Improved Quantitative Measurement of Oxygen Extraction Fraction at 3T

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Synopsis

The oxygen extraction fraction (OEF) is an important indicator of brain tissue viability. The present study uses the SPGR and GESSE (multi-echo gradient and spin echo imaging) sequences to acquire images from normal volunteers. A theoretical model describing signal dephasing in the presence of deoxyhemoglobin was used to estimate OEF and cerebral blood volume (CBV). The SPGR sequence was used to correct for signal attenuation due to inhomogeneities in the large OEF voxels.

Method

Eight normal volunteers were imaged using a Bruker MedSpec S300 3T MRI scanner. The imaging parameters were as follows: (SPGR) TR/TEs = 25/10ms, 256x220x180 of voxel size =1x1x1 mm^3; (GESSE) TEg = 2.6656 ms, 31 echoes, 27 slices of voxel size 1.7x1.7x5 mm^3. The GESSE sequence is used to estimate the OEF by fitting to the model proposed by [1]. Signal attenuation due to inhomogeneities in the large OEF voxels needs to be compensated for before this fit. The method of [2] assumes a constant field gradient across each voxel, hence the signal loss can be expressed as $\mathrm{sinc}(\gamma \cdot \Delta B \cdot t/2)$. In our method the attenuation at time TEs is directly calculated from real space complex SPGR image as the ratio, $R = |(\Sigma Re, \Sigma Im)| / \Sigma|(Re, Im)|$ summed over the group of SPGR voxels corresponding to a GESSE voxel [3], approximately 2x2x5 voxels contribute. The value of R depends on the phase differences between the contributing voxels and is a numerical integration independent of assumptions about the local field gradients. At times other than TEs the relative phases between contributing voxels are scaled appropriately. In this way the signal attenuation for each of the 31 the gradient echoes the GESSE sequence were found. A four parameter fit was then applied to the corrected GESSE images. The OEF estimation is based on the theoretical model that was proposed by [1]. In this model the MR signal suffers dephasing from deoxyhemoglobin in capillaries which can be modeled by paramagnetic particles in randomly oriented cylinders, and is hence given by:

$$S(t) = \rho(1-\lambda)\exp[-\lambda \cdot f_c(\delta\omega \cdot t)] \quad \text{with} \quad f_c(x) = \frac{1}{3} \cdot \int_0^1 (2+u) \cdot \sqrt{(1-u)}\, \frac{1 - J_o(\frac{3}{2} \cdot x \cdot u)}{u^2} \cdot du \qquad (1),$$

where ρ is the proton spin density, λ is CBV, δω is the frequency shift induced by deoxyhemoglobin, t is the time measured from the spin echo and J_0 is the zero order Bessel function. The OEF is then calculated from δω using the expression: $\delta\omega = \gamma \cdot 4/3 \cdot \pi \cdot \Delta\chi_0 \cdot Hct \cdot OEF \cdot B_0$ (2). Where γ is the gyromagnetic ratio, $\Delta\chi_0$ is the susceptibility difference between fully oxygenated and fully deoxygenated blood, Hct is the fractional hematocrit and B_0 is the main magnetic field. A four parameter fit was applied to the corrected data to simultaneously obtain the parameters T_2, ρ, λ + δω and λ - δω in Equation (1). The function f_c was accurately pre-calculated and quadratic interpolation was used in the fitting program. T_2 decay and diffusion effect cause a reduction of the SNR in the data for later echo times [4]. This effect was allowed for in our fitting routine by increasing the standard error on data points as a function of echo time. After applying the fitting routines, the chi-square test is used to measure the goodness of the fit to the data, voxels having large chi-squared values were excluded from the averages shown in Table 1.

Results

Fig 1(a) shows a slice of raw data from GESSE sequence, (b) shows unwrapped phase map in SPGR space (c) shows a derived attenuation map at the last echo from the same slice, (d) shows the fitted OEF map for the same slice. Table 1 shows the mean OEF taken from white and grey matter from the whole brain of subjects.

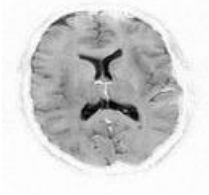

Fig 1 (a)

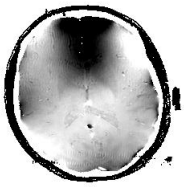

Fig 1 (b)

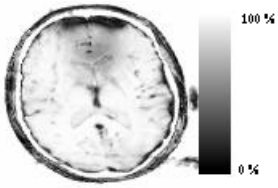

Fig 1 (c)

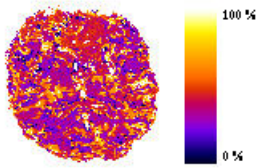

Fig 1 (d)

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Subject 7	Subject 8
White matter	0.39	0.4	0.36	0.44	0.41	0.37	0.4	0.42
Grey matter	0.44	0.43	0.42	0.44	0.43	0.41	0.42	0.43

Table 1

Discussion

The unwrapped phase map shows very fine detail of the brain. The attenuation is about 5% in the white and grey matter regions at the last echoes. Some details of the brain's anatomy can be clearly seen in these maps. The OEF values obtained are close to expected value of 40% for normal volunteers. The average OEF value for grey matter seems to be less variable in between subjects. The use of SPRG image data has improved the accuracy of our results compared to our previous study [5].

References

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