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TRFGE 뇌기능 영상

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TRFGE Functional Imaging

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INTRODUCTION

The sensitivity of a gradient echo MR imaging to the susceptibility provides a means to detect tissue oxygenations that are due to the amounts of the paramagnetic deoxyhemoglobin produced in the capillary. Recently, the effects have been exploited to study human brain functions by gradient echo imaging techniques, which is particularly sensitive to the local magnetic susceptibility(1,2). The conventional gradient echo imaging technique which is believed to be sensitive to the T_2^* effect due to the local susceptibility, however, also sensitive to the in-flow effect of arterial as well as venous blood, thereby, complicates the analysis of the functional image data. The signal changes believed to be dependent on the susceptibility during the external stimulation, i.e., the time course signal intensity variation is dependent on the several factors such as RF pulse flip angle α, echo time TE, repetition time TR, and is not only sensitive to T_2^* effect but also extremely sensitive to the in-flow effect from the fresh unsaturated spins entering into the imaging slice(3).

Some of those problems can be overcome by using a new pulse sequence known as tailored radio frequency gradient echo (TRFGE) technique. This proposed TRFGE technique has been used for the venography, and uses the tailored RF pulse which enhances the signal intensity especially when the susceptibility effect exists but suppresses otherwise. As will be reported, using TRFGE technique we have obtained functional imaging mainly due to the susceptibility, not mixed with in-flow effect. The latter is a unique advantage of the TRFGE method compared with the other gradient techniques most of which suffer large in-flow effect thereby complicates the true oxygenation measurement. In this paper, therefore, we have compared and analyzed systematically both CGE and TRFGE by varying flip angle(α), repetition time (TR), and echo time(TE). Experimental results obtained with a 2.0T MR scanner indicate that the observation of the pure susceptibility effect is limited in CGE technique due to the inflow effect, however, with TRFGE technique most of images obtained appear to be free from in-flow effect.

THEORY

Let us assume that the selected slice thickness (z) is larger than the transverse directional resolution (x,y). Therefore, the susceptibility in a voxel is more or less sensitive only to the z-directional inhomogeneity when the gradient echo technique is used for imaging. In an ideal case with no field inhomogeneity, by application of a rectangular slice selection RF pulse (real sinc pulse with no imaginary component), all the spins in the slice will be well-refocused, therefore, result in a large signal. If field inhomogeneity due to the magnetic susceptibility is introduced, i.e., a strong localized field gradient exists within a voxel in the z direction, the resulting spin phase distribution will be incoherent and the resulting signal will be reduced (1,2). If a slice selection RF is designed so that it has a bi-linear phase distribution (from 0 to 2π along z-direction) around the slice center along the slice selection direction the phases of the spins in the normal tissue where no susceptibility effect exists will be totally dephased and become incoherent. In other words the phase distribution generated will be solely determined by the phase distribution of the applied RF pulse (real pulse with non-zero imaginary component), i.e., the resultant phase distribution will be bi-linear, therefore, all the spin phases will be dephased. On the other hand, if the local susceptibility or susceptibility gradient (which usually have a strong localized field gradient) exists the applied bi-linear phase distribution of the RF will partly compensate the phase distribution thereby partially refocusing the spins initially dephased due to the local susceptibility.

Let us first consider the case of local susceptibility imaging. In this case, the phase distribution will become partially

coherent when the tailored RI pulse is applied, since, ideally, an exact half of the spin phase distribution will be compensated provided the linear phase gradient produced by the local susceptibility effect is exactly canceled by the RF phase distribution. In general the signal intensity follows the relation given by

$$S = \left| 2\pi M z_0 \mathrm{sinc}\left(\frac{P_{sus}}{2\pi} z_0\right) * \mathcal{F}^{-1}\left[\exp\left(i\frac{4\pi}{z_0}|z|\right)\right] \right|, \qquad [1]$$

where M and P_{SUS} are the magnetization and the susceptibility phase gradient generated by the local field inhomogeneity, respectively, and * and $\mathcal{F}^{-1}$ represent the convolution and inverse Fourier transform operators, respectively, and $\exp(i\frac{4\pi}{z_0}|z|)$ is the phase term generated by the tailored RF pulse (1,2). The unique feature of this result is that, contrary to the case of normal tissues, the signal intensity will increase proportionally with increasing phase gradient value, i.e., the signal intensity will increase with an increase of the local susceptibility (1,2). Using this fact, susceptibility effect enhanced imaging (using TRFGE technique) can be accomplished.

