Phase-Correction Algorithms for Fat-Water Separation with Dual-Echo Sequences

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Introduction

Dual-echo sequences are advantageous for two-point fat-water separation studies, as both in-phase and out-of-phase echoes are acquired following each excitation, allowing coverage of large volumes within a breath-hold. Dual-echo images are often characterised by gradual phase changes along the readout direction, associated with asymmetric echoes and eddy currents. This work investigates the use of phase-correction algorithms [1] for fat-water separation with dual-echo pulse sequences. Phase drifts along the readout direction are quantified, and the value of correcting linear phase drifts prior to fat-water separation is investigated. In addition, we compare two different types of quality map to guide the region-growing process in phase-correction algorithms: the original quality map based on phase gradients [1] and a new quality map based on phase uncertainty.

Methods

Experimental: This work was undertaken at 1.5T (GE Signa HDMR/echo-speed gradients, Milwaukee, USA). A spoiled gradient-echo dual-echo sequence was employed to acquire both in-phase and out-of-phase complex images. A spherical object filled with $CuSO_4$ solution and oil was imaged at 10° with the oil-water interface, to provide a linear water-oil gradient. In addition, volunteers gave their informed consent in agreement with the Local Authority Ethics Committee guidelines and were scanned in common applications of fat-water separation techniques: joints, abdomen (liver) and parotids.

Algorithms: Two-point region-growing phase-correction algorithms were implemented in IDL (IDL 6.1, RSI, Boulder, Colorado, USA) using two different types of quality maps to direct the region-growing process:

(i) The original **Q**uality **M**ap that directs the region-growing process to areas where the **P**hase **G**radient is lowest (**PGQM**) [1].

(ii) A new **Q**uality **M**ap based on the **P**hase **U**ncertainty (**PUQM**). The phase uncertainty of either in-phase or out-of-phase images is inversely proportional to the image SNR [2]. The quadrature sum of the in-phase and out-of-phase images approximates the inverse of the phase uncertainty for uncorrelated noise sources, and the region growing process is directed to areas of lowest phase uncertainty.

Each of the two quality maps considered is employed twice: (I) directly to high resolution images (256 x 256), the **O**riginal **P**hase-**C**orrection method (**OPC**) and (II) starting with low resolution images and stepping towards the full resolution (64x64, 128x128 and finally 256x256) [3]. The later strategy on **V**oxel **S**ize **M**anipulation (**VSM**) has the advantage of starting the process with higher resolution images, and is less disturbed by partial volume effects. All algorithms were applied with and without pre-processing of the images to remove the linear phase drift along the read out direction prior to fat-water separation. Therefore each dataset was processed 8 times, and the results were compared.

Results

Results are summarised on Table 1. After subtraction of the in-phase phase map from the out-of-phase, the linear component of the remaining phase drift along the readout direction ranged from 4.1°/pixel to 1.1°/pixel (Figure 1). The linear phase drift depends on geometric parameters (FOV, gradient directions) and varies slightly slice to slice within datasets (Table 1 lists mean values). Only for the datasets with phase drifts above 3º/pixel the pre-processing to remove the phase drift significantly improves the performance of phase-correction algorithms. VSM algorithms perform significantly better than the OPC algorithm. The quality map based on phase uncertainty may offer some advantages in test objects, but proved problematic in images with flow-related phase shifts. In thin head slices (Parotids low SNR) blood vessels caused errors which propagated to larger areas of the images.

Discussion

Eddy currents are likely to be a significant factor in generating phase drifts. All algorithms tolerated some degree of phase drift along the readout direction. The VSM algorithm outperformed the OPC algorithm in all applications, indicating that the advantages of VSM algorithms extend beyond the parotid images studied previously [3]. Quality Maps based on Phase Uncertainty may require saturation bands to suppress in-flow effects.

Table 1

Subject	mean phase drift (degree per pixel)	Nb of images in dataset	Nb of images with errors							
			Without pre-processing				With Pre-processing			
			PGQM		PUQM		PGQM		PUQM	
			OPC	VSM	OPC	VSM	OPC	VSM	OPC	VSM
TestObj 1	-2.6	5	5	1	1	0	2	0	1	0
TestObj 2	-2.6	4	0	0	0	0	1	0	1	0
TestObj 3	2.6	4	4	0	2	4	2	1	1	0
TestObj 4	4.1	5	5	2	0	0	2	0	0	0
Parotids (low SNR)	1.3	25	4	0	11	0	4	0	13	2
Parotids (high SNR)	-3.5	15	0	2	1	2	0	0	1	0
Abdomen	-1.8	20	12	1	10	3	6	3	12	3
Knee	-1.3	16	0	0	0	0	0	0	0	0
Ankle	-1.1	16	0	0	1	0	0	0	1	0

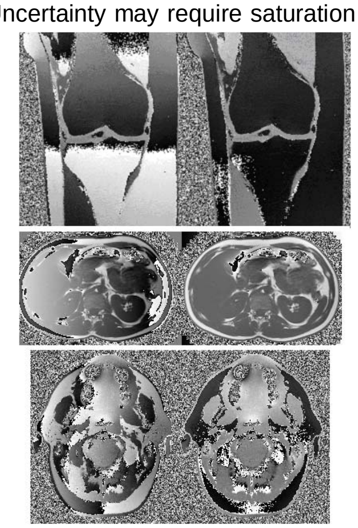

Figure1- Phase maps before (left) and after (right) pre-processing to remove linear phase shift.

References

1. J Ma, Magn. Reson. in Med 52:415-419 (2004).
2. TE Conturo and GD Smith, Magn. Reson. in Med. 15,420-437 (1990).
3. M.A. Schmidt and K.M. Fraser, Proceedings14th ISMRM Meeting, p.2401 (2006).