Simultaneous and Quantitative Investigation of the Cerebral Arterial and Venous Vasomotor Reactivity Using Phase-Contrast Magnetic Resonance Imaging Technique: A Multi-fractional CO2 Inhalation Approach

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Introduction: Inhalation of carbon dioxide (CO2), with similar effect of vasodilatation as intravenous injection of acetazolamide, could serve as a stimulus of vasomotor reactivity (VMR), which has been demonstrated to be important in approaching cerebrovascular diseases such as transient ischemic attack (1). Although both being noninvasive methods, phase-contrast magnetic resonance imaging (PCMRI) is superior to transcranial Doppler sonography by the ability for simultaneous measurement for multiple cranial vessels to avoid inter-experiment variations. Prior researches have shown that non-triggered 2D phase contrast magnetic resonance angiography (PCMRA) to be a useful tool for rapid flow measurement in phantom study (2) and human arteries (3). Recently, PCMRA has been applied to investigate the cerebral VMR by breath-hold challenge (4) and carotid artery compression (5). Our prior study has shown that the BOLD signals, which is mostly resulted from the increase of oxygenated blood flow, of the human brain is strongly positively associated with the fractions of inhaled CO2 (6). In this study, we aim to evaluate VMR of the human brain by approaching the cerebral blood flow quantitatively of both arteries and returning veins under graded CO2 inhalation (room air, 3%, 5% and 7%) on healthy volunteers using PCMRI.

Method: Six healthy subjects (mean age of 29 years, ranging from 23 to 37 years) given informed consent were recruited and scanned by non-triggered 2D PCMRI on a 1.5T whole-body system (Siemens Vision plus, Erlangen, Germany). An oblique slice approximately vertical to the target vessels on a localizer MRA) slab in the sagittal plane was chosen to include the left (LICA) and right internal carotid artery (RICA), basilar artery (BA), sinus rectus (SR), superior sagittal sinus (SSS) (Fig 1). 2D PCMRI measurements were performed with conventional protocol using optimal scan parameters (TR/TE= 29/7 ms; flip angel=30°; matrix size 115×256; FOV 120x240; Venc=150 cm/sec; slice thickness=5mm.). The number of averages (NEX) was 4 and the scan time was 14 sec. This non-triggered 2DPC scan was repeated at a 15-second interval with a total of 98 scans (duration = 24.5 min). During the 98 scans, room air and CO2 gas were alternatively supplied as illustrated (Fig.2). The mean blood flow values were calculated semi-automatically after manually defining ROI regions of the target vessels as proposed by Huang et al.(7) at the steady state (last 1 minute) of each gas condition. The percentage change of mean blood flow was calculated as: $(\text{flow}_{CO2} - \text{flow}_{\text{room air}}) / \text{flow}_{\text{room air}} \times 100\%$.

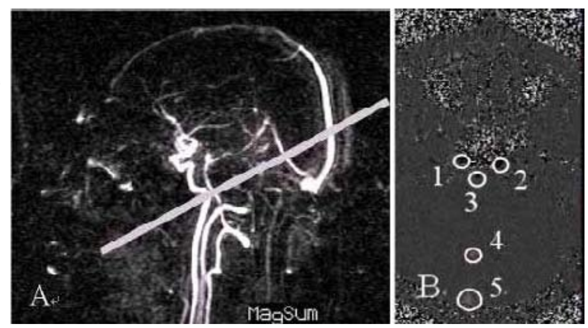

Fig1. (A) Sagittal localizer MRA. (B) Phase image with ROI (1) RICA (2) LICA (3) BA (4) SR (5) SSS.

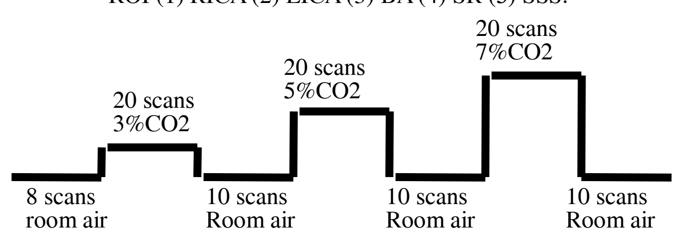

Fig2. Illustration of the experiment paradigm that measures cerebral blood flow in the different CO2 concentration.

Results: Figure 3 showed the mean blood flow of five vessels averaged from all subjects. The blood flow was proportionally increased with the inhaled CO2 concentration. Figure 4 showed the percentage change under all three different concentrations of CO2.

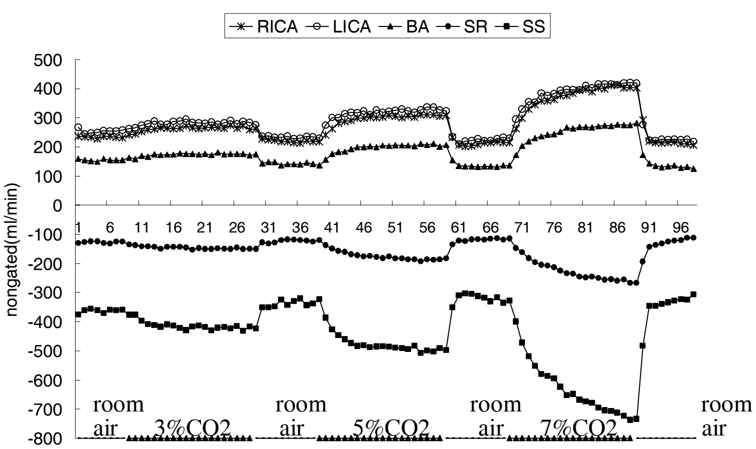

Fig3. The mean blood flow of RICA,LICA,BA,SR,SSS as a function of time for the six subjects included in this study.

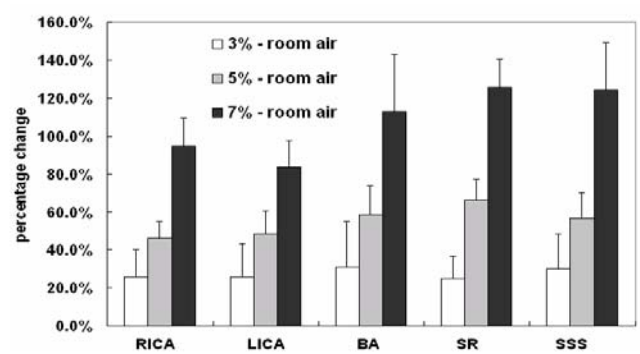

Figure 4. The percentage change of blood flow changes under different CO2 concentrations.

Discussion: Our results provided a simultaneous and quantitative approach of the cerebral vascular flow as a nonlinear function of inhaled CO2 fraction. The overall blood flow showed a 25% (3% CO2), 50% (5% CO2), and 100% (7% CO2) of increase after CO2 perturbation. The response time of blood flow to the CO2 challenge was increased under the perturbation of higher CO2 fraction. We conclude that non-triggered 2D PCMRI allows a simultaneous and quantitative investigation of complete of the human cerebral VMR invasively. The usefulness of graded CO2 perturbation in the clinical field deserves further research to verify.

Reference:

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