Iterative Fat-Water Separation in Steady State with Dedicated MRI Systems

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· INTRODUCTION

It has been for the last two decades that dedicated MRI tomographs have revealed to be a valid compromise between increasing clinical requirements and system complexity. Thanks to continuous hardware improvements, even modern MRI techniques, well established at high field strengths and particularly demanding due to both the fast gradient driving and the post-processing complexity, have been successfully included also in clinical protocols running on dedicated systems. Steady-state sequences are a particularly meaningful example both for their hardware stress and resulting imaging quality, being short T_1 values a further beneficial aspect. According to diagnostics requirements, a useful step forward for a high SNR and CNR imaging is to provide it with an efficient fat-water separation. In the case of small chemical shifts, typically a few tens of Hertz, frequency selective excitation or separation are not feasible. Inversion recovery techniques are not very time-efficient and not easily implemented in steady state. Thus, multi-echo steady-state sequences provided with an iterative 'Dixon'-type reconstruction technique [1] appear to be the best choice in terms of diagnostic potential and MRI efficiency.

· METHODS

A multi-echo 3D SSFP-FID sequence as shown in Fig. 1 was implemented on a G-Scan system (Esaote, Genoa, Italy). The G-Scan system is equipped with a 0.25 T permanent tilting magnet, with the peculiar feature to allow weight-bearing condition examinations. G-Scan gradients support an amplitude of 20 mT/m and a slew rate of 25 mT/m/ms. The phase encoding gradient is played out only once after each excitation, such that the alternating readout gradient encodes the same *k*-space line at multiple echo times. Sufficiently high bandwidth acquisition ensures a negligible chemical shift artifact, that otherwise would appear in opposing directions for odd and even echoes. Imaging parameters are: 3 echoes, ΔTE = 9 ms, TR = 32 ms, FOV = 18x18 cm^2, slab thickness = 13 cm, BW = 111 Hz/pixel, acquisition matrix = 256x200, 42 partitions, flip angle = 60°, acquisition time = 4' 28". Chemical shift between fat and water is about 36 Hz.

A phantom consisting of a swine bacon vacuum-sealed package was used for the MRI experiment, in order to simulate a complex tissue structure with likely T_1 and T_2 values.

The fat-water separation was performed using an iterative approach as described in [1] and [2]. Furthermore, an initial stage of the post-processing procedure, analysing the phase differences between the echoes, was introduced in order to recover from the possible inconsistencies between odd and even echoes, due to gradient delay, eddy currents and other effects related to gradient polarity reversals, on the basis of what is proposed in [3].

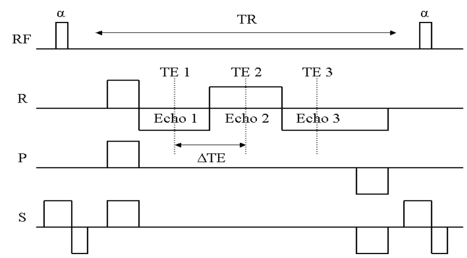

Fig. 1: Pulse sequence diagram for the multi-echo 3D SSFP-FID sequence.

· RESULTS

The results of the phantom experiment are shown in Fig. 2. In the left column the magnitude images of the three echoes sampled, from top to bottom, at echo times of 7, 16, 25 ms are displayed, which correspond, at about 10.2 MHz, to a chemical dephasing of about 90, 205 and 320 degrees respectively. The right column shows, from top to bottom, the metabolite magnitude maps for water and fat and the B_0 field map scaled in field parts per million. All images are individually scaled for best display results.

· DISCUSSION & CONCLUSION

This study confirms the feasibility of fat-water separation with a multi-echo 3D SSFP-FID sequence and an iterative 'Dixon'-type reconstruction even with dedicated MRI systems, where the field homogeneity over the FOV of interest can be a severe constraint. The sequence technique provides good resolution and SNR in clinically compatible scanning time. The multi-echo design requires a much higher sampling frequency than multiple single-echo acquisitions with shifted echoes. However, high sampling frequencies help reduce possible inconsistencies related with the chemical shift. Moreover, a multi-echo interleaved acquisition should ensure a reliable superposition between reconstructed images, since the echoes experience almost the same effects possibly due to sample motion or flow, external interference, system instability and any other source of signal fluctuation. This might not exactly be the case of multiple single-echo sequences that are acquired sequentially. Thus, multi-echo design should also be well suited to potentially extend this technique to investigations implying critical motion artifacts severity, like weight-bearing examinations. Finally, note that at 0.25 T the ratio between the first fat-water in-phase gradient echo time and the T_2* value might not be completely negligible in the standard shimming conditions in the FOV. Thus, the optimal choice for the echo times has to be a compromise between maximizing the effective number of signal averages (NSA), that is to sample echoes such that the phase differences between fat and water signals are evenly distributed over the unit circle, and keeping the longest TE short enough in order to avoid possible signal voids in case of relevant off-resonances over the FOV of interest. Further acquisition protocol optimisations and reconstruction algorithm refinements will be soon investigated in order to improve the result reliability even for *in vivo* more challenging conditions.

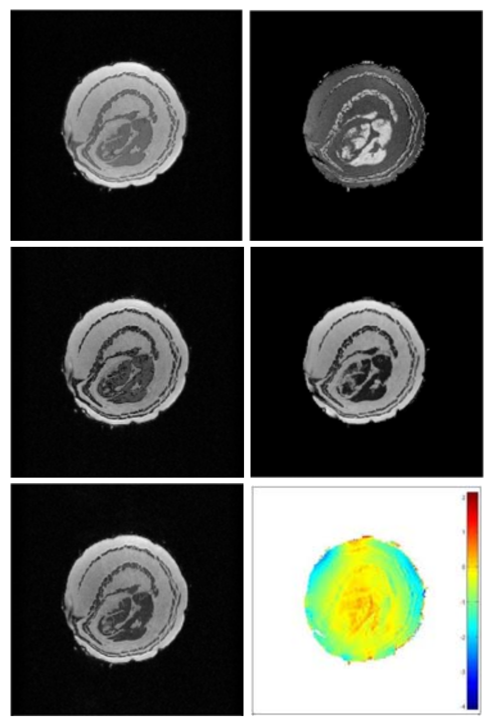

Fig. 2: Iterative Dixon reconstruction for a phantom. Left, top to bottom: original images for the three echoes at TEs = 7, 16, 25 ms. Right, top to bottom: reconstructed magnitude images for water and fat and B_0 field map scaled in parts per million.

· REFERENCES

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[3] W. Lu *et al*., MRM **60**: 198-209, 2008.