Evaluation of respiratory fluctuation in cerebral venous blood oxygenation for diagnosis of arteriolar function

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Target audience

MR Physicist, Neuroradiologist

Purpose

Cerebral venous blood oxygenation in the resting state fluctuates because of neuronal activity and arteriolar vasomotion driven by respiratory partial arterial pressure of carbon dioxide ($PaCO_2$) changes. The fluctuation of cerebral venous blood oxygenation at respiratory frequency reflects arteriolar vasomotor function which is an early sign of dementia[1)]. In order to obtain the respiratory fluctuation of cerebral venous blood oxygenation in sagittal sinus, we developed a method to differentiate spin-echo EPI signal fluctuations of the sagittal sinus into velocity and blood oxygenation fluctuations[2)]. However, the turbulence caused by the flow from confluent venous vessels and arachnoid granulations in the sinus prevents the proper measurement of the fluctuation of blood oxygenation. We improved our method to find the best position in the sagittal sinus for precise measurement by using blood velocity mapping, and first evaluated respiratory fluctuation of blood oxygenation in healthy volunteers.

Materials and Methods

A single slice perpendicular to the superior sagittal sinus at 3 different location was imaged at every 250 ms for 45 s by using a spin-echo EPI (TE = 30 ms) with a surface coil under a 1.5T MRI for 5 male volunteers. This imaging was performed with varying slice thickness (7, 9, 11, 13, 15 mm). The linearity between the average signal intensity of the sagittal sinus during the 45 s and the slice thickness was evaluated by the determination coefficient (R^2) of the regression line. Blood velocity mapping of the superior sagittal sinus was performed by imaging using 2D fast phase contrast (VENC = 40 cm/s) synchronized with the pulsation at systole. At each location on velocity mapping where SE-EPI performed, the velocity derivative along flow direction was calculated. Then, R^2 versus the velocity derivative at each location was plotted. The time courses of MR signal of SE-EPI at the location with high precision were Fourier-transformed and the integrated power spectral intensities (PSI) of respiratory (0.2–0.5 Hz) frequency ranges were obtained. PSI versus average signal intensity was plotted and regression line was drawn. The MR signal can be written as

$$S = C \cdot e^{-R_2 \cdot TE} \qquad (1).$$

Where C is the proportional constant, R_2 is a relaxation rate and can be given as

$$R_2 = C_1 \cdot (1 - Y)^2 + C_2 \qquad (2)$$

Where C_1、C_2 are the constants and Y is the blood oxygenation. Using Eq.1 and 2, the following equation is obtained as

$$\frac{\Delta S}{S} = 2C \cdot (1 - Y) \cdot TE \cdot \Delta Y \qquad (3)$$

The $\frac{\Delta S}{S}$ is the quotient of signal fluctuation and averaged signal intensity which can be calculated from the slop of the regression line; the value of $2C\,(1-Y)$is 14[3)]. The fluctuation of blood oxygenation (ΔY) can be calculated.

Results

The R^2 got larger when absolute value of velocity derivative got smaller (Fig.1). At the range of [-0.12 0.12] for velocity derivative, the R^2 was higher than 0.77 meanwhile the significant correlation for average signal intensity and slice thickness was obtained ($p<0.05$). All the PSI and average signal intensity from the location where the velocity derivative was in the range of [-0.12 0.12] showed a significant correlation ($r = 0.82$, $p<0.05$) (Fig.2). The respiratory fluctuation of blood oxygenation was calculated as 8%.

Discussion

When there is no turbulence in the sagittal sinus at the imaged location, the average signal intensity should be in proportional to slice thickness theoretically. At the range of [-0.12 0.12] for velocity derivative, average signal intensity and slice thickness showed a significant correlation ($p<0.05$). Therefore the precise measurement of oxygenation fluctuation in sagittal sinus can be achieved at the location where velocity derivative was in the range of [-0.12 0.12].The significant correlation of PSI and average signal intensity (Fig.2) shows that venous blood oxygenation clearly fluctuates according to the respiratory frequency. For health volunteers, the respiratory fluctuation of blood oxygenation was calculated as 8% for the first time. This value of blood oxygenation fluctuation reflecting arteriolar vasomotor function may be a new biomarker to diagnose dementia.

Conclusion

Precise measurement of fluctuation of blood oxygenation in sagittal sinus can be achieved by using blood velocity mapping. The cerebral venous oxygenation fluctuates by 8% at respiratory fluctuation in healthy human. This value would be a control value to diagnose arteriolar vasomotor function.

References

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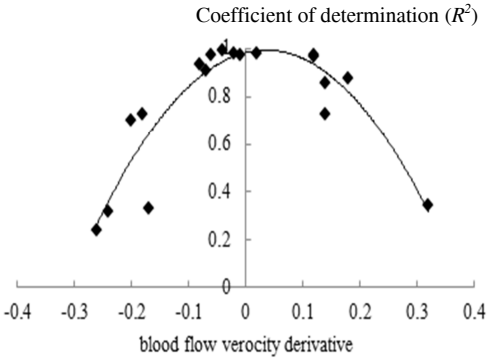

Fig. 1 The relationship of blood flow velocity derivative and the coefficient of determination of the correlation between the average signal intensity and slice thickness. The solid line represents the regression curve.

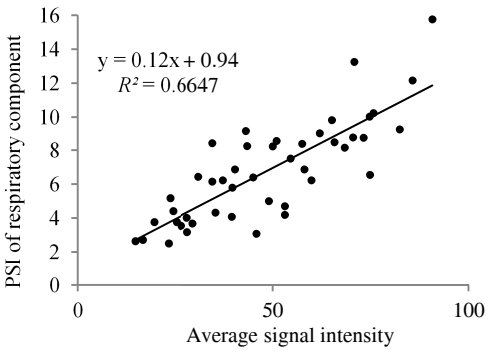

Fig. 2 The relationship of PSI of respiratory component and the average signal intensity. The solid line represents the regression line.