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Simultaneous Mapping of Activation - Induced ΔR2* and ΔR2 in the Human Brain Using a Combined Gradient-Echo and Spin-Echo EPI Pulse Sequence

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PURPOSE:

Maps of activation induced changes in transverse relaxation rates R2* and R2 in the human brain are simultaneously created using a time-course collection of T2 and T2*-weighted image pairs of the same plane obtained with a combined gradient-echo and spin-echo echo planar imaging (EPI) sequence. The two directly registered maps are then used to create a ΔR2*/ΔR2 map, revealing useful information regarding the predominant vascular radii from which the brain function - related blood oxygenation level dependent (BOLD) contrast arises.

INTRODUCTION:

As paramagnetic deoxyhemoglobin in the vasculature is decreased by neuronally triggered vasodilatation, static (T2*-related) and diffusive (T2-related) spin coherence increases. Changes in ΔR2 and ΔR2* can be obtained from observed signal changes in spin-echo and gradient-echo sequences respectively by: ΔR2(*) = -ln(Sa/Sr)/TE, in which Sa and Sr are the respective active and resting signals (1).

Biophysical models (2, 3) suggest that, at a given blood volume, blood oxygenation, Bo, and TE, the ratio ΔR2*/ΔR2 is dependent upon the water diffusion coefficient and vessel radius. At a given diffusion coefficient, ΔR2*/ΔR2 increases with increasing radius. ΔR2 has a maximum at a diffusion distance about equal to vessel radius, and ΔR2* increases continuously with increasing radius.

One goal of magnetic resonance functional neuroimaging is to be able to associate the distribution of the induced MR signal change with the actual cortical distribution of increased neuronal activity. The more extensive the activated cortical region, the more likely it is that large draining vessels will increase in oxygenation, thus reducing the functional resolution.

In addition, the primary vascular scale contributing to BOLD contrast may vary significantly with relative blood oxygenation and the distribution of vessel sizes in each pixel, necessitating the need to create a pixel by pixel map of ΔR2*/ΔR2 to assess such spatially variant factors.

Due to subject motion and the variation in magnitude and spatial extent of activation induced signal enhancement between trials, the use of successive spin-echo and gradient-echo sequences in separate trials compromises the accuracy of measured relative ΔR2* and ΔR2 values. It is therefore necessary to simultaneously obtain spin-echo and gradient-echo time-course series to create spatially and temporally registered ΔR2 and ΔR2* maps.

METHODS:

We use, on a 1.5 Tesla Signa magnet equipped with an inserted three-axis local gradient coil, a combined single-shot 64 x 64 resolution gradient-echo and spin-echo EPI sequence. Figure 1 illustrates the sequence, (with 8 x 8 resolution for illustrative clarity). TR = 1 to 2 sec. Slice thickness = 4 to 10 mm. FOV=24 cm. Phase correction is performed using a two-line internal reference for each image. ΔR2 and ΔR2* are independent of TE in the ranges used (4). During the time-course collection of the image pairs, a brain activation task is given periodically. Images during activation and rest are averaged to create Sa and Sr maps. After a threshold is applied to eliminate non-activated regions, maps of ΔR2*, ΔR2 and ΔR2*/ΔR2 are created.

In addition to mapping the relative relaxation values spatially, it is possible that examination of the ΔR2 and ΔR2* time courses will reveal additional information about the relative hemodynamic responses in different vessel sizes.

RESULTS:

To demonstrate the technique, a bilateral finger movement experiment was performed in which a time course of gradient-echo (TE = 30ms) and a spin-echo (TE = 110ms) image pairs were collected. The values of ΔR2*, ΔR2, and ΔR2*/ΔR2 were calculated for the pixels in the primary motor cortices showing activation, and mapped directly onto an anatomical image. The maximum values of ΔR2, ΔR2*, and ΔR2*/ΔR2 were in different areas. Averaging across the activated pixels, we found that ΔR2* = -0.49 ± 0.04 s^{-1}, ΔR2 = -0.16 ± 0.01 s^{-1}, and ΔR2*/ΔR2 = 3.57 ± 0.27. Figure 2 shows simultaneously-obtained time courses of ΔR2* and ΔR2 from the same pixel in the motor cortex during cyclic activation.

CONCLUSIONS:

We have demonstrated the spatial variation of ΔR2*/ΔR2 in activated brain regions by the use of a combined gradient-echo and spin-echo EPI pulse sequence which simultaneously obtains directly registered pairs of T2* and T2-weighted images. This information provides a useful correlate to biophysical models and may be the key to identifying the inhomogeneous distributions of blood volume, blood oxygenation, and vessel radii across pixels showing brain activation induced BOLD contrast.

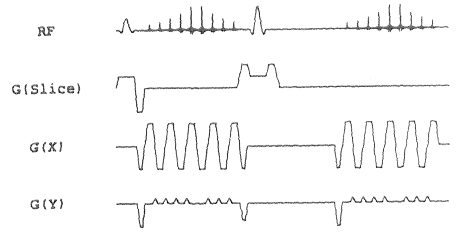

Figure 1

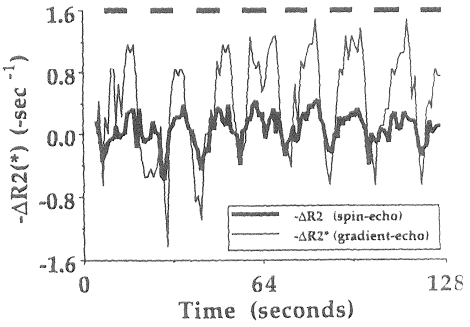

Figure 2

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