뇌의 기능영상에있어서 자화율효과와 혈류효과 연구

(o)
박종배[1], 정순철[1], 박세혁[1], 노용만[2], 조장희[1]
1. 한국과학기술원 정보및 통신공학과, 2. 대전대학교 전산과

Susceptibility Effects v.s Flow Effects in Functional MRI

J.B.Park[1], S.C.Chung[1], S.H.Park[1], Y.M.Ro[2], Z.H.Cho[1]
1.Dept.of Information and Communication, KAIST, 2.Dept.of Computer Sciences,Taejon University

ABSTRACT

In MR functional imaging, it is shown that the signal change during photic activation is composed of two terms, i.e., the inflow effect and the susceptibility effect. Relatively the inflow effect affects the data obtained by CGE on the condition of short T_E(15ms) and large α (90degree). The susceptibility effect, however, mainly contributes to the data on the condition of large T_E(35ms) and small α(30degree). In this apper, we will discriminate the susceptibility effect for the intermingled data affected both flow effect and susceptibility effect. Finally susceptibility only functional imaging is proposed by using TRFGE.

INTRODUCTION

Current MR functional studies are based on the oxygenation level dependent susceptibility effect change[1,3]. CGE(Conventional Gradient Echo) sequence with long echo time has been used for the functional imaging, because of its capability to detect T_2^* change due to the susceptibility change[2]. When the photic stimulation was applied, the oxygenation level in visual cortex area or venous blood vessel are changed and hence altering magnetic susceptibility. But the fast CGE imaging such as FISP(fast imging stedy-state precession) is known to be sensitive to the flow effect in the voxel especially when the flip angle is large. So, we suspected that rescently reported functional imaging results may have contain subtle fraction of flow effect in the voxel. Thus, in this paper we have studied the fraction of flow effect in functional imaging and give an effort to seperate the inflow effect and susceptibility effect. For this, we have used two pulse sequences, one is CGE , the other is TRFGE(Tailored RF gradient echo). This sequence is shown in Fig.1.

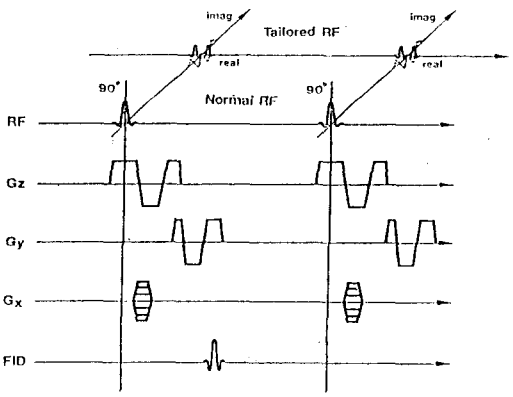


Fig. 1 Gradient Echo Sequence with conventional RF and Tailored RF.

THEORY

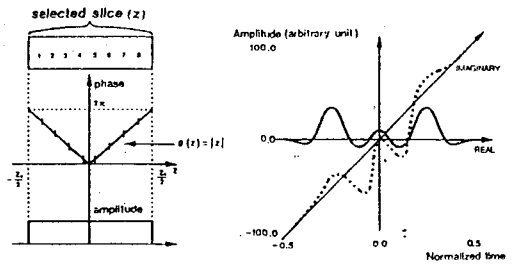
The inflow effect and susceptibility effect in gradient echo(CGE) are affected by several factors such as the flip angle α, echo time T_E, and repetition time T_R[4]. It is, therefore, strongly suspected that both effects are separated somewhat in CGE. The flow effect plays an important role in the gradient echo functional imaging where T_E is usually made short while α is kept ralatively large. On the other hand, where T_E is usually made long while α is kept relatively small, the susceptibility effect plays an important role in the gradient echo functional imaging.

The tailored RF pulse produces a bi-linear phase distribution centered around the middle of the selected rectangular slice as shown in Fig.2(a) and its time domain pulse shape is shown in Fig.2(b)[5]. For the imaging, the effects of this tailored RF pulse gradient echo(TRFGE) imaging are dephasing of spins in the selected slice[5,6,7]. The phase distribution within the selected slice is designed so that the intravoxel spins in the normal tissues where the field is homogeneous, cancel each other. In Fig.3(a), this dephasing effect for the normal tissues which are free from susceptibility effect is shown. This characteristics of the tailored RF pulse equally applies to the flowing spins if they do not possess susceptibility effect. While the spins in the slice affected by susceptibility, such as the venous blood vessel and capillary, become somewhat coherent phase distribution. So, by applying the tailored RF pulse, the signal affected by susceptibility effect are enhanced. This TRFGE technique is, therefore, effective in suppression of the signal from both the stationary tissues as well as flow. The resulting signal obtained comes only from the flow affected by the susceptibility. And, this simplified illustrations of the resulting phase distributions expected in the selected voxel is shown in Fig.3(b).

