주파수 변조 DANTE를 이용한 자화율 효과의 감소

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Reduction of Susceptibility Effect Using Frequency Modulation DANTE

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I. ABSTRACT

An frequency modulated (FM) DANTE pulse sequence generates a quadratic phase toward the transverse of image by an FM RF pulse. In the image of a serious susceptibility effect, the phase due to the difference of the susceptibility in the pixel occurs susceptibility error which arise signal loss. But the signal loss due to the susceptibility effect in the pixel is reduced when the quadratic phase adds in the pixel. In this paper, we have generated a quadratic function toward the transverse (X-Y) using FM DANTE sequence and the susceptibility effect is reduced in the gradient echo (GE) imaging. Computer simulation and experimental results is obtained by using a whole-body KAIS 2.0T NMR system.

II. INTRODUCTION

The DANTE sequence was applied to ultra fast MR imagings in the DUFIS and OUFIS sequences among others [1,2]. Fast imaging using the DANTE pulse sequence, however, has the advantage that it does not require high speed gradient switching. The DANTE fast imaging sequence can easily be implemented on conventional MRI systems. To improve the signal to noise ratio, the phases of individual RF pulses in the DANTE pulse train were modulated to excite more spins in the object [2,3]. Recently, a new DANTE sequence have introduced using FM (Frequency Modulation) and the signal intensity and excitation profiles were analyzed.

Since the introduction of the gradient-echo technique, it has become possible to achieve many fast MR imagings such as the SSFP [4,5], FLASH [6,7], and GRASS [8,9]. These techniques, however, have been hampered in clinical situations due to the severe inhomogeneity artifacts arising due to the gradient refocusing which is inherent in the method. Consequently use of the various gradient-echo techniques has been limited despite greatly improved field inhomogeneity of whole-body magnets available today. This local field inhomogeneity, due to susceptibility, often leads to severe artifacts in images and is difficult to correct [10]. The susceptibility effects arising from the air-tissue interface around the nasal cavity in human head image has been particularly difficult to correct. As is known, inhomogeneity due to the chemical shifts or static field can be corrected easily [11,12]. Susceptibility artifacts or signal loss is known to be due to the spin-dephasing within a selected slice because of local field inhomogeneity induced by the susceptibility. Correction of the inhomogeneities due to the susceptibility has been especially difficult because of relatively sudden changes or a highly localized nature. The susceptibility artifacts are especially pronounced when the thickness of the slice selection is large since the lager phase spreads along the direction of the slice.

We will describe characteristics of the FM function , resulting phase dispersions due to the susceptibility and a possible correction scheme using quadratic phase generates by FM DANTE sequence.

III. THEORY

1. Signal Loss Due to Susceptibility Effect

If field inhomogeneity due to the susceptibility is introduced so that a strong localized gradient exists within a voxel as shown in Fig. 1(b), the resulting phase distribution will be incoherent, and consequently the resulting vector sum will produce a much reduced signal. Now let us consider that, normally, the total signal S obtainable in NMR is given by

$$S = \sqrt{R^2 + I^2}\,, \qquad [1]$$

where R and I are the sum of real and imaginary components of magnetization in a voxel, respectively. The signal S simply becomes

$$S = M_0 z_0 \left| sinc\left(\frac{P_{sus}}{2} z_0\right)\right|. \qquad [2]$$

2. FM (Frequency Modulation) Technique

Using FM, selection profile of the pixel is determined not by the envelope of the pulse train but by the bandwidth of the sweep frequency as well as sweep rate [13,14]. In addition, the salient point of the FM technique is that the magnitudes of the pulses the DANTE RF pulse train(real and imaginary) are identical, thereby, all ways

