# Imaging Cerebrovascular Reserve using Combined ASL Blood Flow and BOLD: A Study using Acetazolamide Challenge in Patients with Chronic Stenosis of Major Arteries

Deqiang Qiu[1], Junjie Wu[1], Fadi Nahab[2], and Seena Dehkharghani[1]

*[1]Radiology and Imaging Sciences, Emory University, Atlanta, GA, United States, [2]Neurology, Emory University, GA, United States*

**Target Audience:** Radiologists and Clinical Scientists Interested in using MRI for Assessing Cerebrovascular Reserve

**Introduction:** Cerebrovascular reserve (CVR) capacity in patients with chronic stenosis or occlusion of major arteries including the carotid provides valuable information in predicting their risks of developing strokes subsequently[1]. Arterial spin labeling (ASL) is a recent advance of MR technique that allows repetitive assessment of cerebral blood flow (CBF) without injection of contrast medium and is therefore a good candidate as an imaging modality for CVR assessment. Nonetheless, ASL is sensitive to variations in transit delay of the tagged blood, which may pose as a problem in patients with cerebrovascular diseases. BOLD on the other hand may provide complementary information to ASL in assessing CVR[2]. Therefore, in the current study, we propose to assess CVR using both ASL and BOLD with the injection of acetazolamide (Diamox) in a group of patients with known unilateral or bilateral cerebrovascular diseases. BOLD and CBF augmentation was then quantified and compared between hemispheres with normal and those with moderate to severe vascular diseases.

**Method:** Ten patients were included in the study. The CVR assessment included ASL sequences before and after the Diamox injection as well BOLD acquisition during the injection of Diamox. Figure 1 shows a schematic of the imaging protocol. The ASL acquisition was performed using a multi-delay single-shot 3D Gradient And Spin echo readout (GRASE) and FAIR tagging mechanism with following parameters: TR/TE = 3600/19.3ms, FOV=320x160mm, Slice Thickness=3.5mm, 32 Slices, 5 Averages, 10 post-label delays: first TI=300ms, increment=300ms). BOLD experiment was performed using a Gradient Echo EPI sequence (TR/TE=2000/30ms, FOV = 220mm, Matrix = 64x64, Slice Thickness=4mm, 30 Slices). CVR was calculated as percentage augmentation between pre- and post- Diamox CBF values measured by ASL and BOLD signals. For each subject, brain hemisphere was assigned as "stenosis" or "normal" based on whether it had moderate to severe stenosis/occlusion of the ipsilateral internal carotid and/or middle cerebral arteries as assessed by MRA (MR angiography) and/or DSA (digital subtraction angiography). Mean pre-/post- Diamox, CVR measurements using both ASL and BOLD were calculated for each hemisphere, the comparisons were made between "stenosis" and "normal" hemispheres using Student's T test.


Fig. 1 shows a schematic of the imaging protocol, a multi-delay ASL sequence was acquired before the injection of Diamox, the BOLD sequence was started for continuous acquisition, 5 minutes of baseline images were acquired before the 3-minute infusion, the BOLD sequence ends 20 minutes from the start of Diamox injection. A post-Diamox ASL was then acquired.

**Results:** Figure 2 shows the ASL and BOLD maps as well the CVR metrics in a female patient with occlusion of the left internal carotid artery. Reduced CBF measured by ASL as well as augmentations measured by both ASL and BOLD can be observed in the left middle cerebral artery territories. ASL CVR map further showed reduced augmentation in the left anterior cerebral artery territory. BOLD augmentation is modulated by baseline blood volume with sagittal sinus showing substantially higher augmentation due to its high blood volume. Out the 20 hemispheres of the 10 subjects, 11 were assigned as "stenosis" with moderate to severe stenosis/occlusion of the ipsilateral major arteries, and the rest 9 hemispheres were assigned as "normal". Table 1 shows mean CBF, BOLD signal before and after Diamox injection as well as CVR for the "normal" and "stenosis" hemispheres. Significantly reduced in ASL CVR was observed in the "stenosis" hemispheres compared to the "normal" hemispheres, while the difference approaches statistical significance for BOLD CVR.

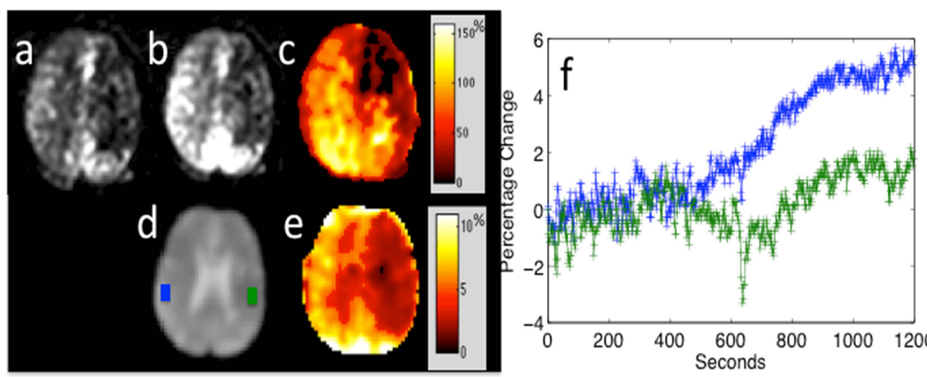


Fig 2. shows (a) ASL CBF map pre Diamox, (b) ASL CBF map post Diamox, (c) ASL CVR (d) mean BOLD image, (e) BOLD CVR, (e) time series of voxels indicated on (d). Reduced CBF measured by ASL as well as augmentations measured by both ASL and BOLD can be observed in the left middle cerebral artery territories. ASL CVR map further showed reduced augmentation in the left anterior cerebral artery territory. Images are in radiological convention.

| | | "Stenosis" mean (SD) | "Normal" Mean (SD) | P value |
|---|---|---|---|---|
| BOLD | CVR (%) | 3. 3 (1.3) | 4.3 (1.0) | 0.061 |
| | post-pre (A.U.) | 18.4 (9.8) | 25.4 (8.8) | 0.120 |
| | pre (A.U.) | 643.8 (63.9) | 611.7 (75.6) | 0.316 |
| | post (A.U.) | 662.3 (67.5) | 637.0 (82.5) | 0.460 |
| ASL | CVR (%) | 24.3 (9.0) | 38.1 (13.7) | 0.015* |
| | post-pre (ml/min/100g) | 5.8 (3.3) | 9.3 (6.9) | 0.152 |
| | pre (ml/min/100g) | 22.7 (5.9) | 25.1 (8.3) | 0.456 |
| | post(ml/min/100g) | 28.5 (8.6) | 34.4 (14.5) | 0.272 |

Table 1 shows mean CBF, BOLD signal before and after Diamox injection as well as CVR for the "normal" and "stenosis" hemispheres.

**Discussions & Conclusions:** ASL and BOLD CVR provide complimentary information about cerebral vascular reserve. ASL on the one hand may provide inadequate information in regions with long arterial transit time, while BOLD augmentation is heavily modulated by baseline blood volume. Combing ASL and BOLD augmentation provides more complete picture of the cerebral vascular reserve. Preliminary analysis showed a significantly reduced CVR in brain hemispheres with moderate to severe vascular disease. In conclusion, combined CVR with ASL and BOLD may a valuable diagnostic tool for predicting risk of stroke in patients with cerebral vascular diseases.

**References:** ***1.*** Gupta A, et al. Stroke. 2012; 43:2884-91. ***2.***. Thomas BP, et a. JCBFM. 2014;34:242-7