In general, the intravoxel signal intensity generated by the tailored RF pulse can be written,

$$S = \left| 2\pi M z_o \sin c\left(\frac{P_{SLICE}}{2\pi}\right) * \mathcal{F}^{-1}[\exp\{i\theta_{RF}(z)\}] \right|$$

where * means the convolution operation. The signal intensity with the tailored RF pulse appears the convolution of the signal intensity and the fourier transformed phase distribution. This mathematical expression shows that the intravoxel signal intensity affected by the susceptibility can be controlled by the RF generated phase distribution within the voxel. For imaging the susceptibility effect only, a saw-tooth-like phase distribution is suitable[6]. Because the phase is distributed from 0 to 2π with the form of saw-tooth, the net phase distribution is zero for the intravoxel spins in the normal tissues or in flow. However, the field within the selected slice appears linear gradient due to the susceptibility. So, the resulting phase distribution affected by applying the tailored RF pulse will be rephase or become coherent. For the ideal case, about an half of the spins in the selected voxel are rephased. As a result, signal will be generated only from these spins affected by the susceptibility and all other spins in the normal tissues as well as in flow are dephased.



(a) (b) Tailored RF pulse

Fig. 2 (a) Phase distribution of the bi-linear phased tailored RF pulse employed for the susceptibility only measurement. (b) Phase distribution of the tailored RF pulse in the time domain.

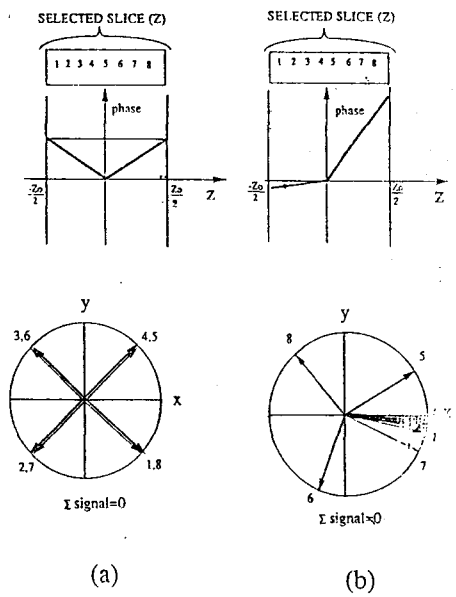


Fig. 3 (a) Resultant phase distribution of spins in the voxel of the normal tissues when the tailored RF pulse is applied. The net phase or signal produced in the voxel is zero due to the cancellation. (b) Resultant phase distribution of spins in the voxel due to the combined phase affected by the tailored RF pulse and the susceptibility therein. The net phase or signal produced in the voxel is not zero.

EXPERIMENT AND DISCUSSION

Experments were done with a 2.0T KAIST whole body imaging system. In each experiment, sagital image were obtained to find the primary visual cortex area using CGE sequence. Thereafter axial images around primary visual cortex area were obtained for the reference image. Repetition Time(TR) was 65 ms and Slice Thickness was 8 mm. 128 Phase Encodings were obtained with 50 dummy pulses. Imaging time, therefore, took a time about 12 sedonds.

For all experiments, 20 continuous image sets were obtained for time course study. Stimulation was applied from image number 6 to image number 10 by the visual stimulator. Images before stimulation and after stimulation are for control. Visual stimulator was a home-made binocular periscope type for eliminating interference with a red LED array board mounted on one end of it. LED was drived by controller at 8 Hz (duty 50%).

Two experiments were performed using CGE sequence and TRFGE sequence respectively. In CGE, echo time T_E and flip angle α was varied for flow or susceptibility dominated imaging, in TRFGE T_E and α are fixed on 15 ms and 90 degree respectively.

Fig.4(T_E=15ms, α=90degree) and Fig.5(T_E=35ms, α=30degree) are obtained by CGE sequence, the signal change in Fig.4 is originated from the inflow effect of the voxel, the signal intensity changes at the vein(Fig.4.(a)) is larger than that of the visual cortex(Fig.4.(b)). In Fig.5, the signal is mainly due to the susceptibility effect, but have a subtle fraction of the inflow effects. Fig.5.(a) is from the vein, Fig.5.(b) is from the visual cortex area. The shape of the signal is something different to that in Fig.4. Flow dependent signal shape is retangular, it means that the activation of blood flow due to stimulation arise quickly, i.e., the speed is fast. But the susceptibility dependent signal shape have a little delay time. This is belived that the oxygenation levels are changed in tissues.