For functional imaging using the TRFGE sequence, therefore, the signal from the visual cortex would decrease during external stimulation since the oxygenation in the capillary is increasing, thereby decreasing the susceptibility effect. On the other hand, during the rest period, the signal from the visual cortex would increase because of the increased deoxygenation of the capillary. Therefore, the signal changes during the time course by TRFGE-fMRI is basically opposite from that of the CGE-fMRI, i.e., TRFGE-fMRI gives a large signal if susceptibility increases instead of deceasing. Advantage of this reverse characteristic compared with CGE is obvious. For instance, the susceptibility effect alone can be observed without interference from the other background signals such as that from normal tissues. As is known, the signal changes in CGE-fMRI is likely that during the stimulation the signal from the cortex is increasing compared with rest because of the increase of fresh (arterial) blood supply which in effect believed to reduce local susceptibility effect in the conventional gradient echo sequence. The problem with the CGE technique is that both the oxygenation and blood flow are proportional, i.e., the in-flow effect is proportional to the susceptibility decrease. The time course data obtained with the TRFGE sequence is, therefore, not only different, but is opposite in comparison to the CGE sequence.

Furthermore, the obvious advantages of the TRFGE sequence is that the method is insensitive to the in-flow effect, especially to the arterial bloods which are usually fast flow and believed to be primarily responsible for the in-flow effect in the conventional gradient echo imaging. This is because of the fact that the arterial bloods have no susceptibility effect, therefore, spins will be dephased just like normal tissues. Although, the TRFGE technique is still affected by in-flow effect of venous blood, the effect is negligibly small due to the slow velocity of the venous blood. On the contrary, in the conventional gradient echo (CGE) imaging, the signal change is not only affected by the susceptibility but is also affected by the in-flow effect of the blood flow of both arterial and venous bloods. In the CGE sequence, therefore, signals are changing according to the RF flip angle α, TE, and TR, as well as to both susceptibility and in-flow effect. For example, in CGE, the susceptibility contrast increase of echo time, but the signal loss (both susceptibility contrast signal and inflow effect signal) also increases thereby decreasing overall SNR. As has been discussed, this apparent controversy can be overcome by use of the TRFGE technique in which susceptibility contrast is independent of TR and flip angle α as well as TE.

EXPERIMENTAL RESULTS AND DISCUSSIONS

With a 2.0T whole body MRI with a surface coil, a series of experiments using the TRFGE imaging sequence were carried out and compared with the conventional gradient echo(CGE) technique. For the time course study, TR of 35~65ms, TE of 16~35ms, and, RF flip angles of 30°~90° were used in combination to observe the in-flow effect as well as susceptibility effect. In all experiment, 50 continuous axial image sets near the visual cortex were obtained with the photic stimulation applied in imaging from image number 11 to 20, and rest of the images were obtained without stimulation. Visual activation was applied by photic stimulation using 8Hz LED checker board. Imaging time for single 8mm thick slice was about 7 sec.

Figure 1(a) shows the time course data of the signal change obtained using the TRFGE sequence with flip angles (α) ranging from 30° to 90° and repetition times (TR) of 35msec, 55msec, and 65msec in three steps, respectively. For this experiment, to examine the inflow effect, a relatively short echo time TE=16msec was used. As shown in Fig.1(a), in the TRFGE time course data, nearly identical signal variation, independent of the RF flip angle α as well as repetition time TR, suggests that the signal variation is not affected by the in-flow effect(see Fig.1(b) for comparison with CGE results) but probably due to the susceptibility effect. However, as shown in Fig.1(b), in the CGE-time course data, the inflow effect is pronounced as flip angle increases and similar trend is also observed as the repetition time decreases. If, in fact, inflow effect is the dominant factor, these observations are expected in CGE sequence. On the other hand, in CGE sequence, increasing

susceptibility effect should be observable as the flip angle decreases with increasing repetition time as well as echo time. This expected signal change observed in CGE was small even with relatively large TR and small α which believed to be of the susceptibility effect dominant, i.e., overall results appear small and signal to noise ratio found to be poor. Fig.1 is a clear indication of the strong and dominant role of the in-flow effect observed in CGE-fMRI.

