Static and Dynamic Characteristics of Cerebral Blood Flow during the Resting State

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Introduction

There has been growing interest in investigating brain activity "at rest". PET studies showed that resting-state cerebral blood flow (CBF) of the posterior cingulate cortex (PCC), medial prefrontal cortex (MPFC), visual cortex, thalamus and insula are significantly higher than the whole brain average [1]. Functional MRI studies, mostly based on BOLD contrast, demonstrated temporal correlations of the resting signals in specific brain networks [2]. However, these static and dynamic characteristics of resting-state signals have not been systematically studied under a single modality on the same subjects. In this study, we investigated spatial distribution of static (average) CBF and dynamic fluctuations of CBF during the resting state. From the CBF time course measured using an arterial spin labeling (ASL) technique, characteristics of functional integration (functional connectivity) and functional segregation (local synchrony and local fluctuation intensity), as well as the average CBF, were assessed.

Materials and Methods

Data acquisition. Twelve healthy subjects (26.33±6.40 years old, 9 females) were scanned with a pulsed ASL (PASL) sequence based on the flow-sensitive alternating inversion recovery (FAIR) echo-planar imaging (EPI) method on a 3T Siemens MR scanner. Imaging parameters of the PASL sequence were: TI/TR/TE = 1400/2000/33 ms, flip angle = 90°, bandwidth = 4112 Hz/pixel. Ten 6-mm thick AC-PC paralleled oblique slices were prescribed to cover a large part of the default mode network [1] with a 64×64 in-plane matrix at a resolution of 3.44×3.44 mm^2. Twelve minutes of continuous PASL data were acquired for each subject, during which subjects were instructed to keep their eyes closed.

Data analysis. The PASL data were preprocessed using AFNI [3], including slice-timing correction, motion correction, linear detrending, spatial normalization to Talairach space with a resampled resolution of 3×3×3 mm^3 and spatial smoothing with a 6-mm Gaussian kernel. Subsequently, the PASL data were high-pass filtered at the cutting frequency of 0.125 Hz to extract high-frequency perfusion components and demodulated to low frequency [4] using MATLAB. ICA group analysis was performed using MELODIC in FSL to remove components related to cerebrospinal fluid (CSF) and blood vessels, and therefore to reduce potential contaminations from physiological noise. After the ICA denoising, an average CBF map was calculated for each subject. The static CBF map of each subject was divided by the mean CBF values of that subject in a brain mask [1], which was the intersection of scanned brain regions of all subjects. Voxel-wise one-sided one-sample *t*-test against 1 was performed on the normalized CBF maps to reveal spatial distribution of CBF significantly higher than the mean CBF in the mask. To evaluate the dynamic characteristics of CBF, three approaches were applied to the PASL data after ICA denoising. Seed-based correlation analysis was employed to examine the temporal relationship between PCC and other brain regions. The correlation values were converted to *z*-scores, one-sample *t*-tests were then performed on *z* maps to determine whether the *z*-scores were significantly differed from zero. Regional Homogeneity (ReHo) [5] was used to measure the similarity of time series between a given voxel and those of its neighbors, reflecting local synchrony. Amplitude of low frequency fluctuations (ALFF) [6] was utilized to detect the regional intensity of spontaneous fluctuations (0 - 0.125 Hz) in the PASL signal. Similar to the static CBF map, ReHo and ALFF maps of each subject were divided by that subject's mean ReHo and ALFF values, respectively, and then one-sided one-sample *t*-test against 1 were performed on the normalized maps. Finally, spatial correlations were calculated between these statistical *t* maps to measure spatial similarity.

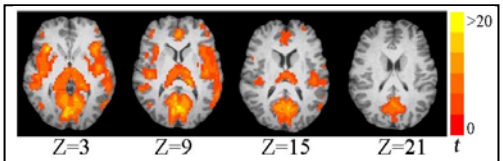

Fig. 1. Static characteristics of CBF signal. Statistical *t* map of CBF, $p < 0.001$, corrected.

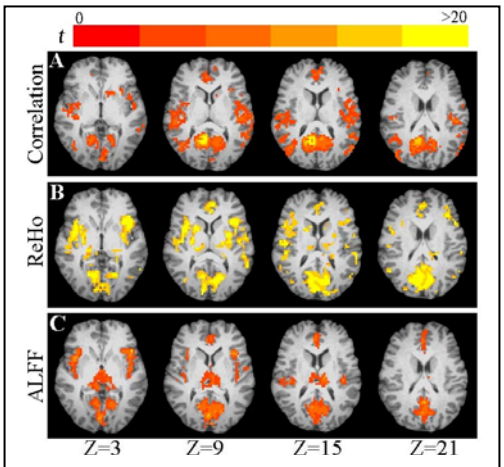

Fig. 2. Dynamic characteristics of CBF signal. Statistical *t* maps of PCC-based correlation (A, $p < 0.001$, corrected), ReHo (B, $p < 0.0001$, corrected) and ALFF (C, $p < 0.001$, corrected).

Results and Discussion

A static CBF *t* map is shown in Fig.1, which is very similar to previous PET results [1]. Static CBF of visual cortex, PCC, MPFC, thalamus and insula are significantly higher than brain mean CBF, suggesting higher metabolism in these brain regions during resting. Dynamic characteristics of resting state CBF are shown in Fig.2. Significant correlations between PCC and MPFC, inferior parietal lobe and insula are shown (Fig.2A), similar to those seen in previous BOLD-based connectivity studies. ReHo (measuring regional temporal synchrony) and ALFF (measuring local fluctuation intensity) maps (Fig.2B and 2C) both show significance in brain regions similar to those seen in the correlation map and static CBF map. The spatial correlation coefficients between *t* maps of average CBF and indices of dynamic PASL data (PCC-based correlation, ReHo and ALFF) are 0.40, 0.47 and 0.72 ($p < 0.05$), respectively. The similar spatial distributions between the static CBF and the indices of dynamic CBF fluctuations suggest that the default mode network is a unique system in the brain, characterized as having a high blood flow baseline (or metabolism), high synchrony between the components in the network, and high local synchrony and local fluctuation amplitude. The high energy consumption of the default mode circuit in the brain, the highest energy-consuming organ suggests the importance of the network and supports further investigation on its functions.

References

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