Vessel Size Mapping in Human Brain using a Bolus Injection of Gd-DTPA and Combined GE and SE EPI

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Introduction:

The magnitude of the measured functional MRI blood oxygenation level dependent (BOLD) signal depends on a number of vascular factors, such as the blood volume fraction, vascular compliance, and vessel size. Variations in these factors across different brain regions can often dominate underlying differences in the neuronal activation. Techniques that quantitatively map differences in the vascular structure are therefore important both for clinical applications of identifying pathologies and for an improved understanding of the BOLD signal.

In a recent study, a comparison of spin-echo (SE) and gradient-echo (GE) signal changes before and after an injection of contrast agent was used to map the vessel sizes in a rat brain (1). A similar technique was used in human studies of brain tumors (2). The goal of the current study is to use this technique to map the variation in vessel sizes in the normal human brain, and to compare this vessel size index to BOLD activation.

Instead of the ultrasmall superparamagnetic iron oxide contrast agent used in the animal studies, we used a bolus injection of gadopentetate dimeglumine (Gd-DTPA) (Magnevist, Berlex Lab. Inc). This bolus acts as a strong paramagnetic agent, transiently reducing the MR signal as it passes through the vasculature. The ratio of changes in the GE and SE signal measured during this bolus passage is directly related to the compartment size of the perturber, i.e. the blood vessel. In addition, diffusion weighting was applied on alternate images in the imaging run to reduce possible intra-vascular effects.

Methods:

Multiple series of images of the visual cortex were acquired on 3T General Electric Signa MR system (Waukesha, WI) from 3 subjects using a combined gradient-echo/spin-echo echo-planar sequence. Diffusion-weighting was applied on alternate images. (TR=1s, TE=30ms, FOV=24cm, slice thickness=5mm, matrix size=32x32, 6 slices, 300 volumes/run.) In 4 runs, subjects viewed a contrast-reversing checkerboard for periods of 20s, interleaved with 40s periods of fixation. In 2 runs, subject were at rest, and a bolus of Gd-DTPA (0.1 mmol/kg) was injected (at a rate of 4 ml/s) using a power-injector (Medrad, Inc.) after 1min of scanning.

Activation induced signal changes were obtained by correlating each voxel's signal intensity time course with an ideal reference function (the stimulus timing convolved with a gamma variate). The magnitude of signal changes resulting from an injection of Gd was determined by first averaging the time courses from all brain voxels to obtain an average response to a bolus of Gd, then fitting this average to each voxel. $\Delta R2^*$ and $\Delta R2$ from either activation or Gd were determined by,

$$\Delta R2 = (-1/TE)\ \ln((S_{baseline}+\Delta S)/S_{baseline})$$

Results:

Visual stimulation resulted in MR signal changes of 4.9% and 2.5% for gradient-echo and spin-echo signals, respectively, without diffusion weighting, and 3.0 % and 1.1% with diffusion weighting (see Fig. 1). Bolus injection of Gd-DTPA resulted in a significant reduction in signal (GE: 30-50%, SE: 14-28%). Diffusion weighting reduced the baseline signal, but did not significantly affect the $\Delta R2^*/\Delta R2$ ratio. This suggests that intravascular effects play a minimal role in this vessel size imaging technique. Based on susceptibility contrast models (1,3-5), these measured ratios corresponded to vessel sizes in the activated area from 1µm to 43µm, with an average of 13µm. As expected from previous studies, and shown in Figures 1c,d,e, the largest gradient-echo signal changes corresponded to the largest vessels.

Discussion and Conclusion:

This study demonstrates a robust technique for mapping vessel sizes across the human brain, using a bolus injection of Gd-DTPA contrast agent. The correlation of vessel size with BOLD signal amplitude is improved when the ratio is computed from the Gd injection, instead of the activation. This is because the Gd bolus causes signal changes that are easily detectable, even for spin-echo acquisitions with diffusion weighting. Since this vessel size estimate reflects both arterial and venous structures, it should be considered a complementary technique to other global vascular measures, such as perfusion, the response to hypercapnia, and comparisons of brain activation-induced SE and GE signal changes.

References:

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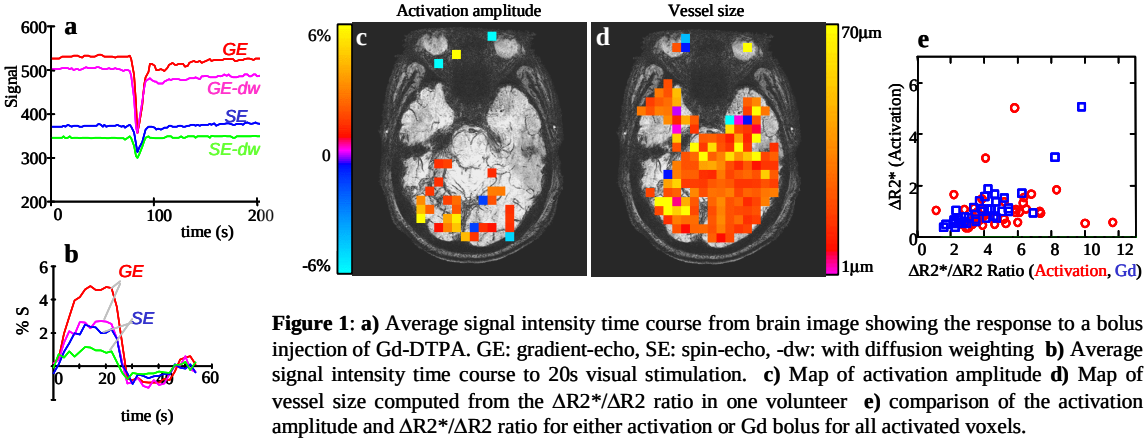

Figure 1: **a)** Average signal intensity time course from brain image showing the response to a bolus injection of Gd-DTPA. GE: gradient-echo, SE: spin-echo, -dw: with diffusion weighting **b)** Average signal intensity time course to 20s visual stimulation. **c)** Map of activation amplitude **d)** Map of vessel size computed from the $\Delta R2^*/\Delta R2$ ratio in one volunteer **e)** comparison of the activation amplitude and $\Delta R2^*/\Delta R2$ ratio for either activation or Gd bolus for all activated voxels.