The contribution of T2* to spin-echo EPI: implications for high-field fMRI studies

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Introduction

While the BOLD signal from the extravascular area around small vessels is generally considered the most localized to neuronal activity, it can easily be obscured by contributions from large vessels or the intravascular space. Theoretical and experimental results advocate the use of high magnetic fields and spin-echo sequences to minimize unwanted contributions [1-4]. In practice, most fMRI studies are performed using an EPI sequence to maintain temporal resolution. Spin-echo EPI has T_2^* weighting as well as T_2 weighting, due to the relatively long gradient echo readout. Furthermore, the effects of T_2^* weighting during the EPI readout in BOLD fMRI are complicated because they depend on the geometry of the activated region. Here we quantitatively measure the relative contributions of T_2^* weighting and T_2 weighting under conditions that are typical for fMRI of the rodent brain at 11.7T.

Methods

BOLD fMRI studies of electrical forepaw stimulation were conducted in 7 rats on an 11.7T scanner [5]. The following image parameters were used: A) conventional gradient echo sequence to measure T_2^* changes, with a TE of 20 ms and a functional paradigm of 8 images during rest-4 images during stimulation-8 images during rest; B) conventional spin echo sequence to measure T_2 changes, same TE and paradigm as A; C) single-shot gradient echo EPI sequence with a 20 ms TE and a paradigm of 120 rest-60 stimulation-120 rest; D) single-shot spin echo EPI sequence with a 30 ms TE and the same paradigm as C. For all sequences, the matrix size was 64 x 64, FOV 1.92 cm, bandwidth 200 kHz, TR 0.5 s, and slice thickness 2 mm. Total EPI readout time was 20 ms. Average percent change during activation was measured in the primary somatosensory cortex and a draining vein for the SE and GE sequences. Due to the short acquisition times used for these images (320 μs/line), signal changes were assumed to be due purely to T_2 and T_2^* weighting, respectively. The change in T_2 and T_2^* during activation was derived from these images and combined with previously measured baseline T_2 and T_2^* values (38 and 23 ms) to calculate the signal change expected with SE-EPI and GE-EPI sequences. This calculation was performed using a program that applied the Bloch equations for an EPI sequence to a numerical model of a rat brain that had a homogeneous activation over an area roughly equal to the activated area in a typical fMRI image. The results were compared to measured values. Calculations were run again with the T_2^* change set to zero to determine what proportion of the SE-EPI signal was due to T_2 weighting.

Results

Figure 1 shows typical activation maps obtained with the four sequences. Figure 2 shows average percent signal changes obtained with each sequence for somatosensory cortex and a draining vein. The conventional GE sequence gave a 9.7 ± 4.8% signal change, corresponding to a 2.7 ms increase in T_2^*. The conventional SE sequence gave a 6.2 ± 2.8% signal change, corresponding to a T_2 increase of 4.9 ms. Simulations gave a value of 7.1% for GE-EPI and 8.6% for SE-EPI, in good agreement with measured values of 7.7 ± 3.5% (GE-EPI) and 9.4 ± 4.7% (SE-EPI). Eliminating the T_2^* weighting reduces the SE-EPI change to 6.2%, indicating 28% of the signal is due to T_2^* with the parameters used. Increasing the echo time to 40 ms gave a 12.0% change, 22% of which is due to T_2^*. Increasing the acquisition time to 32 ms gave 8.2% change, 45% of which is due to T_2^*. Using parameters measured in the draining vein, simulations give a value of 11.7% for GE-EPI and 6.9% for SE-EPI, compared to measured values of 8.6 ± 8.4% and 7.2 ± 7.9%. Eliminating the T_2^* weighting reduces the change to 3% for SE-EPI, so that 57% of the signal change is due to T_2^* weighting.

Discussion

Simulated values corresponded well with measured values for the somatosensory cortex. The change in T_2^* during activation makes a significant contribution to the SE-EPI signal. This effect can be reduced by shortening the acquisition time but at the expense of SNR. In the draining veins, the simulated response for GE-EPI does not match the measured value as well as in the cortex, probably due to the difficulty in obtaining accurate measurements in the vein because of partial volume effects. However, the finding that approximately 60% of the SE-EPI signal from the draining vein is due to T_2^* effects accounts for the persistent appearance of large vessels in SE-EPI images acquired at 11.7T [6].

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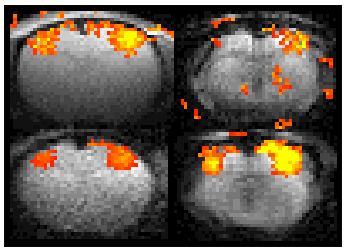

Figure 1 (left). SE (top left), GE (top right), SE-EPI (bottom left) and GE-EPI (bottom right) images showing activation during forepaw stimulation.

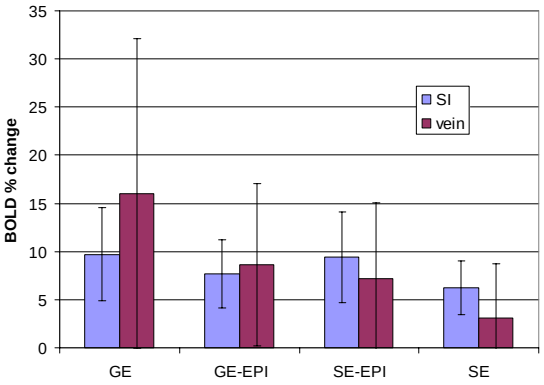

Figure 2 (right). Average percent change during stimulation in the primary somatosensory cortex and a draining vein in the GE, GE-EPI, SE-EPI, and SE images.