In Fig.2, another time course study data obtained by both TRFGE and CGE sequences with varying echo time TE are shown, namely TE of 16msec, 25msec, and 35msec, with varying flip angle α of 90°,50°, and 30°. In an attempt to observe the susceptibility effect, a relatively large repetition time is used, i.e., TR=55msec. As shown in Fig.2(a), again the results obtained by TRFGE sequence suggest that the susceptibility contrast in the TRFGE technique is independent of the TE as expected. However, as shown in Fig.2(b), still pronounced inflow effect is seen in the CGE technique with small TE(=16msec). The signal change at large TE(35msec) is still suspected for some inflow effects. However, the signal change observed could be in large part due to the susceptibility effect. As evidenced from the data, the overall signal decay is clearly visible as TE increases but remains relatively constant, suggesting that the susceptibility contrast is not as strongly affected as the inflow signal shown in Fig.1(b). Therefore, the result of TRFGE sequence is clearly distinguishable from the conventional gradient echo sequence where decrease of the signal is observed with the increase of TE. In short, the TRFGE technique appears to be insensitive to the in-flow effect and the contrast developed seems mainly due to the susceptibility effect produced by the RF pulse rather than TE. This is confirmed in Fig.2(a) where the signal is nearly independent of TE values. The result suggests that the "short echo time" can be used thereby one can eliminate the potential T2 signal decay. It should also be noted that the signal (time course) amplitude variation shown in Fig.2(a) is quiet different from that of data obtained from CGE experiments with similar experimental conditions (see Fig.2(b)). That is, the signal patterns in the case of TRFGE are not only insensitive to the various flow sensitive parameters such as flip angle (α), echo time (TE) and repetition time (TR) but the time course signal decay is much more gradual suggesting that the signal variation is not due to the flow but some from of oxygen metabolism occurring during the photic stimulation.

Consequently, using the conventional gradient echo technique one can observe the signal change that is affected by two factors, i.e., inflow and susceptibility effect. Since the obtained signal intensity or signal to noise ratio is inversely proportional to the TE, it is difficult to increase both the susceptibility contrast as well as signal to noise ratio. The present study confirms that the conventional gradient echo technique contains a substantial amount of inflow effect and, therefore, it is difficult to observe purely quantitative oxygen metabolisms in brain function study. On the other hand, as has been demonstrated and shown, using the tailored RF pulse sequence one can effectively measure the susceptibility contrast which is free from in-flow effect as well as backgrounds. Since the TRFGE sequence effectively suppress the signals from normal tissues which are considered to be not only more sensitive to the susceptibility contrast but also insensitive to the other effects such as the in-flow effect and background signals. The latter eliminates the need of "background subtraction" usually necessary in the conventional fMRI. The TRFGE technique, therefore, could be a suitable method for the "susceptibility only" functional imaging, that is the measurement of the quantitative oxygenation and deoxygenating processes without the interferences from the in-flow effect and backgrounds.(4,5)

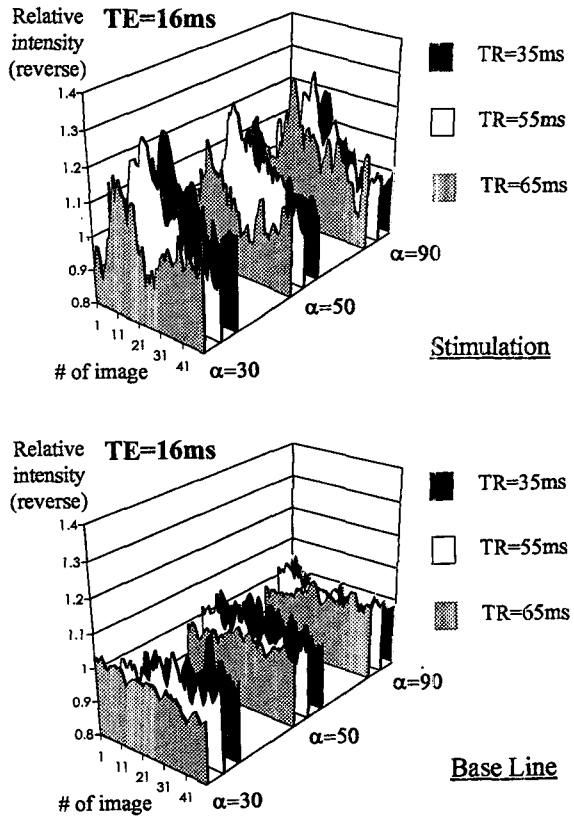

Fig 1. (a)

