Comparison of Dixon Methods for Fat Suppression in Single Breath-Hold 3D Gradient-Echo Abdominal MRI

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Introduction

A variety of Dixon methods has been proposed over the last years that permit a robust fat suppression in inhomogeneous magnetic fields [1-3]. Apart from different strategies to separate water and fat signal, the individual methods are mainly characterized by the number of echo times, or points, that they rely on and by the constraints that they impose on these echo times. In this work, the impact of these two properties on scan efficiency is evaluated in single breath-hold 3D gradient-echo abdominal imaging for different two- and three-point methods, including a new one.

Methods

Four Dixon methods were considered. The first is the three-point least-squares approach by Reeder et al. [1]. It essentially allows a free choice of the echo times, i.e. it makes no fundamental assumption on the relative phase between water and fat signal at any echo time, although the resulting SNR is affected by them. The second and third are the two-point approaches by Ma [2] and Xiang [3]. Both require one in-phase echo time, and the former additionally one opposed-phase echo time. The fourth is a new two-point approach, which essentially follows the third, but relaxes the remaining constraint on one of the echo times. From the product of the conjugate complex signal at the first echo time and of the signal at the second echo time, it derives two alternative error phasors that describe the effect of main field inhomogeneity. One of these is picked by requiring smoothness of the spatial variation of the error phasor. Finally, the water and fat signal are calculated from a set of three non-linear equations: the above product, multiplied by the conjugate complex error phasor, and the squared magnitude of the signal at the first and at the second echo time, which can all be expressed in terms of the two unknowns and the known chemical shift of fat.

Data of volunteers were acquired on Philips 1.5 T and 3.0 T Achieva scanners with a 3D spoiled multi-gradient-echo sequence and 16 element torso receive coils. The FOV was 370 x 250 x 240 mm^3, the voxel size 1.5 x 1.5 x 3.0 mm^3, and the flip angle 10°. With a fixed 2 x 2 acceleration in AP and FH direction by parallel imaging, the overall scan times were in the range of 13 s to 23 s.

Gradient system	Method	TR	TE_1	ΔTE	T
30 mT/m 180 mT/m/ms	$N_E = 3$ -	4.5 (4.5)	1.3 (1.3)	1.0 (1.0)	17 (17)
	$N_E = 2$ IP + OP	4.7 (5.8)	2.3 (2.3)	1.2 (2.3)	18 (22)
	$N_E = 2$ IP	3.5 (5.8)	1.3 (3.6)	1.0 (1.0)	13 (22)
	$N_E = 2$ -	3.5 (3.5)	1.3 (1.3)	1.0 (1.0)	13 (13)
20 mT/m 120 mT/m/ms	$N_E = 3$ -	5.2 (5.2)	1.4 (1.4)	1.2 (1.2)	20 (20)
	$N_E = 2$ IP + OP	4.9 (6.0)	2.3 (2.3)	1.2 (2.3)	19 (23)
	$N_E = 2$ IP	4.9 (6.0)	2.3 (3.4)	1.2 (1.2)	19 (23)
	$N_E = 2$ -	4.0 (4.0)	1.4 (1.4)	1.2 (1.2)	15 (15)

Tab. 1. Comparison of repetition time TR, first echo time TE_1, echo spacing ΔTE (all in [ms]), and overall scan time T (in [s]) of liver protocols at 3.0 T (1.5 T) for two gradient systems and four Dixon methods, specified by the number of echo times N_E and possible constraints on one or more of them (IP: in-phase, OP: opposed-phase).

Results

The different scan times obtained at the two field strengths with two different gradient system configurations are compared in Tab. 1. For the first and fourth method, they are independent of the field strength and vary continuously with the performance of the gradient system. By contrast, they differ substantially between the two field strengths and vary discretely with the performance of the gradient system for the second and third method.

Selected water images, acquired in separate breath-holds on the same volunteer, are shown in Fig. 1. While a correct water-fat separation is achieved by all four methods, the two-point ones reach – with the same simple spectral model – a better suppression of subcutaneous fat. The SNR in the liver is slightly higher for the first method and comparable for the other methods.

The synthesis of in- and opposed-phase images from water and fat images is demonstrated in Fig. 2. No relevant differences were observed between these and actually acquired in- and opposed-phase images.

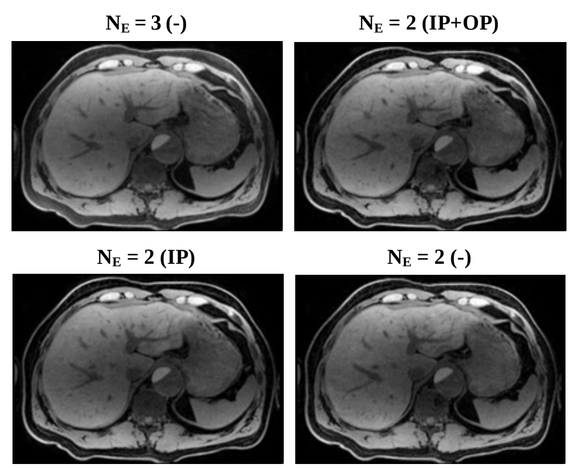

Fig. 1. Examples of water images obtained with the four investigated Dixon methods at 3.0 T.

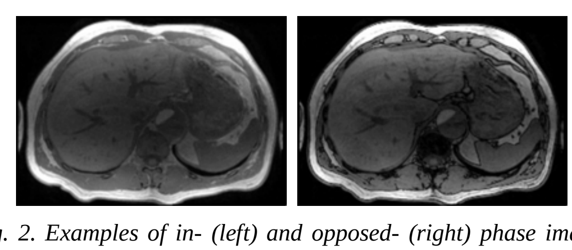

Fig. 2. Examples of in- (left) and opposed- (right) phase images synthesized with the first Dixon method.

Conclusions

Constraints on the echo times in Dixon imaging lead to less flexibility in the choice of protocol parameters and undesirable discrete variations of the scan time with changes in field strength, performance of the gradient system, and spatial resolution. Thus, some three-point methods may actually outperform some two-point methods. Moreover, in- and opposed-phase images may be reconstructed irrespective of the used echo times. Since no fundamental benefits in terms of robustness or SNR were observed either, such constraints should be avoided. The proposed new two-point method combines the flexibility of the considered three-point method with the in principle higher scan efficiency of two-point methods and permits in this way an acceleration of single breath-hold 3D gradient-echo abdominal protocols by up to 40%.

References

1. Reeder SB, et al. Magn Reson Med 2004; 51:35-45. 2. Ma J. Magn Reson Med 2004; 52:415-419. 3. Xiang QS. Magn Reson Med 2006; 56:572-584.