Inferring CBV Changes Using A Single-Shot Half k-Space Stimulated Echo Sequence—Preliminary SE-fMRI Results with a Rat Whisker-Barrel Model at 3T

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Introduction: A single-shot, half k-space stimulated echo pulse sequence with diffusion weighting has been developed that has short TE and is insensitive to in-flow effects. It refocuses susceptibility-gradient-induced static spin de-phasing since every k-space line is a spin echo. As a result, the BOLD effect is minimized. This sequence was used for fMRI experiments in rat whisker-barrel cortex. Negative correlation signals were found that are tentatively attributed to spin density decreases due to increased blood volume.

Materials and Methods: The pulse sequence, Fig. 1, is an extension of one shown in Ref. 1. The key features are:

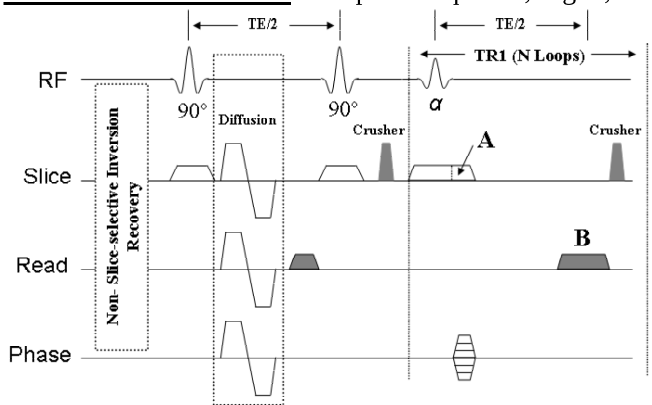

Fig. 1. ***A*** is the rewinding gradient. Its functions are two-fold. i) It refocuses the phase dispersions during the first and the second 90 degree pulses so that the stimulated echo can be generated in ***B***. ii) It de-phases the FID magnetizations excited by the α pulse. This effectively diminishes the inflow spins. As a result, the inflow effect is minimal in fMRI time courses even though TE is short. The flip angles (α) were varied for improved PSF and SNR. TR1 is repeated for N times (N = 36). Either diffusion or inversion recovery (not both) was applied.

1) The rewinding gradient ***A*** not only refocuses the phase dispersions during the first and the second 90° pulses so that the stimulated echo is generated in section **B**, but also de-phases FID signals that are excited by the α pulse. Thus, the inflow effect is minimal although both TR1 and TE are short.
2) Crusher gradients suppress residual spin coherence from previous excitations, which would otherwise lead to band artifacts.
3) The signal intensity at the *n*th k-space line is:

$$S(n) = S_0 e^{-(n \cdot TR1)/T1} \cos^n(\alpha),$$

where S_0 is the signal intensity of the first k-space line, and α is the flip angle of the α pulse. The SNR and *y*-axis point-spread function (PSF) are strongly limited by α, n, and TR1.We employed partial k-space (4 over-scan lines) with a central-out k-space trajectory and variable flip angles (α). The first 4 lines had higher flip angles for better SNR, while the other flip angles were lower for improved PSF.
4) Signal decay due to $\cos^n(\alpha)$ in the k_y direction was corrected line-by-line for improved PSF.
5) Bi-polar gradients were applied between the first and second 90° pulses for uniform diffusion weightings of each k-space line. In preliminary studies, non-slice-selective inversion recovery (15 ms sech pulse) was applied (diffusion was off).

fMRI Experiment: A 3T Biospec 30/60 scanner equipped with local gradient coil and RF coils was used. Data were acquired from three α-chloralose-anesthetized rats under mechanical ventilation (2). Scan parameters: TR= 5 s, FOV = 3.5 cm, matrix size = 64×64, TE = 18 ms (diffusion: b = 50 or 89 s/mm^2, T_{diff} = 5 ms), TE = 8 ms (no diffusion). Paradigm: (100 s off + 100 s on) × 3 cycles + 50 s off. Experiments were repeated 3–4 times and data were averaged to improve the SNR.

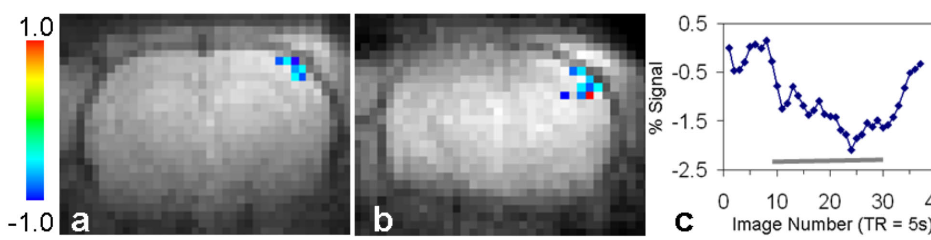

Fig. 2. **a** and **b**: cross-correlation maps from two rats. **c**: averaged response.

Results: Figures 2a and b show negative correlation maps from 2 rats with averaged fractional fMRI signal shown in Fig. 2c. The averaged plateau response was about -1.5%. Another rat did not show significant negative correlation. However BOLD response was also low in that animal when scanned using a regular GE-EPI sequence.

Discussion: 1) With spin echo acquisition at short TE and low b value (50 s/mm^2), the intravascular BOLD signal disappears primarily because of phase cancellation in flowing spins rather than diffusion. Diffusion-induced signal loss is about 14% assuming a water diffusion coefficient of 3×10^{-3} mm^2/s. Phase accumulation of flowing spins is: $\varphi = \gamma \cdot \int G_{xyz}(t) \cdot v(t) \cdot t\, dt$. We estimate φ = 360° for v = 0.6~0.9 cm/s in this sequence. **2)** The negative signal may be due to decreased spin density resulting from increased blood volume (3), since both the intra- and extra-vascular BOLD effects and the in-flow effect are minimized in this sequence. If this is true, CBV information can be inferred non-invasively. Further work is needed to confirm this hypothesis. **3)** The sequence does not require precise shimming, which can make it very useful for fMRI at ultra-high field.

References: 1.Finsterbusch J et al. MRM 2002;47:611-5. 2.Lu H et al. MRM 2003;50:1215-22. 3.Lu H et al. MRM 2003;50:263-74.