Resting-state fluctuations of venous blood oxygenation in the sagittal sinus are a potential indicator of arteriolar vasomotion

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Introduction

Venous blood oxygenation in the resting state mainly fluctuates because of arteriolar vasomotion driven by respiratory $PaCO_2$ changes and the default mode of brain function, which fluctuates at frequencies below 0.1 Hz. To evaluate the global activity of arteriolar vasomotion, we measured the time course of MR signals from the superior sagittal sinus and divided the cause of signal fluctuation into fluctuations caused by blood oxygenation and those caused by blood velocity by using our original method, in which slice thickness dependency was characterized as the cause of fluctuation. Next, we analyzed the correlation between the MR signals from the superior sagittal sinus and gray matter, and showed a new possibility of evaluating arteriolar vasomotion in the brain.

Materials and Methods

A single slice perpendicular to the superior sagittal sinus from each volunteer (4 men) was imaged using a 1.5T MRI (Signa LX, General Electric) at every 250 ms in 45 s by using a spin-echo EPI pulse sequence equipped with a surface coil (TE = 30 ms, matrix size = 128 × 128, and FOV = 170 × 170 mm^2). The time courses of MR signals from the superior sagittal sinus and the gray matter were Fourier-transformed to measure the spectral intensities integrated in low (0–0.2 Hz), respiratory (0.2–0.5 Hz), and cardiac pulsation (0.8–1.2 Hz) frequency ranges. In order to divide the cause of fluctuation in the sagittal sinus into fluctuation caused by blood oxygenation and that caused by blood velocity, slices of varied thickness—7, 9, 11, 13, and 15 mm—were obtained. Correlation between the spectral intensity of each frequency range and the average signal intensity in the sagittal sinus was analyzed for the 5 slices. When signal intensity intrinsically changes according to the fluctuations in blood oxygenation, both the average signal intensity and the spectral intensity of fluctuation should proportionally increase with an increase in the slice thickness. In such a case, a strong correlation should be observed. In contrast, because the fluctuation amplitude of blood velocity is independent of slice thickness, the spectral intensity of blood velocity fluctuation is not correlated with the average signal intensity. Phase-contrast blood flow imaging was separately performed for a volunteer to observe the blood-flow velocity changes in the sagittal sinus. To measure the signal changes for 30 min, a single axial slice of the brain was imaged using a gradient echo pulse sequence at every 2 min and 20 s.

Results and Discussion

The spectra of all the volunteers showed 3 major spectral peaks in the lower, respiratory, and cardiac pulsation frequency ranges. Although the spectral intensity of the cardiac pulsation component was the greatest, its correlation with the average spectral intensity was not significant in 3 out of 4 volunteers, reflecting the blood velocity changes of 170–250 mm/s for the cardiac period observed using phase-contrast imaging, which indicated that the pulsation of right atrium pressure modulates the venous blood velocity in the sagittal sinus. The spectral intensity of a low-frequency component was not strongly correlated with the average signal intensity ($r = 0.64$) (Fig. 1a), indicating the influence of low-frequency fluctuation on MCA blood velocity [1] and the spontaneous fluctuation of functional connectivity [2]. On the other hand, the spectral intensity of the respiratory component showed significant correlation with the average signal intensity ($r = 0.95$, $p < 0.001$) (Fig. 1b), indicating that the global cerebral blood oxygenation fluctuated according to the respiratory frequency. This fluctuation may be explained by arteriolar vasomotion that is caused by the respiratory $PaCO_2$ changes. Therefore, the respiratory fluctuation in the venous blood oxygenation in the sagittal sinus may reflect the global activity of arteriolar vasomotion in the brain. While measuring the signal changes for 30 min, the signal intensities of both sagittal sinus and gray matter decreased, indicating that venous blood oxygenation decreased during this measurement period. The ratio of decrease in the signal intensities of gray matter and sagittal sinus for 30 min was in agreement with the respiratory component ratio between these structures that was measured in 45 s. Thus, respiration frequency fluctuation in the parenchyma may be used for the evaluation of arteriolar vasomotion in the brain.

Conclusion

Cerebral venous blood oxygenation clearly fluctuates according to the respiratory frequency, reflecting arteriolar vasomotion. This fluctuation may provide a new MR imaging technique that would detect arteriolar vasomotion and hence perfusion.

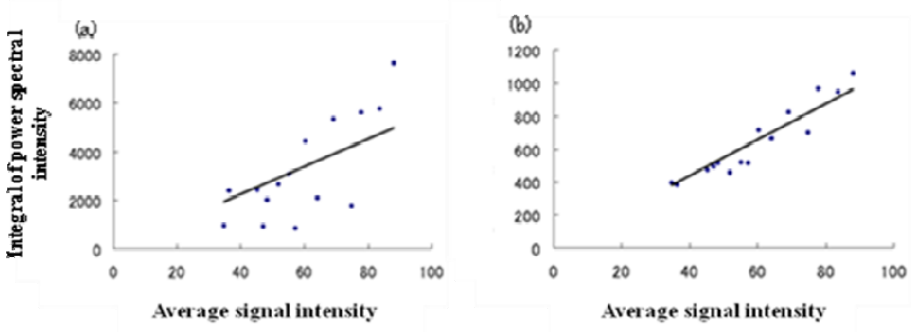

Figure 1. Average signal intensity versus integral of the power spectral of the low-frequency (a) and respiratory components (b) of 3 volunteers. Data of 1 volunteer was removed because turbulence was observed in the sagittal sinus.

References

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