High-Resolution T_1-Weighted Imaging of the Breast with a Flexible Dual-Echo Dixon Method

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Introduction

Dixon methods hold the promise of improving the homogeneity and extent of fat suppression in breast imaging [1,2]. However, they require in general the acquisition of at least two echoes with different echo times for a separation of water and fat signals and thus reduce the achievable spatiotemporal resolution, which is particularly critical in dynamic contrast-enhanced imaging to fully capture both morphological and kinetic information. Traditionally, Dixon methods demand water and fat signals to be in-phase or out-of-phase at the individual echo times. Given the performance of current gradient systems, this commonly leads to a substantial loss in spatiotemporal resolution at 1.5 T due to the comparatively long first in-phase echo time of 4.6 ms, and to a fundamental restriction of the spatial resolution at 3.0 T due to the comparatively short first out-of-phase echo time of 1.15 ms. In this work, these limitations are addressed by employing a recently proposed dual-echo Dixon method with flexible echo times [3], and the relevance of an accurate modeling of the fat signal is demonstrated in this context.

Methods

The composite signal S in image space at two echo times TE_1 and TE_2 is given by:

$$S_1 = (W + c_1 F)\, e^{i\varphi} \quad \text{and} \quad S_2 = (W + c_2 F)\, e^{i(\varphi+\Delta\varphi)},$$

where W and F are the water and fat signals in image space, φ and $\Delta\varphi$ are phase errors, and c_1 and c_2 are complex coefficients that describe the amplitude and phase of a unit fat signal at TE_1 and TE_2. The latter are given by $c_n = e^{2\pi i f_1 TE_n}$ for a single-peak and by $c_n = \Sigma_m\, w_m\, e^{2\pi i f_m TE_n}$ for a multi-peak spectral model of fat, where f_m is the resonance frequency offset of the m^{th} spectral peak of fat relative to water, and w_m is the corresponding normalized resonance area. While f_m is considered as known, w_m is either calibrated once, leading to fixed spectral models such as the seven-peak model employed in this work, or anew for each protocol or patient [4,5]. The data available in dual-echo imaging are in general insufficient for an autocalibration of w_m. However, the separation of water and fat signals does not require knowledge of w_n, but only of c_1 and c_2 [6]. Therefore, c_1 and c_2 were alternatively determined by a direct autocalibration in this work, based on an initial identification of pure fat voxels. The calculation of the solutions of the signal equations for the two echo times and the selection of one of them for each voxel were then carried out as described previously [3].

Patients were examined on a 3.0 T scanner with parallel transmission (Philips Healthcare, Best, The Netherlands), using a 16-element receive coil. A 3D T_1-weighted spoiled dual-gradient-echo sequence with a typical TE_1/TE_2/TR of 1.9/3.4/5.1 ms was inserted after dynamic contrast-enhanced imaging to acquire two source images for retrospective water-fat separation. A typical FOV of 340 x 340 x 200 mm^3 was covered with an actual resolution of 0.8 x 0.8 x 1.6 mm^3 and reconstructed to a nominal resolution of 0.6 x 0.6 x 0.8 mm^3. A sixfold acceleration by parallel imaging led to a total scan time of less than 60 s.

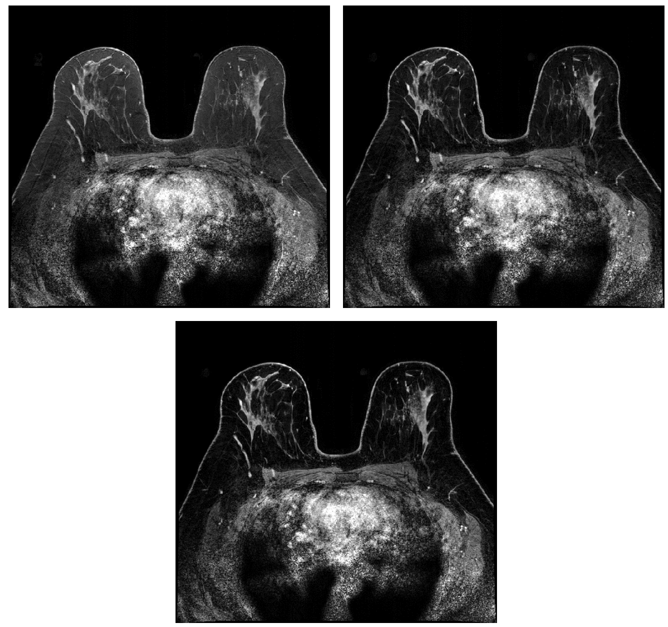

Fig. 1. Water images produced from the same dual-echo acquisition using a fixed single-peak (left), a fixed seven-peak (right), and a calibrated (bottom) spectral model of fat in the separation.

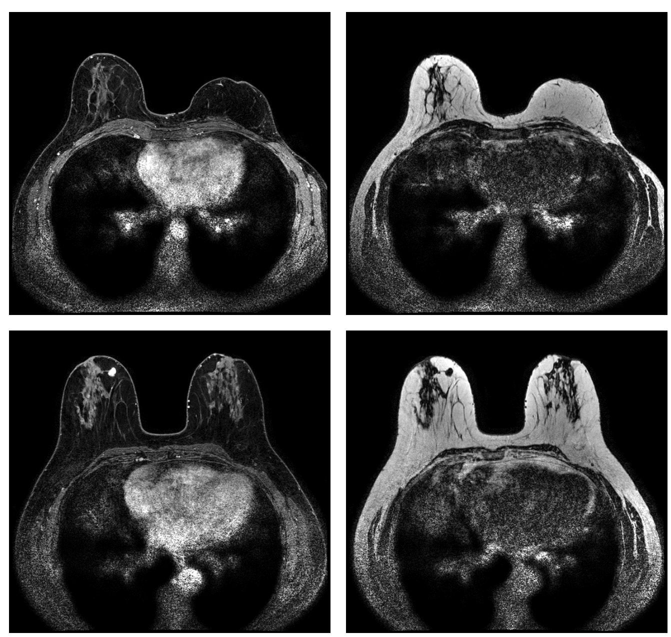

Fig. 2. Water and fat images separated with a fixed seven-peak spectral model of fat.

Results

The relevance of an accurate modeling of the fat signal is illustrated in Fig. 1. The high spatial resolution leads to water and fat signals being closer in phase at TE_1 than at TE_2. Under this condition, the extent of fat suppression is poor using a fixed single-peak model, but excellent using a fixed seven-peak model. A direct autocalibration of the coefficients c_1 and c_2 yields no further improvement. Water and fat images obtained in two other patients with the fixed seven-peak model are shown in Fig. 2. A lesion in the right breast is clearly portrayed in the second case.

Conclusions

By relaxing restrictions on the echo times, the employed dual-echo Dixon method allows to overcome limitations on the spatiotemporal resolution experienced with other Dixon methods in breast imaging. It enables T_1-weighted imaging at 0.8 mm acquired in-plane resolution in less than 60 s at 3 T, even without refraining to ramp or partial echo sampling. The selected fixed seven-peak spectral model of fat proved to be sufficient for an excellent fat suppression.

References

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