A Straightforward Approach for Measuring Blood Transit Time in Major Blood Vessels

Q. Qin[1,2], and P. C. van Zijl[1,2]
[1]Department of Radiology and Radiological Science, Johns Hopkins University, Baltimore, MD, United States, [2]F.M. Kirby Research Center for Functional Brain Imaging, Kennedy Krieger Institute, Baltimore, MD, United States

INTRODUCTION: The transit time in major brain vessels reflects the efficiency of blood circulation, which is clinically relevant in cerebrovascular diseases such as carotid artery stenosis (1), or acute ischemic stroke (2), and diseases like sickle cell anemia, which have a higher risk of cerebral infarction due to increased baseline flow velocity (3). Major vessel transit time is also an important parameter for arterial spin labeling (ASL) methods, where knowledge of the transit time from the tagging region to the slice containing the tissue of the interest is needed to estimate the appropriate labeling delay for measuring cerebral blood flow (CBF) (4,5). Typically, transit times can be estimated by imaging immediately after injection of contrast agent (1,2) or by fitting kinetic models with multiple labeling delays in ASL (5). Here we propose a novel method to measure transit time within major blood vessels directly and quickly, without injecting contrast agents or fitting any models.

METHODS: Our approach applies slice-selective spin labeling as used in ASL (4) to tag the blood water in one specific region, and immediately acquires images downstream within short intervals. It takes advantage of the fast flow velocity within big vessels. For our new technique to perform well, positioning of the imaging slice is crucial: the detection slice to be acquired repeatedly should be as perpendicular to the blood vessel of interest as possible to allow quick washout. At the same time this slice should not include any other upstream vessels excited by previous pulses within a TR. The perturbation of the blood signal in the detection ROI is then a mark of the arrival of the tagged blood.

Experiments were performed on a 3T Philips Intera scanner using body coil transmit and 8-channel head coil receive. Nine healthy volunteers (age:24-49yrs) were enrolled with informed consent. Scan planning: 3D Time of Flight (TOF) covering the Circle of Willis was performed to depict major cerebral arteries (CA) such as anterior (ACA), middle (MCA), and posterior (PCA). TR/TE/FA=23ms/3.5ms/18º, FOV=160x160x21mm^3, acquisition matrix =304x194x30 and resolution after reconstruction was 0.3x0.3x0.7mm^3, acquisition duration: 50s; 2D phase contrast angiography images were acquired in both the coronal and sagittal planes to visualize the location of major neck vessels (TR/TE/FA=20ms/5.8ms/15º, FOV=250x250mm^2 with a 50mm slab, acquisition matrix =212x107 and final resolution was 1.1x1.1mm^2, acquisition duration: 40s).

In Fig. 1, the pulse sequence diagram for measuring blood transit time in major blood vessels is described. It contains a slice-selective (SS) adiabatic inversion pulse followed by an initial delay time (T_{delay}(1)=50ms) and series of (N_{Tdelay}=25) SS 90º excitation pulses (THK=5mm) separated by a short interval (ΔT_{delay}=200ms). The blood velocity measured from our healthy subjects was about v>30cm/s in major intracranial arteries and v>5cm/s in the internal jugular vein (IJV). All spins entering the imaging slice have not experienced any previous SS excitations (ΔT_{delay}>THK/v). Flow compensation (FC) gradients are used to reduce the phase loss caused by through-plane flow (6). For data acquisition (6-segment gradient echo EPI with SENSE factor=2, TE=15ms), the same fractions of k-space are sampled with different T_{delay}s after each inversion. Using a rapid series of excitation pulses, static spins will be saturated and little background signal is visible (7,8). Other parameter: FOV=200x150mm^2, acquisition matrix=192x132, resolution after reconstruction was 0.78x0.78mm^2. Total measurement time ≈ 0.2s(ΔT_{delay})x25(N_{Tdelay})x6(N_{shots})=30s.

