Phase and Amplitude Correction in Bipolar Multi-Gradient-Echo Water-Fat Imaging

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Introduction

The use of bipolar readout gradients promises to further improve the efficiency of multi-echo water-fat imaging with chemical shift-based separation. It entails mismatches between the signal from odd and even echoes, however, which mislead generalized multi-point Dixon methods [1]. These mismatches are mainly caused by eddy currents and by shifts of the fat signal in opposite directions [2]. In this work, an approach to resolve this problem is proposed, which appears particularly suited for applications in continuously moving table whole-body imaging [3]. It involves the selection of high receive bandwidths to neglect the shift of the fat signal [4], and the acquisition of more echoes per repetition time to preserve a sufficiently long encoding time and thus high signal-to-noise ratio and to permit a spatially resolved estimation and subsequent correction of phase and amplitude errors.

Methods

To accommodate the phase and amplitude differences that are caused by opposite readout gradient polarity, the composite signal s_k from echo k, acquired at time t_k, is modeled in image space by

$$s_k = (s_W + s_F\,e^{i2\pi f_{WF} t_k})\,e^{i2\pi f t_k} \cdot \begin{cases} 1 & , k = 1, 3, ... \\ e^{\alpha + i\beta} & , k = 2, 4, ... \end{cases}.$$

s_W and s_F denote the water and fat signal, and f_{WF} and f denote the resonance frequency offset due to chemical shift and main field inhomogeneity. The exponential $e^{\alpha+i\beta}$ serves the phase and amplitude correction of the signal from even echoes. It may be linearized in the same manner as $e^{i2\pi f_{WF} t_k}$, allowing both to be treated alike in the water-fat separation [1], but requires a more careful choice of the step width in the iteration. As to the field map f, a non-linear local filter was applied to both e^{α} and β to further stabilize the fit.

Imaging was performed on healthy volunteers with a 1.5 T Achieva scanner (Philips Medical Systems, Best, The Netherlands). A volume of 52x30x200 cm^3 was covered with an isotropic resolution of 5.4 mm. Five echoes with a TE/ΔTE of 1.3 ms/0.7 ms were sampled in a TR of 5.3 ms, leading to a fat shift of ±0.045 pixels. The table advanced perpendicular to the frequency encoding direction, which was left-right, with 14 mm/s. The total scan time amounted to 146 s.

Results

Fig. 1 summarizes results of applying the proposed extended fit to one of the acquired 3D whole-body data sets. The phase and amplitude error maps demonstrate the feasibility of estimating both simultaneously with the field map and the water and fat signal spatially resolved. The fit error maps underline the achieved improvement in modeling the composite signal's evolution and consequently in separating the water and fat signal. The phase error map exhibits not only a linear variation in readout direction, as to be expected from gradient delays, but also a non-linear variation both in readout and preparation direction. The complex spatial dependence is even more apparent in the amplitude error map, which shows noticeable variations in particular towards the head and the legs, where the asymmetric frequency characteristic of the body coil used for signal reception manifests itself because of varying load conditions.

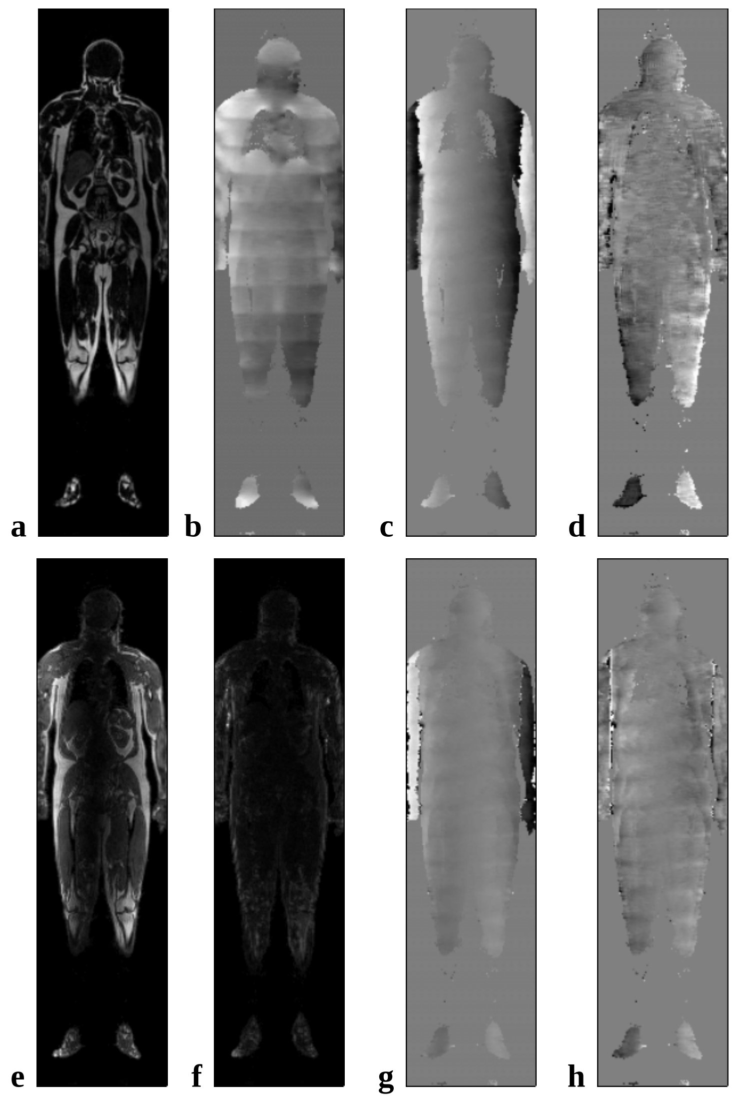

*Fig. 1. Results for a selected coronal slice. The shown fat image (**a**), field map (**b**), and phase (**c**) and amplitude (**d**) error maps were estimated from five images acquired at increasing echo times. The fit error reduces from (**e**) to (**f**) using the phase and amplitude error maps to correct the signal from even echoes. The subtraction of a linear (**g**) and non-linear (**h**) variation in readout direction from the phase error map reveals an underlying, more complex spatial dependence of the phase error. The periodic variation in preparation direction is due to the continuous table movement during the measurement of the 3D whole-body data sets.*

Discussion

The mapping of phase and amplitude differences in image space between the signal from odd and even echoes in bipolar multi-gradient-echo imaging permits to address both gradient system and receive coil imperfections and to eliminate associated artifacts in separated water and fat images. The proposed approach does not rely on initial calibration measurements and thus readily copes with spatial variations of eddy currents and loading. The information gained on phase and amplitude differences may also form the basis for correcting subsequent localized scans.

References

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