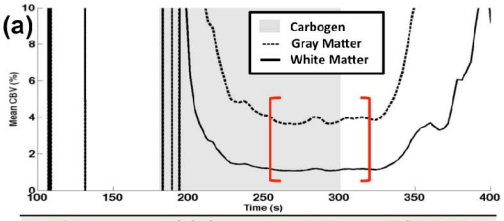
# Vessel Size Index and Cerebral Blood Volume Maps using Hypercapnic Contrast at 3T

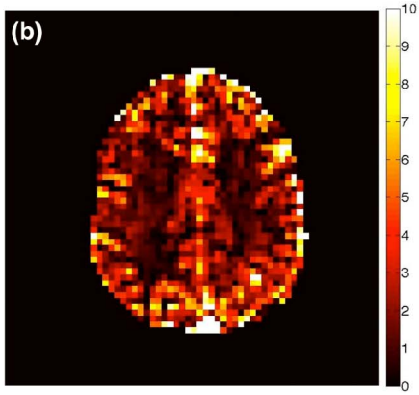
Thomas Christen[1], Georges Hankov[1], Heiko Schmiedeskamp[1], Roland Bammer[1], and Greg Zaharchuk[1]
[1]*Department of Radiology, Stanford University, Stanford, California, United States*

**Introduction:** Recent studies using respiratory challenges and MR BOLD-based contrast have shown the possibility to create cerebral blood volume (CBV) maps using 50% $O_2$ gas at 3T [1] or the mean vessels radius (VSI) with carbogen (95% $O_2$, 5% $CO_2$) at 7.0T [2]. These measurements do not require intravenous injection of a contrast agent and could be useful to study pathologies such as stroke, trauma or tumor. In the present study, we used a carbogen challenge to compute both CBV and VSI maps at 3T. The use of a multiple spin and gradient echo (SAGE [3]) EPI sequence allowed the acquisition of VSI and CBV values simultaneously with a high temporal resolution. This was used to determine the period of time during which the carbogen gas induced enough difference of magnetic susceptibility between blood and tissue to allow accurate measurements.

**Material and Methods:** Magnetic resonance imaging was performed at 3T using a GE Sigma 750 whole-body scanner (GE Healthcare Systems, Milwaukee, WI) and an 8-channel head coil. The study was approved by the IRB and all subjects signed written informed consent. 5 subjects were scanned using the following protocol: MR acquisitions were performed during carbogen inhalation using a SAGE EPI sequence (TR=3000ms, TE= 13.1, 24, (gradient echoes) 48.2, 59.1 (asymmetric spin echo) and 70.0 (spin echo) ms, 160 acquisitions). Nine 5 mm thick slices, with 2 mm spacing and in-plane resolution of 64x64 voxels were acquired with FOV = 22 cm. During the experiment, the volunteers were breathing spontaneously through an adult non-rebreathing mask (Hudson RCI, USA). Hemodynamics were manually modulated by introducing medical air and carbogen into the breathing circuit at a rate of 10 liter/min. The carbogen breathing period was 2 minutes, adequate to reach a steady-state, and was preceded and followed by 3 minutes of medical air breathing.
Relaxation maps using the multiple echoes were created every TR as follows: T2* (T2*B) were obtained voxelwise using a linear exponential fit of the first 2 gradient echoes (TE=13.1-24ms) and 3 last echoes (TE=48.2-59.1-70ms) respectively. T2 was computed as 2/(1/T2*+1/T2*B) [4]. VSI was computed according to the formulas presented by Shen et al. [5] using the ratio: $q=\Delta R_2/\Delta R_2^*$ into $r(q)=\exp(\sum_{n=0:6}(a_n.\log^n(q)))$ (with $a_n$ being a predetermined regression coefficient) to obtain mean vessel size radius at each time points. CBV was obtained following the method of Bulte et al. [1]. This method implies the division of the signal intensity maps by the value of pure blood signal. In our study, the sagittal sinus signal was used.