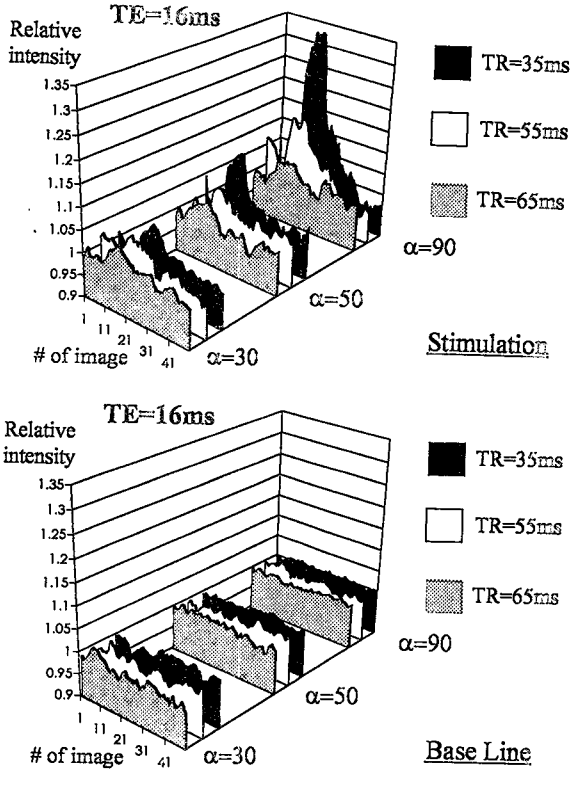

Fig 1. (b)

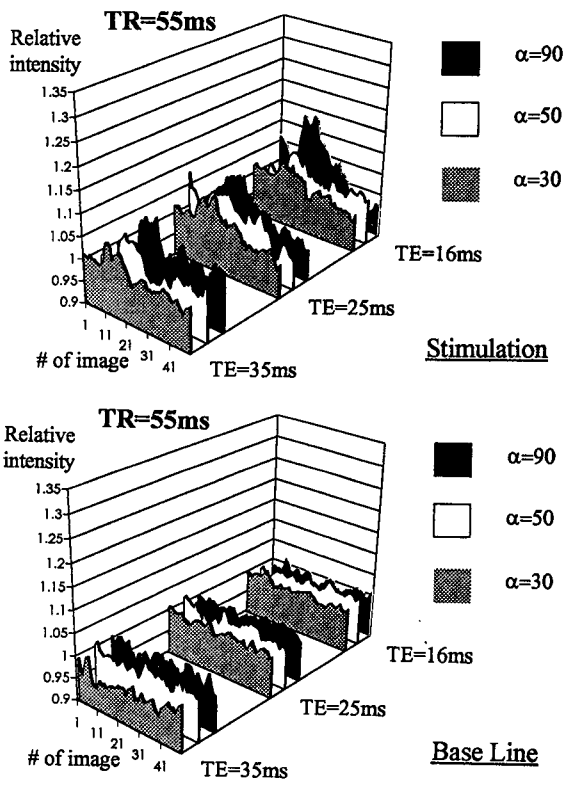

Fig 2. (b)

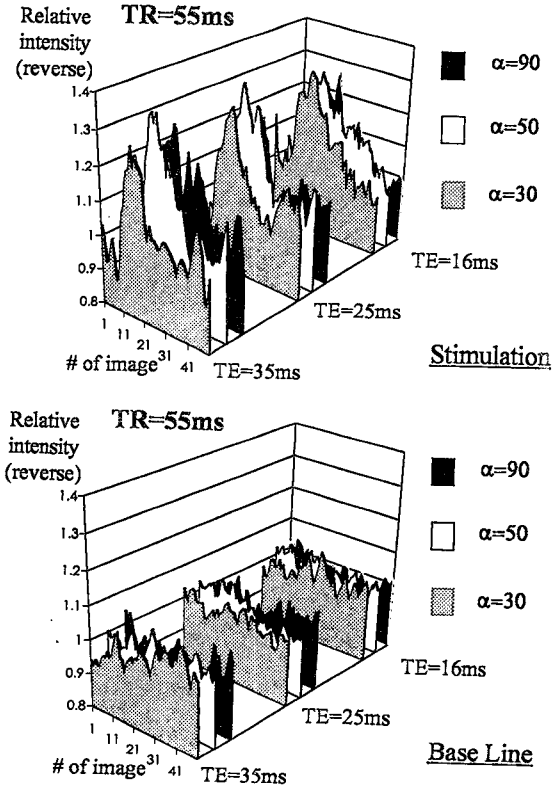

Fig 2. (a)

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FIGURE CAPTIONS

Fig.1. (a) Data obtained by TRFGE sequence with varying the RF flip angle α (30° to 90°)and repetition time (35msec to 65msec) for a fixed TE(16msec). (b) Same time course data obtained by CGE sequence. To examine the inflow effect, relatively short echo time (TE=16msec) was used. For both (a) and (b), the base line data (with no stimulation) are shown for reference at the bottom.

Fig.2. (a) Another TRFGE time course data which were obtained by varying echo time TE from 16msec to 35msec and RF angle α from 30° to 90° for a fixed TR(=55msec). (b) Same as (a) but obtained by CGE technique. Again for both (a) and (b), the base line data are shown for reference at the bottom.