Multiplex RARE Dixon: a novel multislice RARE sequence applied to simultaneous slice fat-water Dixon imaging

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Introduction
Multislice excitation methods have been widely used to increase efficiency in volume coverage. In the simultaneous spin-echo refocusing sequence (SER) [1], two or more slices are excited simultaneously and refocused with a train of 180° pulses which act simultaneously on both slices. However, the SER sequence does not fulfil CPMG conditions, and requires special spoiler gradients to eliminate undesired stimulated components. This leads to signal loss and limits echo train length. Recently, a modification of SER was introduced, called multiplex RARE (mRARE) [2], which allows two spin-echo trains to be simultaneously excited and interleaved, while satisfying CPMG conditions. Here we show an application of mRARE in a novel, fast Dixon fat-water sequence which acquires two slices simultaneously. The sequence is similar to the GRASE-Dixon sequence reported in Ref [3], but although Ref [3] fulfils the CPMG condition for timing, it does not fulfil the CPMG condition for phase accumulation and shows artifacts from stimulated echoes.
Technique
The mRARE Dixon sequence is shown in Fig. 1. Two slices are simultaneously excited and refocused by an interleaved train of their own slice selective pulses. At the spin-echo for one slice, e.g. S_1, only the signal from slice 1 has been fully rephased while slice 2 remains dephased in the slice and phase directions. Rephasing slice 2 will dephase slice 1 and vice versa. There will be crosstalk between slices if there is insufficient dephasing because of susceptibility gradients or if unwanted signal from imperfect refocusing pulses are insufficiently crushed by spoiler gradients A and B. The spin-echoes occur halfway between their refocusing pulses, and by considering the gradient moments, it can be seen that the CPMG condition for phase accumulation is also satisfied. Thus stimulated echoes will coincide with the spin-echoes as with RARE. Note that Dixon images with symmetric sampling have some redundancy [4], and that out-of-phase gradient echoes need only be collected on one side of the spin-echo. Therefore, it is possible to fit in echoes from another slice on the other side of the spin-echo. In Fig. 1, a gradient- and a spin-echo from different slices are collected on one side of each of the spin-echoes. Two-point Dixon fat-water separation can then be performed.

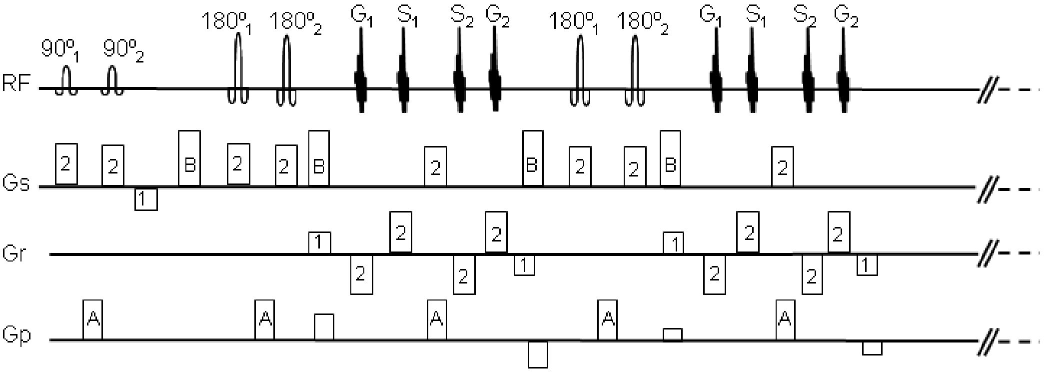
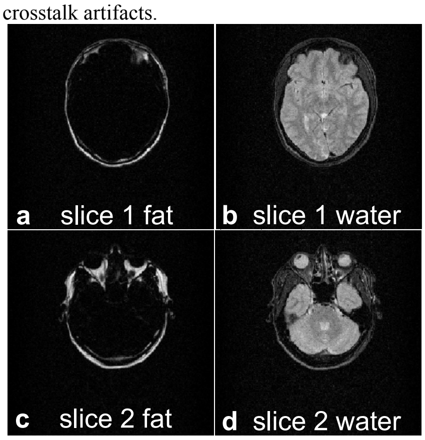
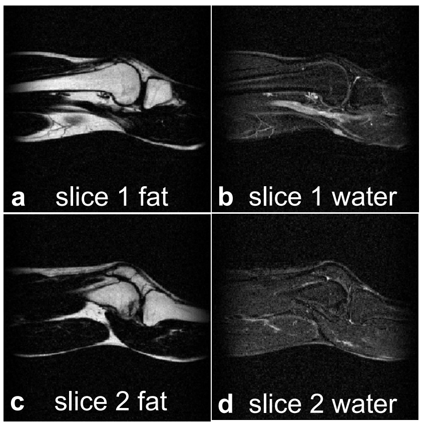


Fig 1. mRARE Dixon sequence. S = spin-echo; G = gradient echo. The subscripts refer to slice number. The gradient lobes A separate the echoes in the phase encoding direction. The gradient lobes B suppress unwanted signal from imperfect refocusing pulses. Sequence parameters were: TR/TE = 1500/120 ms, slice thickness = 5 mm, FOV = 300 × 300 mm^2, BW = ±83.3kHz, echo train length (ETL) = 19, averages = 1, matrix = 256 (read) × 266 (phase).

Method
The sequence was implemented on a 1.5 T system (Magnetom Sonata, Siemens). RF pulse durations were 1.4 ms, with a separation of 1.79 ms between spin and gradient echoes, corresponding to a fat-water angle in the gradient echoes of 140°. Although Fig. 1 shows 180° pulses, in fact a transition between pseudo steady states (TRAPS) scheme [5] was used to generate a large stimulated echo component. Spoilers of 0.5 ms duration were used to give a phase wrap of 7π and 1.4π per voxel in the slice and phase direction respectively. The echo-spacing was 12.0 ms. Fat and water images were obtained using the POP algorithm [6].
Results
Figs 2 and 3 show fat and water images from two simultaneously acquired slices in the head and knee respectively, with successful fat-water separation without crosstalk artifacts.





	fTED	mRARE Dixon
SNR	1	0.7
Echo spacing (ms)	10.4	12.0
Volume acquisition efficiency (slices/unit time)	1	1.7
SAR	1	1.7

Table 1. Comparison of mRARE Dixon vs fTED.

Discussion
Unlike Ref [3], the images show no artifacts from stimulated echoes, demonstrating that mRARE fulfils CPMG conditions for both phase and timing. Table 1 shows a comparison between fTED [7], another fast Dixon method, and our method. Due to the shorter readout time per slice, mRARE Dixon has lower SNR, but it collects 1.7 times as many slices per unit time as fTED, at the cost of increased SAR. However, because mRARE fulfils the CPMG condition, SAR may be reduced by using <180° pulses [5]. In summary, mRARE Dixon is suitable for a high SNR situation where the signal can be traded off for a faster volume coverage, or where simultaneous slice excitation is desired.
References
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