Improved quantification of cerebral blood flow change using phase information of SWI, corrected by arterial oxygen saturation

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Introduction

Phase image of MRI contains information about local difference of magnetic susceptibility, including paramagnetic substances, such as iron, hemorrhage, and deoxyhemoglobin (deoxyHb) in the vein. Oxygen saturation and venous blood flow can be measured by using the phase difference between the vein and background tissue [1,2]. However, the previous studies used formulas under the several assumptions; arterial oxygen saturation, arterial blood flow, and oxygen consumption are constant during the measurements. If these values are taken into account in the formula, the flow measurements might become more accurate.

Objective

We propose a new formula, in which arterial oxygen saturation is taken into account, to calculate venous flow change using phase information. The purpose of this study is to compare two formulas (previous studies and our proposal), in the measurements of venous flow change under the drug and physiological load, and to compare the results with cerebral blood flow change measured by arterial spin labeling (ASL) technique.

Materials and Methods

Eight healthy volunteers with informed consent, were included in this study. Susceptibility weighted imaging (SWI) and arterial spin labeling (ASL) were performed on a 1.5 T MR scanner (Magnetom Avanto, Siemens, Erlangen, Germany) with 4-channel, 3-element head coil. Three respiratory challenges; carbogen (5 % CO_2, 95% O_2) inhalation, hyperventilation, and pure oxygen inhalation, and drug challenge using the administration of acetazolamide (1.0 g), were done. During these scan, percutaneous oxygen saturation was recorded on their right forefinger.

A fully flow-compensated three-dimensional fast low-angle shot (FLASH) was used to obtain phase images with the following parameters: TR/TE/FA = 49 ms/40 ms/20°, matrix = 264 x 448, (FOV = 201 x 256 x 300 mm^3), bandwidth = 80 Hz/pixel, and parallel imaging factor = 2. For ASL, flow-sensitive alternating inversion recovery (FAIR) was used with the following parameters: TR/TE = 2000/8.7 ms, matrix = 64 x 64, FOV = 256 x 256 mm, slice = 5 (thickness, 8 mm), duration of tagging bolus = 700 ms, and the delay time = 1000 ms.

The venous oxygen saturation and flow changes (SWI-flow) were quantified from the automated method that we developed using phase image of SWI [3, 4]. The mapping was done with both previous formula and present formula in which venous flow was corrected by arterial oxygen saturation and flow velocity. CBF quantification was done on ASL.

The flow changes under each challenges were compared with values at rest. One way ANOVA and Dunnett's multiple comparison post hoc test were used for statistical test. Difference with $p < 0.05$ was considered to be significant. Pearson product-moment correlation coefficient was used to find a correlation between SWI-flow and ASL-CBF.

$$f\_previous = \frac{\Delta Y}{0.45 - \Delta Y} = \frac{-(\Delta\varphi_1 - \Delta\varphi_0)}{\Delta\varphi_1} \qquad f\_new = \frac{S0 - S1 + \Delta Y}{S1 - 0.55 - \Delta Y}$$

ϕ : phase difference

Y: venous oxygen saturation

f: velocity change

S: arterial oxygen saturation

Results

The flow changes under each challenges, calculated from previous formula and from present one were similar; SWI-flow was significantly decreased with hyperventilation, and was significantly increased with acetazolamide. Carbogen increased SWI-flow, but the change was not significant ($p = 0.11$). Oxygen inhalation also induced no significant change. Significant correlations between SWI-flow and ASL-CBF were only observed in the resting state and pooled data with both formulas; however, increased correlations were observed in carbogen and oxygen inhalation with current formula compared to the previous one (Table 1).

	CBF/flow	pre	Carb	HV	Oxy	AZ	pooled data
previous formula	correlation coefficient	0.554229	-0.0257	-0.16644	0.016744	0.065768	0.495894
	P value	0.0259	0.9247	0.5378	0.9509	0.8088	<0.0001
present formula	correlation coefficient	0.547765	0.286001	0.004577	0.337734	-0.1775	0.557995
	P value	0.0281	0.2829	0.9866	0.2008	0.5108	<0.0001

Table 1: The correlation between ASL-CBF and both SWI-flow with and without correction by arterial oxygen saturation

Conclusion

Although the flow quantification using phase image of SWI still has unsolved problems, the flow formula corrected by arterial oxygen saturation can be more accurate than previous formula without correction.

Reference

1) Haacke EM, et al. Magn Reson Med. 2004;52:612-618. 2) Haacke EM, et al. Human Brain Mapping. 1997;5:341-346. 3) Shen Y, et al. Magn Reson Imaging. 2007;25:219-227. 4) Zaitsu Y, et al. ISMRM 2009, p.1939.