High-Resolution T₁-Weighted Imaging of the Breast with a Flexible Dual-Echo Dixon Method
Holger Eggers1, Marko K Ivancevic2, Gillian M Newstead3, and Gwenael Herigault4
1Philips Research, Hamburg, Germany, 2Philips Healthcare, Cleveland, OH, United States, 3University of Chicago Medical Center, Chicago, IL, United States, 4Philips Healthcare, Best, Netherlands

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 TE₁ and TE₂ is given by:

\[ S_n = (W + c_1 F) e^{i\phi} \quad \text{and} \quad S_2 = (W + c_2 F) e^{i(\phi + \Delta \phi)}, \]

where W and F are the water and fat signals in image space, \( \phi \) and \( \Delta \phi \) are phase errors, and \( c_1 \) and \( c_2 \) are complex coefficients that describe the amplitude and phase of a unit fat signal at TE₁ and TE₂. The latter are given by \( c_n = e^{i\phi_n} \) for a single-peak and by \( c_n = \sum w_m e^{i\phi_m} \) 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 \( w_m \) 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 T₁-weighted spoiled dual-gradient-echo sequence with a typical TE₁/TE₂/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 mm³ was covered with an actual resolution of 0.8 x 0.8 x 1.6 mm³ and reconstructed to a nominal resolution of 0.6 x 0.6 x 0.8 mm³. A sixfold acceleration by parallel imaging led to a total scan time of less than 60 s.

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 TE₁ than at TE₂. 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 T₁-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