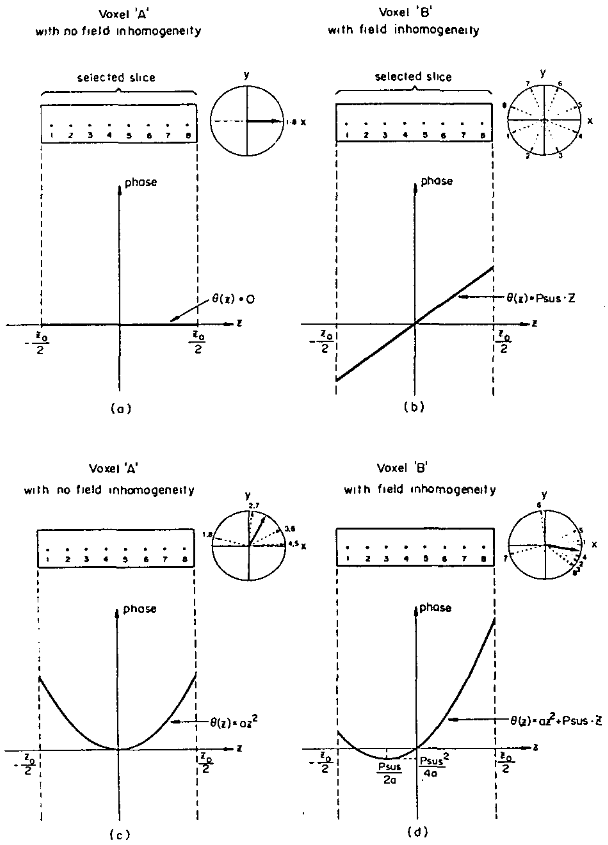


Fig. 1

producing equal magnitude echo signals. The general form of an FM function is given by

$$R(t) = A\exp[i\int 2\pi f(t)dt] \quad [3]$$

$$= A\exp[i\phi],$$

where $f(t)$ is a frequency sweep function, ϕ is a phase and A is a constant. Figure 2(a) shows a typical FM function with a linear sweep and its resulting frequency domain selection profile. By changing the sweep function, the selection profiles of the pixels in the object domain can be changed. Figure 2 (a) is an example of a linear sweep function where the frequency is swept linearly in time, i.e., $f(t) = \alpha t$. An FM pulse having linear sweep function has the form $\exp[i\pi\alpha t^2]$ where α is the sweep velocity and is defined in as [15]

$$\alpha = \frac{BW}{t_s} \text{ or } \frac{\text{Frequency Bandwidth}}{\text{RF sweep time}}, \quad [4]$$

where BW is frequency bandwidth and t_s is RF sweep time. By applying an FM RF pulse with a sweep velocity α and an RF duration of t_s, i.e., from $\frac{-t_s}{2}$ to $\frac{t_s}{2}$, the frequency range from $-\alpha\frac{t_s}{2}$ to $\alpha\frac{t_s}{2}$ would be linearly swept as shown in Fig. 2.

An FM function produces a quadratic phase distribution within a pixel as shown in Fig. 2(b).

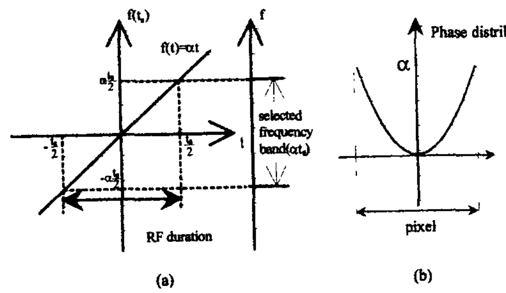


Fig. 2

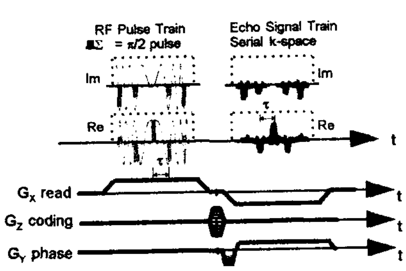
3. Compensation of the Susceptibility-Induced Signal Loss

Let us now consider two field inhomogeneiy patterns within a given voxel, namely, a case where one field with phase distribution $\theta(z) = P_{sus}z$ like voxel B as shown in Figs. 1a and 1b. The latter like voxel B could be the case where the local susceptibility induced a field.

