Multislice Water-Fat Imaging with Simultaneous Echo Refocusing (SER-Dixon)

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Introduction

Phase sensitive imaging for fat-water separation was first proposed by Dixon [1]. For each slice, two or more images are acquired at different echo times with fat and water magnetization vectors at different relative phases. The need to acquire each slice at different echo times increases the minimum imaging time (T_{min}). In a multiecho Dixon sequence [2,3], although T_{min} can be reduced by decreasing the separation between echoes, there needs to be a minimum interval for adequate phase evolution [4]. However, if the separation between the echoes from one slice is slightly extended and the gap in between used to sample another slice, T_{min} could be reduced. This is achieved by combining Simultaneous Echo Refocusing (SER) [5,6] and the 2-point Partially-Opposed-Phase Dixon method, POP [7] in a new pulse sequence, SER-Dixon.

Method

The pulse sequence diagram (not to scale) is shown in Fig. 1. RF1 and RF2 are 90° pulses of 1 ms duration, separated by 2.3 ms, and modulated to select different slices approximately 3 cm apart. They are refocused with a 1ms, dual slice selective 180° pulse. Both slices share the same phase encoding. The read gradient was adjusted so that each read gradient lobe encodes an in-phase spin-echo from one slice, and the partially-opposed-phase echo from the other slice. The time between an in-phase echo and a partially-opposed-phase echo in one gradient lobe, e.g. SE2,i and SE1,o was 510 us. The time between SE1,i and SE1,o was 1790 us, giving a fat-water angle, $\alpha = 140°$, at 1.5T. The time between SE2,i and SE2,o was 2810 us, giving $\alpha = 220°$. The choice of fat-water angles gives the same effective number of signal averages NSA >1.95 for both slices when reconstructed with the POP algorithm [7]. The sequence was implemented on an Infinion 1.5T scanner (Philips Medical Systems) with maximum gradients and slew rate of 30 mT/m and 120 mT/m/ms respectively. Images were acquired from the abdomen (with body coil) and calves (with head coil). Scan parameters were: TR/TE_{ave} = 400/7 ms, NEX = 3, and matrix size per slice = 128 (phase) × 256 (read).

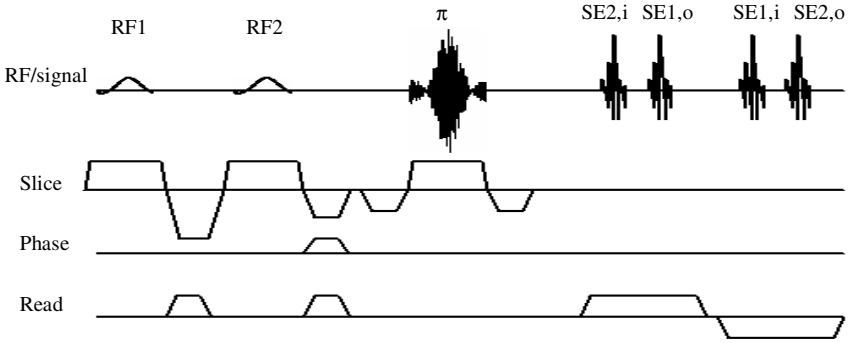

Figure 1. Pulse sequence schematic. Numbers refer to slice. Index i = in-phase; o = partially-opposed phase. The time between SE1,i and SE2,i is adjusted to be equal to the time between RF1 and RF2.

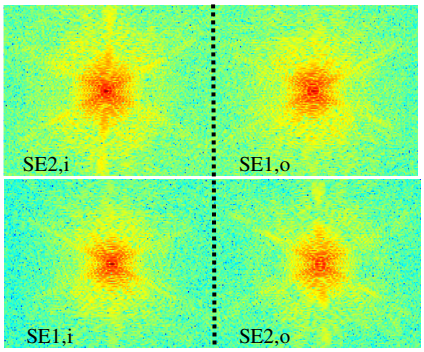

Figure 2. Log scale display of data, showing division between k-spaces from different slices.

Results

The data were divided into two halves in post-processing, corresponding to the slices (see Fig 2), and reconstructed with fat-water separation using the POP algorithm. Representative images below show satisfactory fat-water separation with no evidence of crosstalk between slices.

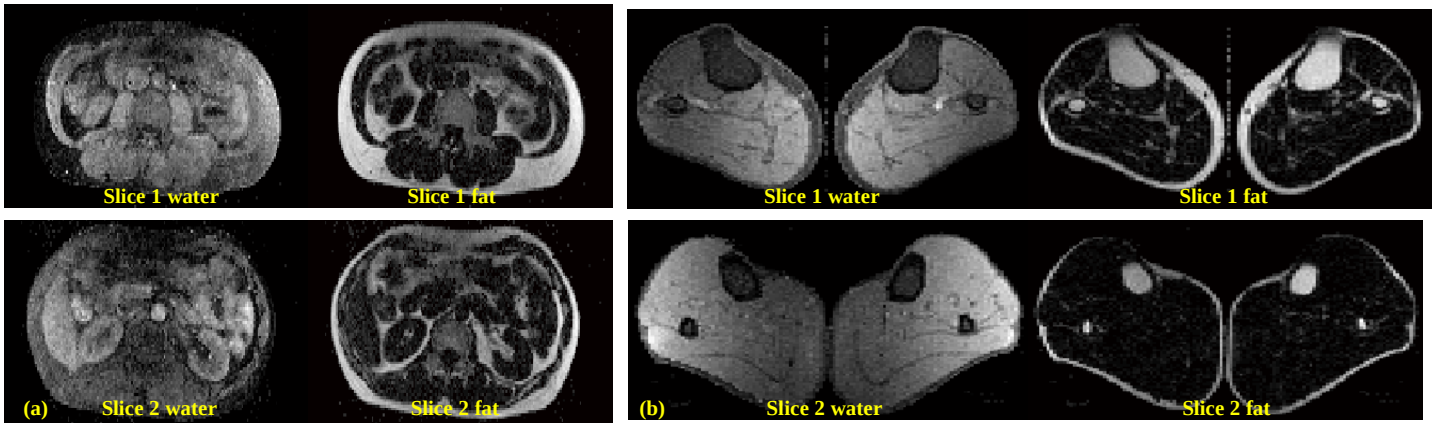

Figure 3. Water and fat images after POP reconstruction from (a) abdomen (b) calves.

Discussion

This work demonstrates that by slightly increasing the fat-water phase angle to 220° for one slice, it is possible to fit in data from another slice with a smaller $\alpha = 140°$ by using Simultaneous Echo Refocusing. This will reduce T_{min} if the slightly increased readout plus extra RF pulse results in a TR less than 2*TR of a standard multi-echo Dixon. This time saving will increase with more refocusing pulses. This preliminary investigation used only one slice selective refocusing pulse. Work is in progress on a multiple spin-echo version which will utilise careful design to overcome the non-CPMG condition [6]. A known artefact of SER is ghosting from overlap between high-frequency regions of k-space. In future, this may be reduced by using larger read gradients to increase separation in k-space, or using POMP [8] to separate the slices in the phase encoding direction.

References

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