Jointly-Processing Fast Spin-Echo Triple-Echo Dixon Images with a Two-Point Dixon Phase Correction Algorithm

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Introduction: Fast spin echo (FSE) triple-echo Dixon (fTED) sequence replaces each FSE readout gradient with a set of fast-switching triple echo readout gradients and does not require interleaved acquisitions for generating Dixon water and fat separated images.[1] In its original implementation, three images corresponding to the triple echo readout are timed to have water and fat signals out-of-phase, in-phase, and out-of-phase, respectively. In post-processing, the first out-of-phase image and the in-phase image are fed into a two-point Dixon processing algorithm to produce a first set of water and fat separated images. Independently, the second out-of-phase image and the same in-phase image are fed into the same two-point Dixon processing algorithm to produce a second set of water and fat separated images. The two sets of water and fat separated images are then combined for a final pair of water and fat separated images for improved SNR.

A potential drawback of independently processing the images is that any local failure in the two-point Dixon processing or a failure in consistently identifying the two sets of separated images before the final image combination will lead to incomplete local or global water and fat separation. In this work, we propose to address the issue by jointly (rather than independently) processing the two sets of the images in a multi-seeded and multi-leveled region growing based two-point Dixon phase correction algorithm.[2] The proposed approach was shown to be capable of reconstructing uniformly separated water and fat images even when anatomic regions are separated by large signal-void.

Method: The raw fTED images from the triple echo readout are expressed as:

$S_- = (W-F)e^{i(\phi_0-\phi_-)}$; $\quad S = (W+F)e^{i\phi_0}$; $\quad S_+ = (W-F)e^{i(\phi_0+\phi_+)}$;

where W and F represent magnitudes of water and fat signals, respectively. ϕ_0 is the echo shift-independent phase-error. ϕ_- and ϕ_+ are non-chemical shift related phase errors accumulated between the 1st and the 2nd echoes and between the 2nd and the 3rd echoes, respectively. Since $e^{i\phi_0}$ can be easily extracted from S, the task of determining W and F boils down to determining $e^{i\phi_-}$ and $e^{i\phi_+}$. Mathematically, this is equivalent to determining the correct vector solution from two possible vector candidates **A** and **B** from the first pair of images and another vector solution from two other possible vector candidates **A**' and **B**'.[3-5]

It is important to realize that selecting **A** or **B** from the first pair of images (or similarly selecting **A**' and **B**' from the second pair of images) as the vector solution for a given pixel is equivalent to deciding whether the pixel is water or fat-dominant. Since a given pixel can only be either water-dominant or fat-dominant and since the first pair and the second pair of images are acquired from the exactly same locations, the correct solutions from the two pairs of images should only be either **A** and **A**', respectively, or **B** and **B**', respectively. In this work, we incorporated this constraint in a multi-seeded and multi-staged region growing based two-point Dixon phase correction algorithm[2]: the region growing for the two pairs of images is performed concomitantly and follows the same path of growth. The result from the region growing initiated from a seed pixel is accepted only when the first pair and the second pair of images yielded a consistent result (i.e., either **A** and **A**', or **B** and **B**'). Otherwise (e.g., if the results were either **A** and **B**', or **B** and **A**'), the region growing from the chosen seed will be aborted and a new seed pixel is used for another round of region growing. By delaying the decision making for those inconsistent pixels until all the consistent pixels have first been processed, the possibility of local failure in phase correction or global misidentification is virtually eliminated. Once $e^{i\phi_-}$ and $e^{i\phi_+}$ are jointly determined, they can be removed from S_- and S_+ to produce two pairs of water and fat separated images, which are combined for a final set of water and fat output images.

Experiment and Results: The proposed algorithm was implemented in MATLAB (MathWorks) and was used to process in vivo images acquired with the fTED sequence. Fig. 1 shows a case in which the original region growing based algorithm[1] yielded inconsistent water and fat separation for the right leg between the first pair of images (W1 and F1) and the second pair of images (W2 and F2) from a coronal fTED acquisition of two legs. As a result, the final combined water and fat separated images (W and F) do not have clean water and fat separation. In contrast, the consistency constraint in the proposed algorithm forced the region growing to select a new seed and start a new round of region growing that produced consistent and uniform water and fat separated images in Fig. 2.

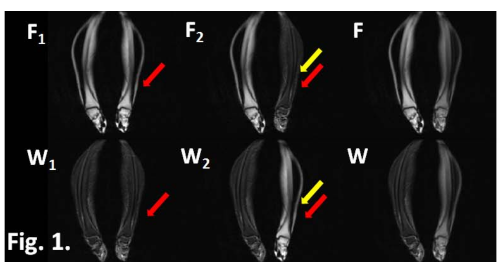

Fig. 1.

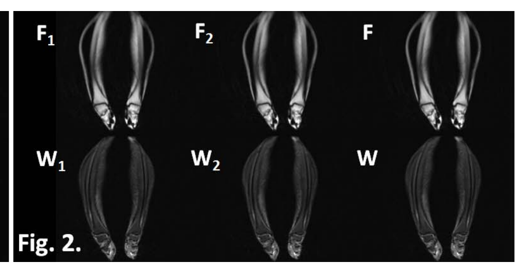

Fig. 2.

Discussion: In general, phase-correction in Dixon based imaging becomes challenging and is subject to errors when the background phase becomes "unsmooth". The phase "unsmoothness" can be a result of a multitude of causes such as noise and artifacts. Processing the "smoother" pixels first has been shown to greatly improve the robustness of the phase correction.[2] For the fTED data, the availability of the two pairs of images for the same location allowed cross-checking the decision-making in phase correction and delaying the processing of the inconsistent pixels in the multi-seeded multi-leveled region growing algorithm. This "joint-processing" strategy decreases the computation time and greatly increases the robustness of phase correction in the challenging pixels. The same approach can be helpful in other applications such as phase-sensitive inversion recovery imaging with multiple receivers.[6,7]

References: [1] Ma J, et. al., MRM 2007;58(1):103-109. [2] Ma J, et. al., ISMRM 2013. p. 2414. [3] Xiang QS. MRM 2006;56(3):572-584. [4] Berglund J, et al. MRM 2011:65(4):994. [5] Ma J. ISMRM 2011. p. 2707. [6] Xiang QS, JMRI 1996;6(5):775-872. [7] Ma J. MRM 2005;53(4):904-910.