As described below, signal loss due to the susceptibility or the field gradient created by the susceptibility can be minimized by using a suitably tailored RF pulse. As is known ,the RF pulse in the conventional imaging generally has a constant phase distribution, i.e., the spin phases with in the selected slice(voxel) are constant in the direction of the slice selection. If the RF pulse is suitably tailored such that it has a quadratic phase distribution ($\theta_p(z) = az^2$) along the slice selection direction for much of that due to the susceptibility. In other words, by superimposing the phase - compensating RF pulse on the susceptibility-induced field inhomogeneity along the slice selection direction, it is possible to create a new modified phase distribution which has much less phase dispersion. An example of superposition of two phases, i.e., quadratic phase and linear field inhomogeneity, can be given as

$$\theta(z) = \theta_p(z) + P_{sus}z = az^2 + P_{sus}z \quad [5]$$

where a is a coefficient chosen as the design parameter of the RF pulse. Figure 1c shows a sample case where a quadratic phase RF pulse is applied to voxel A where the field is originally homogeneous while Fig. 1(b) represents the phase distribution of the spins when the same RF pulse is applied to voxel B where linear field inhomogeneity exists.

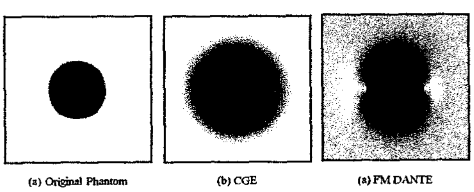


Interlaced FM-DANTE Pulse Sequence

Fig. 3

IV. COMPUTER SIMULATION

To verify the usefulness of FM DANTE technique especially for susceptibility artifact reduction, a computer simulation was first performed. A phantoms of 128 x 128 matrix size which consists of one air tubes surrounded by water was designed. Field inhomogeneity due to the susceptibility effect was calculated based on the magnetostatic field calculation[16]. Using the calculated field inhomogeneity, conventional frequency encoding technique, conventional gradient echo image and FM DANTE gradient echo image were obtained. First, conventional gradient echo image was obtained and the results is shown in Fig. 4(b). As expected, the image is distorted around the air tube.
Then the FM DANTE technique was used and improved results were observed as shown in Fig. 6c. In conventional gradient echo technique, each voxel around the air tube has a distorted phase caused by field inhomogeneity which reduces the signal intensity for that voxel. In FM DANTE technique, each voxel has a quadratic phase with field inhomogeneity. The result image on the same condition to a conventional gradient echo is shown in Fig. 4(c). The signal intensity of voxel around the air tube are partially improved, since the phase compensation occurred by quadratic phases in distorted field. This result shows that FM DANTE gradient echo technique can improve susceptibility artifact.



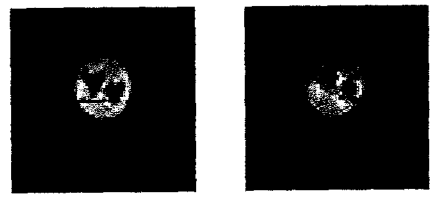
(a) Original Phantom (b) CGE (a) FM DANTE

Fig. 4

V. EXPERIMENTAL RESULTS AND DISCUSSIONS

To verify the susceptibility effect reduction of the proposed FM DANTE sequence obtained in experiment and a compare the results with the other existing conventional gradient echo (CGE) sequence. The pulse sequence of an FM DANTE sequence is shown Fig. 3. In the experiments, repetition time and echo time were 500ms and 19ms, respectively with a slice thickness of 5mm. Within the phantom, a 5cm diameter and 5mm diameter tube were inserted. The experimental results of the FM DANTE sequence and CGE sequence are shown Fig. 5. As shown in Fig. 5(a), (b), experimental results obtained using the FM DANTE sequence show the reduced susceptibility effect due to the quadratic phase of the FM RF pulse compared with the CGE pulse sequence.