RESULTS AND DISCUSSION: The first row in Fig. 2 shows the planning and measurement of transit time from neck arteries to an M1 segment at the left MCA. Measurements of the ransit time from the Posterior Superior Sagittal Sinus (PSSS) to IJV is shown in the second row. Within the Maximum Intensity Projection (MIP) of the 3D TOF (Fig. 2a) and the coronal and sagittal view of 2D phase contrast angiography (Fig. 2b,c,g,h), the blue shading indicates the labeling slice and the orange line the imaging slice (green box: shimming volume). Detection ROIs are in red for MCA (Fig. 2d) and in blue for IJV (Fig. 2i). Finally the signal magnitudes averaged within each ROI (SD: error bar) at every delay time were plotted in Fig. 2e,j. The arrival of the labeled blood could be clearly visualized with the bottoming of the curve. It was about 500 ms for blood to travel from neck arteries to the M1 segment of MCA and about 1000 ms from PSSS to IJV. Transit time measurements in other vessels are listed in Table 1.

Since the sampling time used in this work was 200 ms (ΔT_{delay}), estimation errors are in this range. So the results can reflect transit time difference between different blood segments (larger than 200 ms), but not detect difference between people in the same blood segment. In principle, this sampling time can be shortened if blood flows fast. For arteries (v>30cm/s), it can potentially be reduced to 50ms to still washout blood in a 5 mm slice (50msx30cm/s=15mm>5 mm).

CONCLUSION: We have shown that transit time in major blood vessels can be measured efficiently *in vivo* (within 0.5 min) exploiting the inflow of fresh blood into the big vessels. This can provide important clinical information about vascular circulation, and also facilitate the selection of labeling delay in ASL for quantification of CBF.

REFERENCE: 1. Kikuchi K, et al. *AJR* (2002) 179, p229; 2. Sorensen AG, et al. *Ragiology* (1999) 210, p519; 3. Adams R, et al. *NEJM* (1992) 326, p605; 4. Detre JA, et al. *MRM* (1992) 23:p37; 5. Buxton RB, et al. *MRM* (1998) 40:p383; 6. Butts K, et al. *JMRI* (1992) 2:p285; 7. Qin Q, et al. *ISMRM* (2009) 17, p3624; 8. Qin Q, et al. *ISMRM* (2009) 17, p3655; grants : P41RR015241; RO1EB004130;
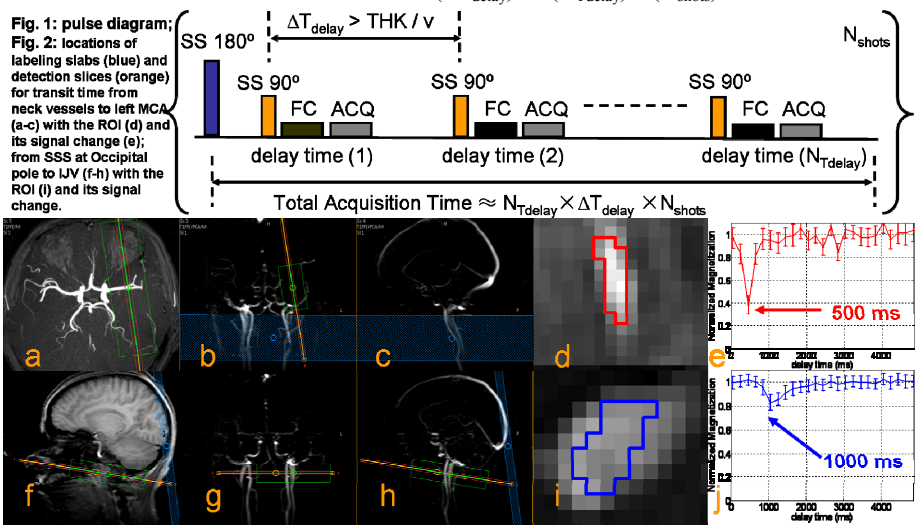
Fig. 1: pulse diagram; **Fig. 2:** locations of labeling slabs (blue) and detection slices (orange) for transit time from neck vessels to left MCA (a-c) with the ROI (d) and its signal change (e); from SSS at Occipital pole to IJV (f-h) with the ROI (i) and its signal change.

Table 1:

from	neck artery vessels (ICA, VA)				Top SSS	Posterior SSS	Transverse Sinus
to	M1, left MCA	M1, right MCA	A1, ACA	P1, PCA	IJV		
Transit time (ms)	500	500	500	500	1500	1000	500