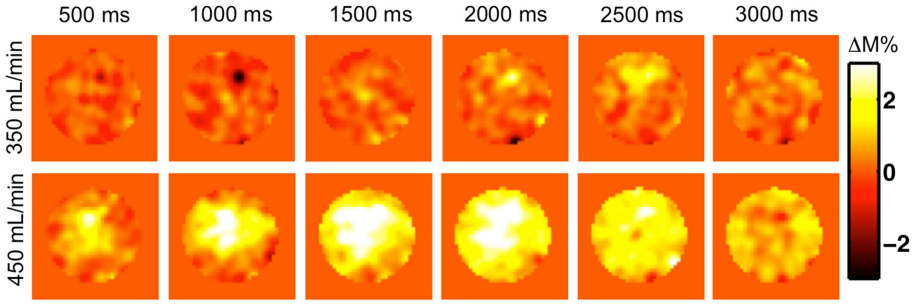

Fig. 2 – ΔM% images at 2 flow rates with variable postlabeling delays

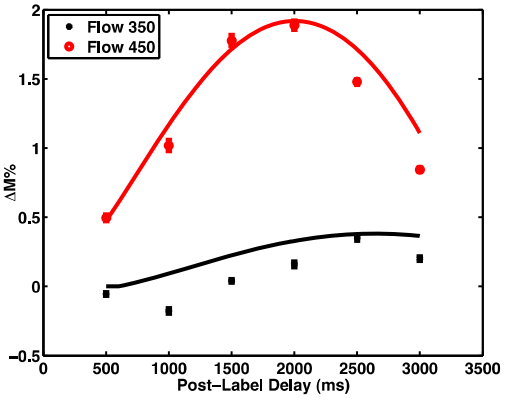

Fig. 3 – Measured ΔM% from ROIs in Fig 2. Solid lines represent simulated ΔM% using a Gaussian-based dispersion model.

Results: The measured T_1 of the perfusate solution was approximately 1320 ms, and the proton density of the mesh relative to the perfusate was 0.20. Sample images are shown in Fig. 2 from a 28-mm circular ROI drawn over the center of the phantom for the various experiments. Although the signal changes are not uniform across the ROI, increasing the pump flow increases the signal in the percent difference images. Varying the post-label delay also allows for temporal analysis of the 1500-ms label bolus passage through the mesh. The measured percent difference from these ROIs (Fig. 3) confirmed the desired tissue-mimicking behavior of the labeled perfusate exchange within the mesh.

Discussion: As shown in Fig. 2, the exchange of labeled and unlabeled perfusate within the mesh represents a more realistic model of tissue-level perfusion compared to previous designs[2,3]. One limitation of this phantom is the current design has a high magnetic susceptibility near the fiber mesh due to the glass beads and the shell of the chromatography column. Thus, the current design is not well suited for precise high-order shimming needed for echo-planar imaging (EPI) acquisitions. The discrepancies between the measured ROI data and the dispersion simulation suggest a more appropriate model is needed. Future work will improve the phantom design to allow for both EPI-based data acquisitions, and simulation of multiple tissue types.

References: [1] Williams, *PNAS* 1992; 89: 212. [2] Noguchi, *MRMS* 2007; 6: 91. [3] Oliver-Taylor, *ISMRM* 2012; p 1995. [4] Wu, *MRM* 2007; 58: 1020.