Functional MRI with an ultra-short echo time sequence

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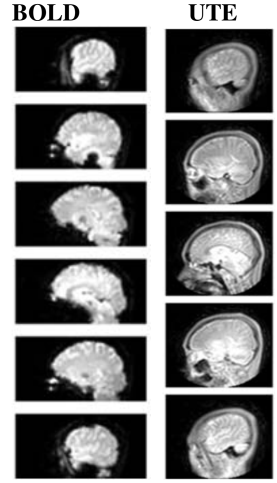
Introduction: The blood oxygen level-dependent (BOLD) fMRI technique is the most popular fMRI method (S. Ogawa, 1993). To provide an optimal BOLD contrast, a gradient-echo MRI sequence with an echo-planar imaging (EPI) acquisition is usually used with a typical echo time (TE) of about 30 ms on a 3 Tesla MRI system (P.A. Bandettini, 1994). BOLD signals usually consist of intravascular and extravascular components from both small and large vessels. Another complication factor for BOLD fMRI signals is that interpretation of results of BOLD fMRI signals is usually complicated and thus signal changes with physiological bases are not fully understood because these signals come from changes in several physiological parameters, such as cerebral blood flow (CBF), cerebral blood volume (CBV), and oxygen consumption rate ($CMRO_2$) (R.B. Buxton and L.R. Frank, 1997). The purpose of this study was to investigate an fMRI technique with an ultra-short TE (UTE) sequence. The UTE-based fMRI signal was obtained with a three-dimensional UTE sequence during visual stimulations with TE=0.15 ms that was about 200 times shorter than that of BOLD or about 67 times shorter than that of signal enhancement by extravascular water protons (SEEP) (P.W. Stroman, 2003).

Materials and Methods: Seventeen young healthy volunteers (7 males, 10 females; mean 25.4±2.1 years; range: 23 - 30 years) were recruited from the local community. Two functional sessions, BOLD and UTE, were included in this study. The paradigm for visual stimulation was used for two conditions. A cross-sign was used for the fixation or baseline condition, but a black-and-white checkerboard was used for the stimulation condition. This alternation was repeated three times for each session. The fMRI study was performed on a 3 Tesla MRI System (Achieva, Philips Medical System) with an 8 channel phase-array SENSE coil. The UTE-based fMRI data with the volume repetition time (TR) of 5000 ms were acquired using the three-dimensional sagittal fast field-echo (FFE) technique with an UTE sequence (J. Rahmer, 2006). The detailed acquisition imaging parameters were: TR=2.2 ms, TE=0.15 ms, field of view (FOV)=230 x 230 x 168 mm, matrix size=64 x 64, voxel size=3.6 x 3.6 x 4 mm^3, slices=42, and SENSE factor=1.5. The excitation for this sequence was optimized with a maximum phase pulse with the flip angle of 10 degree. In addition, axial BOLD fMRI data were also acquired using a two-dimensional gradient-echo EPI sequence for comparisons between UTE-based and BOLD fMRI techniques. Statistical parametric mapping version 8 software (SPM8) was used for data pre-processing and statistical analysis. Two contrast maps, increase and decrease, were generated for each session of UTE-based or BOLD fMRI data. For the group level analysis, the two contrast maps obtained from the individual level analyses were used to investigate the average of all subjects using the one-sample t-test. In addition to voxel-based analyses, regions-of-interest (ROI)-based analysis was performed by using the results of the voxel-based analysis for each subject.

Fig. 1. Raw images for fMRI studies

BOLD **UTE**

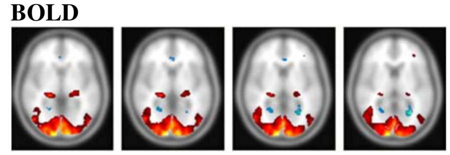


Results : Figure 1 shows sample slices of raw images of BOLD and UTE fMRI experiments obtained from a young female subject. UTE images provide better image quality than BOLD ones, especially in the frontal and temporal areas in the brain. Figure 2 shows the results of the group analysis using the one sample t-test for UTE and BOLD fMRI data. Areas of decreased or increased signals during visual stimulation compared to the baseline signals are overlaid on the standard axial T1 template and are shown with blue or red colors, respectively. The UTE-based method only had voxels with decreased signals with the visual stimulation in the right cuneus and the left lingual gyrus of the occipital lobe. The BOLD method had voxels with both decreased and increased signals during the visual stimulation. The percent differences of signal changes between the two conditions were -0.478±0.367% (mean±SD) obtained from UTE-based data and 1.707±0.869% obtained from BOLD data.

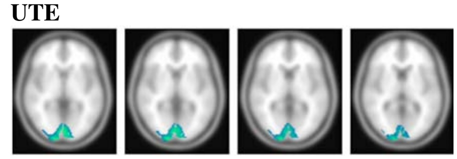
Discussions: In this study, we found a decreased signal in the visual cortex areas of the brain using the UTE-based fMRI acquisition during the period of the visual stimulation. We did not find any significant increases under the visual stimulation condition compared to the baseline condition. However, BOLD fMRI data showed both activation and deactivation with the visual stimulation, as we knew it. The first possible reason of signal alternations in the UTE-based fMRI may be alternations of cerebrospinal fluid (CSF) in the cortical voxels. The second possible reason of signal alternation in the UTE-based fMRI may be alternations of relaxation times of water protons in the cortical voxels. The third possible reason of signal alternations in the UTE-based fMRI may be alternations of local blood volume in the tissue during the stimulation. Therefore, the UTE fMRI may have similar neuronal responses to those from vascular space occupancy (VASO) fMRI technique that is measured the signals of cerebral blood volume (CBV) changes (H. Lu, 2003).

Fig. 2. Results of fMRI with a visual task

BOLD



UTE



Conclusion: We have investigated a new fMRI contrast using an ultra-short echo time sequence. Decreased rather than increased signal changes were observed in the visual cortex areas during the visual stimulation. The UTE-based fMRI methods hould improve spatial localization and provide image data with much lower sensitivity to field inhomogeneities. Therefore, the UTE-based fMRI method offers an alternative to conventional the BOLD fMRI method and can be applied in the neurosciences and clinical populations.

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