Applying the TRFGE sequence, Fig.6(T_E=15ms, α=90degree) was obtained. The TRFGE sequence is free from the inflow effect and the signal change is essencially originated from the susceptibility effect change in the voxel. And the signal polarity is reversed on the contrary to the Fig.4. and Fig.5. It is the characteristic aspects of the TRFGE sequence. During the photic stimulation was applied, the excess oxygen supply decrease the deoxyhemoglobin level, and thus signal intensity descended in the TRFGE sequence.

Comparing Fig.4., Fig.5. and Fig.6., it is suspected that the signal intensity change during photic stimulation has contain the inflow effect and susceptibility effect. We have shown that the signal intensity change which obtained during the photic stimulation was composed of both susceptibility effect and inflow effect.

In summary, the TRFGE sequence is very useful for MR functional imagings and it has potential to the susceptibility only imaging. The CGE sequence used for functional imaging is not free from the inflow effect and thus functional imaging results may have been overlooked the inflow effect. Using TRFGE sequence, the inflow effect in functional imaging can be eliminated. Experimental result conforms the elimination of the TRFGE sequence.

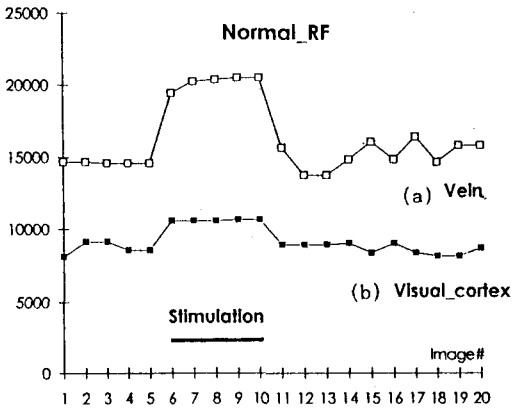


Fig. 4 Signal change due to flow effect (CGE, TR/TE=65/15ms, α=90(degree)) (a) at Vein (b) at Visual_cortex

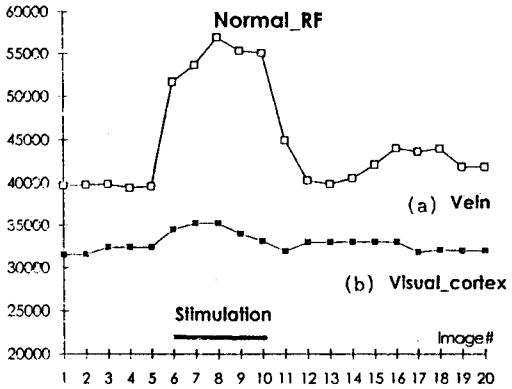


Fig. 5 Signal change due to susceptibility effect (CGE, TR/TE=65/35ms, α=30(degree)) (a) at Vein (b) at Visual_cortex

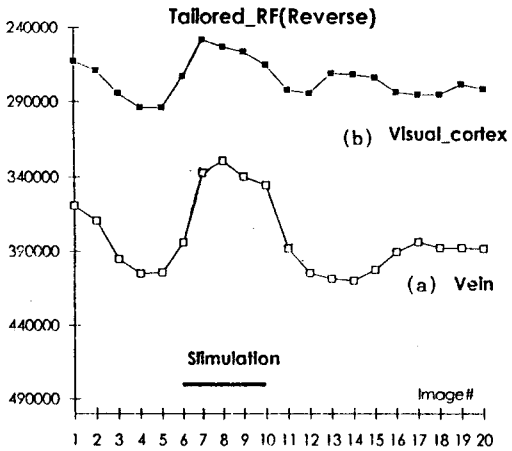


Fig. 6 Signal change due to susceptibility effect (TRFGE, TR/TE=65/15ms, α=90(degree)) (a) at Vein (b) at Visual_cortex

REFERENCE

1. S.Ogawa, T.M.Lee, A.R.Kay, and D.W.Tank.(1990) Proc.Natl.Acad.Sci. USA 87, 9868-9872

2. S.Ogawa, D.W.Tank, R.Menon, J.M.Ellermann, S.G.Kim, H.Merkle, and K.Ugurbil(1992) Proc.Natl.Acad.Sci. USA 89, 5951-5955

3. P.A.Bandettini, E.C.Wong, R.S.Hinks, R.S.Tikfsky, and J.S.Hyde.(1992) Magn.Reson.Med. 25, 390-397

4. Z.H.Cho, Y.M.Ro, R.L.Ong, R.Mennon, S.G.Kim, and K.Ugurbil.(1993) Proc.Natl.Acad.Sci. 90, in press

5. Z.H.Cho, Y.M.Ro, and T.H.Lim(1992) Magn.Reson.Med. 28, 25-38

6. Z.H.Cho, and Y.M.Ro(1992) Magn.Reson.Med. 23, 193-200

7. Y.M.Ro, and Z.H.Cho(1992) Magn.Reson.Med. 28, 237-248