Physiological Magnetic Resonance Imaging (PMRI)

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Introduction

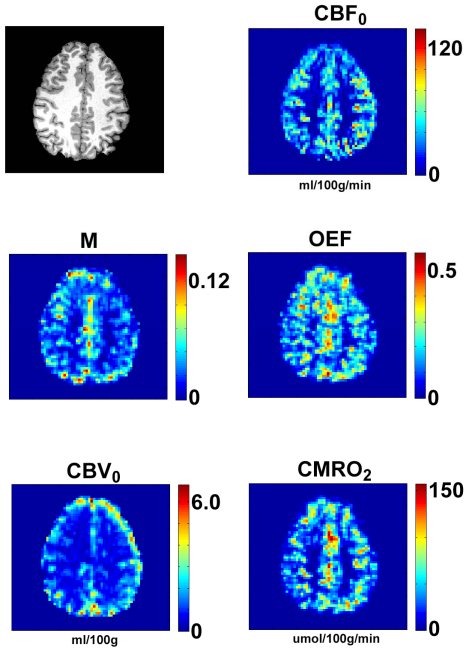
Most functional MRI studies suffer from being non-quantitative. Either only a single physiological parameter is measured or only relative changes in a parameter are obtained during the performance of a task or stimulus. Here we present a short, robust paradigm for obtaining whole brain images of the theoretical BOLD maximum (*M*), resting CBF, CBV, cerebrovascular response (CVR), arterial arrival time (AAT), oxygen extraction fraction (OEF) and $CMRO_2$. The technique uses a combined hyperoxia and hypercapnia paradigm with a modified multi-TI pseudo-continuous ASL (PCASL) sequence.

Theory & Methods

Most BOLD calibration techniques are based on the estimation of the maximum theoretical BOLD signal change *M*. Methods of determining *M* include using a hypercapnia stimulus[1] or using a hyperoxia stimulus[2] to increase the venous saturation. If both of these calibration methods below are combined, then the resultant data can be used to determine the OEF, as well as a variety of other physiological parameters.

$$\text{Hypercapnia: } \frac{\Delta BOLD}{BOLD_0} = M\left(1-\left(\frac{CBF}{CBF_0}\right)^{\alpha-\beta}\right), \qquad \text{Hyperoxia: } \frac{\Delta BOLD}{BOLD_0} = M\left(1-\left(\frac{[dHb]}{[dHb]_0}\right)^{\beta}\right)$$

Where α=0.2 is the Grubb coefficient for veins, and β=1.3 at 3T. 10 healthy volunteers were scanned on a 3T Siemens Verio with a 32-channel head coil, using a PCASL sequence[3] with a gradient-echo EPI readout (TR=3.91s, TE=22ms, 6/8 k-space) which had been modified to increase the amount of BOLD contrast by increasing the TE and removing pre-saturation pulses. Twenty-six axial slices in ascending order (4×4×5.5mm voxels, 0.5mm inter-slice gap) were prescribed. Labelling duration was 1.4 sec and five different post labelling delay times were adopted. The 18 minute paradigm consisted of delivering, via a sealed facemask, 2x2 minute blocks of 4% CO2 in air and 2x3 minute blocks of 50% oxygen, balance nitrogen. Each hypercapnia block was followed by 1 minute of normal air, and each hyperoxia block by 2 minutes of normal air. BOLD-weighted images were produced by averaging the tag and control images, each image was averaged with both its predecessor and subsequent image to maintain the temporal resolution. The multi post-labelling delay ASL data from the normal air and hyperoxia periods were used to produce a resting CBF image and an arterial arrival time image, by fitting the data to the ASL kinetic model[5]. The BOLD signal changes and the relative CBF changes during the hypercapnia periods relative to normal air periods were used to produce an estimate of the theoretical maximum BOLD value *M*[1,6]. The OEF was then calculated using the hyperoxia calibration equation[2] which has unknowns of OEF and *M*, by using the *M* calculated from the hypercapnia epochs. The $CMRO_2$ was then calculated from the product of OEF and CBF. The cerebrovascular reactivity can be calculated from the perfusion response to hypercapnia and the measured end-tidal values. Finally, the BOLD data during the hyperoxia and normal air phases were used to produce resting CBV maps using the hyperoxia contrast method[4]. Two subjects withdrew because of claustrophobia, and 3 subjects had problems with the facemask leaking.



Results

Group averaged values for the 5 subjects who completed the paradigm are shown in the table below. AAT could not be included as inappropriate inversion times were used. The figure shows the images calculated for a single slice from a representative subject, and an anatomical image for comparison.

Discussion and Conclusions

The technique introduced here shows promise as a means of producing clinically relevant cerebral metabolic and physiological data from single subjects without contrast agents. The means of delivering the gases needs careful attention to prevent leaks. This level of diagnostic imaging information was previously only available from O-15 PET.

	CBF (mL/100g/min)	*M*	*OEF*	*$CMRO_2$ (μmol/100g/min)*	*CVR (%ΔCBF/mmHg)*	*CBVv (mL/100g)*
Mean ± s.d.	41.3±8.3	0.067±0.01	0.35±0.05	146±30	5.15±1.1	2.86±0.65

References

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