***Fig 1:*** *(a) gray / white matter **CBV** estimates during the challenge period in one volunteer. (b) Corresponding CBV map averaged over the stable period of carbogen inhalation (red brackets in Fig1a). (c) CBV (mL/100g) averaged over the stable period in all volunteers.*

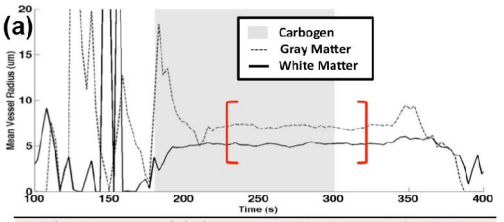


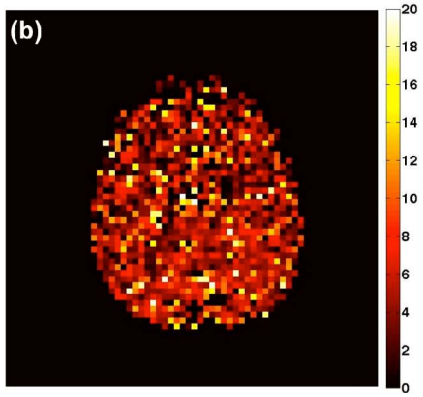




(c)

| Subject | Global | Gray Matter | White Matter |
|---|---|---|---|
| 1 | 2,78 ± 0,37 | 3,39 ± 0,41 | 1,12 ± 0,04 |
| 2 | 3,24 ± 0,36 | 3,84 ± 0,42 | 0,93 ± 0,26 |
| 3 | 2,92 ± 0,24 | 3,71 ± 0,21 | 1,37 ± 0,17 |
| 4 | 3,27 ± 0,34 | 3,75 ± 0,16 | 1,29 ± 0,36 |
| 5 | 2,81 ± 0,36 | 3,24 ± 0,25 | 0,90 ± 0,37 |
| MEAN ± STD | 3,00 ± 0,24 | 3,59 ± 0,26 | 1,12 ± 0,21 |

***Fig 2:*** *(a) gray / white matter **VSI** estimates during the challenge period in the same volunteer as in Fig1. (b) Corresponding VSI map averaged over the stable period of carbogen inhalation (red brackets in Fig2a). (c) VSI (μm) averaged over the stable period in all volunteers.*




(c)

| Subject | Global | Gray Matter | White Matter |
|---|---|---|---|
| 1 | 7,35 ± 0,82 | 9,17 ± 1,82 | 5,51 ± 0,17 |
| 2 | 6,64 ± 0,57 | 6,95 ± 0,73 | 5,61 ± 0,17 |
| 3 | 6,22 ± 0,31 | 6,59 ± 0,21 | 5,28 ± 0,79 |
| 4 | 5,91 ± 0,13 | 6,19 ± 0,09 | 4,71 ± 0,52 |
| 5 | 7,74 ± 1,05 | 7,48 ± 0,72 | 8,89 ± 2,80 |
| MEAN ± STD | 6,77 ± 0,90 | 7,27 ± 1,33 | 5,99 ± 1,89 |

**Results:** The Gray matter (GM) and white matter (WM) CBV time course in one subject is shown in Fig.1a. It appears to be stable over the last minute of the carbogen inhalation block (red brackets). Before and after this period, the variations of blood magnetic susceptibility are not big enough to allow accurate measurements. A CBV map (averaged over the stable period to increase the SNR) in the same subject is presented in Fig.1b. A good contrast between GM and WM can be observed. Fig 1c represents the values of CBV averaged over the stable period in all volunteers. A total whole brain CBV of 3.00 ± 0.24 mL/100g is consistent with previously reported values [6]. Yet, the measurements appear to be slightly too low considering the expected vasodilatation effect induced by the $CO_2$ inhalation. The VSI results in the same volunteer as in Fig1 are presented Fig2. The stable period of the VSI estimates appears to be longer than the CBV one. An averaged VSI map is presented in Fig.2b. It shows relative homogeneity over the entire brain. A mean vessel size radius (averaged over all subjects) of 6.8 ± 0.9 μm (fig2c) is similar to the value found in previous studies [2].

**Conclusion:** This study suggests that CBV and VSI maps can be obtained using hypercapnic contrast at 3T. Data can be acquired after 1 min of carbogen inhalation and seem to be stable as long as the gas is breathed. Interplay between TR, voxel size, and challenge duration could lead to higher SNR and/or improve spatial resolution.

**References:** [1] Bulte et al., JMRI, 2007. [2] Jochimsen et al., Neuroimage, 2010. [3] Schmiedeskamp et al, MRM, 2011. [4] Ma and Wherli, J Magn Reson B, 1996. [5] Shen et al., Neuroimage, 2011. [6] Barbier et. al, JMRI, 2001. **Acknowledgments:** National Institute of Health (2R01NS047607, 1R01NS066506, 5P41RR09784), Lucas foundation, Oak foundation, GE healthcare.