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A Modified IR Sequence for Multi-Slice Fluid Attenuated MRI

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INTRODUCTION

Fluid attenuation is often desired in MRI in order to reduce dynamic range problems, partial volume effects, as well as flow and motion artifacts induced by the intense signal arising from body fluids such as CSF, urine, synovial as well as amniotic fluid. A method commonly used in clinical practice is the inversion recovery (IR) sequence where the long inversion time (TI) is calculated to null the signal from the slowly relaxing fluid protons (FLAIR) [1]. When applied in the conventional multi-slice mode, the long TI and repetition time (TR) required allow only for a few slices to be selected within one sequence repetition. Another approach is to use a hard non-selective pulse in the beginning of the sequence followed by a number of slices at variable TI. Although this has the additional advantage of suppressing flowing fluid spins all over the imaging volume, the signal attenuation is variable across the slices.

THEORY

We propose a modified IR sequence which provides fluid attenuated multi-slice images with overall imaging time comparable to a conventional spin-echo experiment. In this proposed method the inversion pulse is non-selective but is applied every time prior to excitation of each slice. The effective repetition time of the inverting pulse (TReff=TR/N, where N is the number of slices acquired within a total repetition time TR) is greatly reduced, and the magnetization is forced into a steady-state condition. The value of this residual steady-state magnetization is inversely proportional to the effective repetition time of the inverting pulse and directly proportional to T1. The null point for the magnetization is now given as a function of both TReff and T1:

$$TI = T1 \ln 2 - T1 \ln(1 + e^{-TReff/T1}) \qquad [1]$$

Note that the null point is significantly shortened in the modified sequence, and this reduction depends on the T1 value of the magnetization. It is expected that a wider range of long T1's will be sufficiently suppressed, while contrast between short T1 components will be enhanced. Figure 1 shows an example of the maximum number of slices that can be selected using the conventional IR, a time-multiplexed multi-slice selection IR [2], and the modified sequence. Note that Eq. 1 should also be used for the calculation of the TI in the conventional fluid attenuated IR experiment (where TReff=TR), as in clinical practice the overall repetition time is usually relatively short for the fluid spins to relax adequately before the next sequence repetition, and thus allow the use of the approximate expression TI = T1ln2.

EXPERIMENTAL EVALUATION

The sequence was evaluated using a phantom that consisted of oil (T1 of 200 ms) and several water compartments, each one doped with a different concentration of CuSO4 to give a range of T1 values (300-2200 ms). Eq. 1 was used to calculate the TI for the null point of the longest T1 component (2200 ms) for both the conventional IR and the proposed sequence. Figure 2 summarizes the experimental results on the dependency of signal suppression, as well as the contrast amongst the unsuppressed components, on the accuracy of the calculated TI for both conventional and proposed IR sequences. In the conventional IR sequence the T1 contrast varies significantly with the inversion time, and signal suppression of any

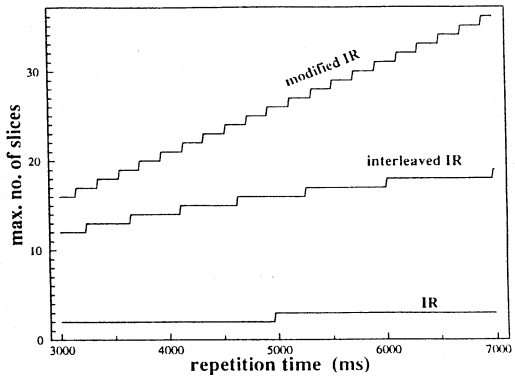

Figure 1. Maximum number of slices which can be selected within a repetition time for the conventional, multiplexed [2], and modified IR sequence (T1=3000 ms and TE=100 ms).

T1 component is strongly dependent on the accuracy of the calculated null point. On the contrary, the modified sequence gives the same signal suppression for a wide range of inversion times. The T1 contrast between short T1 components is also enhanced and remains the same over the range of inversion time values used. The proposed sequence has also been demonstrated *in-vivo* in the abdominal imaging of a normal rat (to suppress the intense signal from the bladder), where a 10-slice data set was obtained in half the imaging time of that required for a 3-slice conventional IR data set.

CONCLUSIONS

The proposed modified IR sequence can produce multi-slice data sets with good fluid suppression within the overall imaging time of an equivalent spin-echo experiment. Only a crude estimation of the fluid T1 is needed, as the signal suppression remains effectively the same for a wide range of inversion times. The T1 contrast is also independent of the inversion time and is significantly enhanced especially for the short T1 components, while there is a decrease in the S/N for longer T1 components. The overall reduction in the experimental time, however, can be traded off for more signal averaging (or increased in-plane resolution). The use of non-selective inversion pulses, as well as the fact that the null point is not strongly dependent on the inversion time, results in good suppression of flowing fluid signal. The sequence would be ideal for the imaging of anatomical locations where contrast between short T1 components is desired while fluid and flow suppression is also required. Some examples are: abdominal imaging (kidneys and liver), joint imaging (cartilage and bone marrow), as well as imaging of lipid deposits in the cardiovascular system.

REFERENCES

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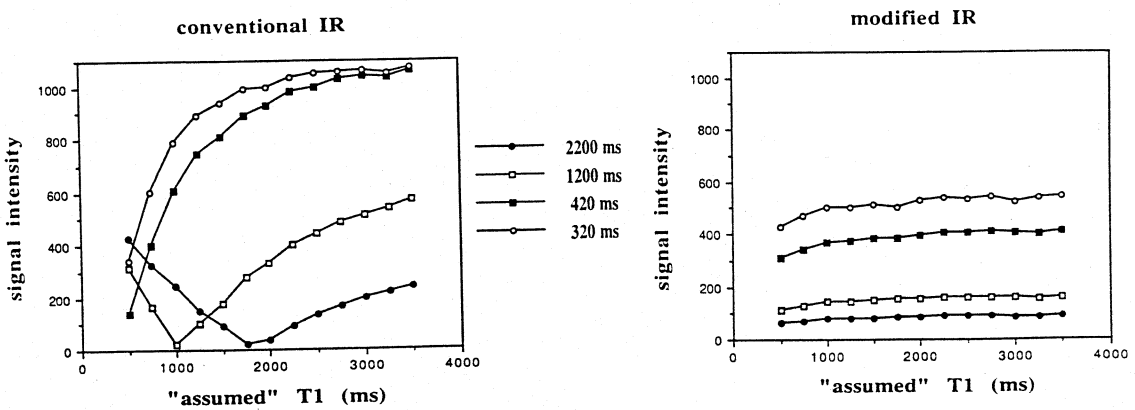

Figure 2. The signal intensity (arbitrary units) of phantom compartments with T1 values of 2200 ms, 1200 ms, 420 ms and 320 ms plotted against the "assumed" T1 value (used to calculate the inversion time) for both conventional and modified IR sequences.