In conclusion, the proposed FM RF pulse technique is found to be useful for compensating the inhomogeneity in general, i.e., the signal loss due to the susceptibility effect in the pixel is reduced when the quadratic phase adds in the pixel. The proposed method will appears particularly useful in many fast imaging techniques where image artifacts are predominantly caused by susceptibility.



(a) CGE (b) FM DANTE

Fig. 5

VI. REFERENCES

1. I.J.Lowe and R.E.Wysong, "DANTE Ultra Fast Imaging Sequence (DUFIS)", *J.M.R Series B*, **101**, 106-109 (1993).
2. J.Hennig, "Fast Imaging Burst Excitation Pulses", *7th SMRM*, p238 (1998).
3. T.J.Mosher and M.Smith, "A DANTE Tagging Sequence for the Evaluation of Translational Sample Motion", *MRM*, **15**, 334-339 (1990)
4. H.Y.Carr, *Phys. Rev.* **112**, 1693 (1958)
5. R.C.Hawkes and S.Patz, *MRM*, **4**, 9 (1987)
6. K. Sekihara, *IEEE Trans. Med. Imaging*, **6**, 157 (1987)
7. Y. Zur, S.Stokar, and P.Bendel, *MRM*, **6**, 175 (1988)
8. A.Hasse, J.Frahm, D.Matthaei, W.Hanicke, and K.D. Merboldt, *JMR*, **67**, 258 (1986)
9. J.Frahm, W.Hanicke, and K.D.Merboldt, *JMR*, **72**, 307 (1987)
10. H.W.Park, Y.M. Ro, and Z.H.Cho, *Phys. Med. Biol.* **33**, 339 (1988)
11. Y.S.Km, C.W.Mun, and Z.H.Cho, *MRM*, **4**, 452 (1987)
12. Y.M.Ro, W.S.Kim, M.H.Cho, and Z.H.Cho, *Proc. SMRM, 9th Annual Meeting*," p.443(1990)
13. A.Anderson, R.Garwin, E.Hahn, et al, "Spin Echo Serial Storage Memory", *J.Appli.Phys*, **26**, 1324-1338 (1955)
14. J.Fridrich, S.Davis and R. Freeman, "Shaped Selective Pulses for Coherence-Transfer Experiments", *J.M.R.*, **75**, 390-395 (1987)
15. D.Kunz,"Use of Frequency-Modulated Radiofrequency Pulses in MR Imaging Experiments", *MRM*, **3**, 377-384 (1986)
16. K.M.Ludeke, P.Roschmann, and R.Tischler, *MRI*, **3**, 329 (1958)

VII. FIGURE CAPTION

Fig. 1 (a) The phase distribution of spins in the voxel when the field is homogeneous. (b) The phase distribution of the spins in the voxel when a strong localized field gradient exists(e.g.,susceptibility). (c) The phase distribution of the spins in the voxel when a quadratic phase RF pulse is added onto a voxel with a homogeneous field. (d) The phase distribution of the spins in the voxel when tailored quadratic phase RF pulse is superimposed onto a voxel where the linear field gradient (inhomogeneity) is created by susceptibility

Fig. 2 (a) Linear sweeping pattern with sweep velocity α. (b) The FM DANTE phase distribution calculated in one pixel.

Fig. 3 An illustration of the interlaced FM DANTE gradient echo pulse sequence.

Fig. 4 (a) Original phantom used in computer simulation. (b) Image obtained by conventional gradient echo pulse simulation. (c) Image obtained by FM DANTE gradient echo pulse simulation.

Fig. 5 (a) Experimental result by CGE. (b) Experimental result by FM DANTE gradient echo.