Time-Multiplexed Multislice Inversion–Recovery Techniques for NMR Imaging

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Multislice imaging techniques effectively applicable to inversion–recovery (IR) imaging are developed and applied to human imaging. These new multislice IR imaging sequences employ the time-multiplexing (TM) technique conventionally used in the slice-by-slice saturation–recovery (SR) imaging. Two new time-multiplexed multislice (TMM) IR imaging sequences are proposed and some of the experimental results obtained with the methods are presented. © 1985 Academic Press, Inc.

INTRODUCTION

Inversion–recovery (IR) imaging sequences have been known and used for various diagnostic imagings for some time. However, there is a drawback to the method in that complete recovery of spin–lattice relaxation ($3T_1$) in living organs usually takes as long as a few seconds and consequently requires a long imaging time (1–3). Recently, it has been shown that multislice imaging is possible in SR imaging by use of a time-multiplexing technique which maximally utilizes the spin–lattice relaxation recovery period (4). The extension of this time-multiplexing technique used in SR imaging into IR imaging is sought and two time-multiplexed multislice (TMM) IR imaging sequences are proposed in this paper. Another problem with IR imaging, already addressed by several investigators, is the contrast reversal at short $T_1$ time (5). A solution to this contrast reversal problem has been suggested by the authors (6) and this phase-correction technique has been incorporated into the proposed TMM technique. This new phase-correction technique has also been successfully combined with the proposed TMM IR imaging and obtained consistent noncontrast-reversal image sets at several slice levels.

TIME-MULTIPLEXED MULTISLICE (TMM) IR IMAGING TECHNIQUES

The First Method

The simplest IR imaging pulse sequence using time multiplexing (TM) is shown in Fig. 1. In this figure, sets of the rf sequences together with $G_x$, $G_y$, and $G_z$ gradients are applied during $T_{D1}$ period with a given repetition time $TR$. $180^\circ$ inversion rf, $90^\circ$ rf, and $180^\circ$ echo rf are all selective rf’s which correspond to the slices selected for

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imaging. $G_z$ gradients are applied for the slice selection in conjunction with rf's and the $G_x$ and $G_y$ gradients are then applied for the encoding in $x$ and $y$ directions, respectively. In this sequence, the maximum number of image slices $N_1$, IR sequence period $T_{D1}$, and total repetition time $T_R$ are related as

$$N_1 = \left\lfloor \frac{T_R}{T_{D1}} \right\rfloor \tag{1}$$

where

$$T_{D1} \approx T_1 + \frac{1}{2} T_E \tag{2}$$

and $\lfloor \cdot \rfloor$ means the integer part of $\{ \cdot \}$. Naturally, the shorter the $T_{D1}$ or $T_1$ is, the more slices can be imaged within a given repetition time period $T_R$. This IR pulse sequence is most efficient when inversion time $T_1$ is relatively short compared with repetition time $T_R$ (since $T_1 \gg T_E$).

The Second Method

The second method employs time-multiplexed sequence somewhat different from the first one, i.e., rf's are multiplexed separately as shown in Fig. 2. In this scheme, $N_2$ 180° inversion rf's are applied consecutively during the $T_1$ period, where $N_2$ is the maximum number of image slices obtainable by the second method. The separation
time $T_S$ between the adjacent $180^\circ$ inversion rf’s (see Fig. 2) should, however, be larger than $T_{D2}$ where $T_{D2}$ is $T_{D2} \approx \frac{3}{2} T_E$ (see Fig. 2). If echo time $T_E$ is relatively short compared with inversion time $T_I$, this technique is more efficient for multislice IR imaging than the first method given above. The maximum number of slices that can be obtained within a consecutive sequence (which is approximately $2T_I$) is given by

$$N_2 = \frac{T_I}{T_S}$$  \hspace{1cm} [3]$$

where $T_S$ is the pulse interval of $180^\circ$ inversion pulses to be applied consecutively or the data collection time of normal sequence shown in Fig. 2. It is, however, assumed that the repetition time $T_R$ is long enough that $T_R > 2T_I$. This technique would be efficient if long $T_I$ is required. Since the total period of a consecutively multiplexed imaging pulse sequence is approximately twice as large as inversion time $T_I$, the time-multiplexing technique given by the first method can be applied in conjunction with this technique. Total maximum number, $N_T$, of IR imaging slices using these two TMM techniques is then

$$N_T = \frac{T_R}{2T_I} \times N_2.$$  \hspace{1cm} [4]$$
FIG. 3. Human brain images obtained by the first method with $T_R = 1.3$ s, $T_i = 150$ ms, and $T_E = 30$ ms.

For example, if $T_R = 1.3$ s, $T_i = 300$ ms, and $T_E = 30$ ms, the total maximum number of imaging slices will be as large as 12 slices, i.e.,

$$N_T = \left\{ \frac{1300}{2 \times 300} \right\}_1 \times \left\{ \frac{300}{30 \times \frac{3}{2}} \right\}_1 = 12. \quad [5]$$

EXPERIMENTAL RESULTS AND DISCUSSIONS

Using the pulse sequences given in Figs. 1 and 2, human brain imagings were carried out. Figure 3 shows the IR images obtained by the first pulse sequence (see
FIG. 4. Human brain images obtained by the second method with $T_R = 1.3 \text{ s}$, $T_I = 300 \text{ ms}$, and $T_E = 30 \text{ ms}$.

Fig. 1) for relatively short $T_I$, i.e., $T_I = 150 \text{ ms}$ with $T_R = 1.3 \text{ s}$ and $T_E = 30 \text{ ms}$. In this figure, the phase-correction scheme developed by the authors was also applied to eliminate the contrast reversals. Figure 4 shows the IR images obtained by the second TMM imaging sequence (see Fig. 2) of the same subject as Fig. 3 except that the inversion time $T_I$ is $T_I = 300 \text{ ms}$. In this sequence, the phase-correction scheme was also applied (6). As it is shown, both techniques result in good quality multislice IR images within an acceptable imaging time.

In both imaging sequences, contrast-to-noise ratios are relatively high since IR imaging usually employs long recovery times (long $T_R$) therefore ensuring large signal recovery and reduces demands of a large number of signal averages. Finally, a set of
FIG. 5. Human brain images obtained by the first method (see Fig. 3a). (a) Phase-corrected IR image processed with magnitude method and (b) Phase-corrected IR image processed with phase correction method proposed in Ref. (6). Note the image polarity reversal in (a) compared with image (b).

contrast reversal corrected images obtained by the combination of the TMM imaging techniques with the phase-correction method (6) is given in Fig. 5. Figure 5a is the image obtained by TMM imaging technique (shown in Fig. 1 and Fig. 3a) with existing magnitude technique (contrast reversal), while (b) is the image obtained with the new phase correction method (6). It would be worth noting that the slice selectivity often appears one of the serious problems in the multislice IR imaging techniques (7). To ensure proper slice selection, therefore, we have employed a truncated sinc shaped rf pulse with several side lobes.

In conclusion, it seems possible that with the new proposed TMM imaging techniques the time-consuming IR imaging can be made more efficient, and therefore, clinically useful. It is also worthwhile to note that both techniques (Figs. 1 and 2) can best be used in conjunction with the phase-correction scheme given in Ref. (6).

REFERENCES