Simultaneous Assessment of Blood Oxygenation and Flow Contributions to Activation Induced Signal Changes in the Human Brain

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PURPOSE:

A combined spin-echo (SE) and gradient-echo (GE) echo planar imaging (EPI) sequence, (SEGE-EPI), is used to simultaneously obtain spatially registered measurements of R2, R2*, and TE = 0 signal values during rest and neuronal activation. Using this information, the contributions of blood oxygenation level dependent (BOLD) and flow (non-susceptibility) dependent signal changes are characterized.

INTRODUCTION:

Brain activation causes an increase in blood flow which decreases the apparent T1 (1) in addition decreasing the amount of paramagnetic deoxyhemoglogin in the vasculature, which decreases R2' and R2 (2,3). The effect on the active and resting MR signal, Sa and Sr, respectively, may be approximated by:

$$Sa = Ma\, e^{-(R2a\, TE)} \textit{ and } Sr = Mr\, e^{-(R2r\, TE)}$$

Steady state magnetizations, Ma and Mr, are altered by changes in proton density and/or T1. R2a and R2r are respective relaxation rates (R2 or R2*). These relative effects were simultaneously analyzed by echo-planar collection of highly sampled R2 and R2* decay curves during rest and activation. Extrapolation of the decay curves to TE=0 allowed for assessment of Ma and Mr. Comparison of ΔR2* and ΔR2 were also made, allowing approximate susceptibility compartment size estimation, using current models (4,5). All measurements and comparisons were made both in a voxel-wise manner and from averaged regions of interest.

METHODS:

Single shot SEGE-EPI of an axial slice through the motor cortex was performed at 1.5 Tesla using a local three-axis gradient coil and a quadrature transmit/receive birdcage rf coil. Resolution was 3.75 x 3.75 x 5 mm^3. Periods of rest and finger tapping were performed while time course series of 20 to 100 sequential R2 and R2* decay curves were obtained using 5 to 100 TE increments per curve. Ma and Mr were calculated by fitting single exponentials to the R2 and R2* decay curves and extrapolating to TE=0.

To show the relative contributions of both flow and susceptibility effects, *measured* signal changes from a SEGE-EPI time course experiment (same ROI) at single TE values were compared with the *calculated* signal changes using: (a) *only* the measured R2 and R2* values (i.e. assuming Ma = Mr) and (b) measured R2 and R2* *and* M values.

RESULTS:

In the study shown, R2 and R2* decay curves were simultaneously obtained from identical regions in motor cortex using 100 TE values: SE TE=100 to 199 ms and GE TE = 25 to 74.5 ms. TR = 1 sec. Activation - induced ΔR2* = -0.812 ± 0.028 (1/s) and ΔR2 = -0.189 ± 0.024 (1/s). Calculated changes at GE TE = 30 ms and SE TE = 110 ms, using *only* measured ΔR2* and ΔR2 were 2.46 ± 0.32% and 2.10 ± 1.51% respectively. Using the calculated Ma and Mr values, the calculated changes of 3.15 ± 0.31% and 2.35 ± 1.55% were closer to the *measured* GE (TE=30) and SE (TE=110) changes of 3.19 ± 0.12% and 2.94 ± 0.15%. This result was found in all of the 5 studies performed. Figure 1 shows percent change vs. TE. The susceptibility effect is shown by the TE dependence and the flow effect is shown by the positive change at TE=0. Figure 2 shows measured and calculated signal differences at all TE values. Calculated differences were obtained using measured values of R2*, R2, and M (arb. units).The relative functional contrasts typically obtained in GE and SE sequences are demonstrated.

CONCLUSIONS:

We demonstrate a method by which susceptibility and apparent T1 contributions to activation - induced signal changes may be simultaneously assessed. The flow related signal changes, while relatively small at TR = 1 sec, are in close agreement with those predicted by Kwong et al (1). The average ΔR2*/ΔR2 ratio of about 4.3 suggests an average susceptibility compartment size on the microvascular scale. Voxel-wise analysis demonstrated significant and spatially heterogeneous changes in R2, R2*, and M with activation.

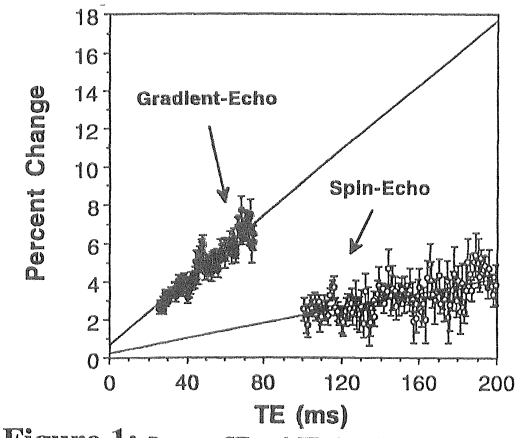

Figure 1: Percent GE and SE signal change vs. TE obtained simultaneously from identical regions in motor cortex

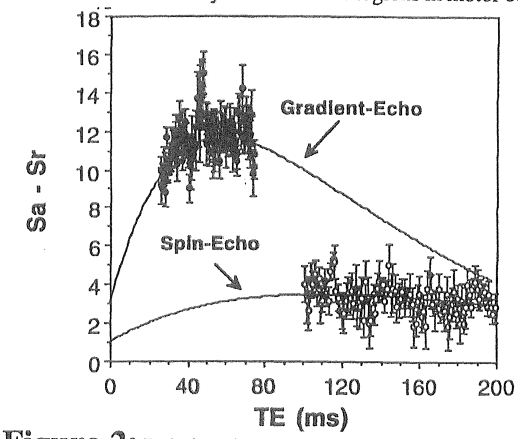

Figure 2: Relative signal differences (arb. units) vs. TE from motor cortex. Solid lines are calculated from measured resting and active R2*, R2 and M values.

REFERENCES:

1.Kwong K.K., Belliveau J.W., Chesler D.A.,et al.*PNAS*, 1992, 89, 5672.
2.Bandettini P.A., Wong E.C., Jesmanowicz A., et al.*12th Ann Sci. Mtg., SMRM.* 1993, p.169.
3.Hoppel B.E., Baker J.R., Weisskoff R.M, et al.*12th Ann.Sci. Mtg., SMRM.* 1993, p.1384.
4.Bandettini P.A.,Wong E.C., Jesmanowicz A., et al. *NMR in Biomedicine* (In Press).
5.Ogawa S., Menon R.S., Tank D.W. et al., *Biophysical J.* 1993, 64, p.803.
6.Kennan R.P., Zhong Z., and Gore J.C., *Magn. Reson. Med.* 1994, 31, 9.