Automatic Virtual Shimming for Robust Fat Suppression in Subtractionless First-Pass Peripheral Angiography

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Target Audience: Physicists and clinicians interested in chemical shift encoding-based water-fat imaging and contrast-enhanced angiography

Purpose: A subtractionless approach to first-pass peripheral angiography based on dual-echo Dixon imaging has recently been proposed[1]. By eliminating the subtraction, it increases the signal-to-noise ratio and reduces motion artifacts compared with the established subtraction approach[2]. However, it relies on a homogeneous fat suppression across large field of views to achieve high contrast between vasculature and background, especially in maximum intensity projections. This is particularly challenging in the lower legs, since the center of the field of view typically remains empty, rendering the resonance frequency determination and shimming less reliable, and the legs appear to be disconnected. In the present work, the previously proposed concept of virtual shimming is adopted[3]. An automated implementation is described and demonstrated to improve the robustness of the fat suppression in the lower legs in difficult cases.

Methods: Unlike real shimming, virtual shimming is performed retrospectively on acquired data and requires neither additional scan time nor additional scanner hardware. It aims at removing spatial variations in the phase of source images that result from large main magnetic field gradients. For an unsupervised execution, first, a rough selection of voxels likely containing water only is made. The two source images were reconstructed at a reduced resolution, and voxels were chosen based on the signal amplitude at the two echo times TE_1 and TE_2. The criteria included a minimum relative signal amplitude to mask out noise, a maximum relative signal amplitude to mask out fat and unavoidably contrast-enhanced vasculature, and a maximum relative signal amplitude variation between TE_1 and TE_2 to mask out voxels containing both water and fat. Then, predefined functions, which mimic local or global, first or higher order real shimming, are fitted to the phase difference between the two source images in all identified voxels. A signal amplitude-weighted estimation of constant gradients in the three spatial dimensions and of a constant offset was carried out, using a phasor representation to avoid unwrapping[4]. Finally, the spatial variations in the phase difference modeled in this way are eliminated from the two source images, and a standard water-fat separation is applied[5].

The described approach was evaluated on 5 problematic subtractionless first-pass peripheral angiography examinations, performed on patients after administration of 0.1 mmol/kg Gadobutrol (Bayer Healthcare, Berlin, Germany) on a 1.5 T Ingenia scanner (Philips Healthcare, Best, The Netherlands) with a 3D T_1-weighted spoiled dual-gradient-echo sequence (TE_1/TE_2 = 1.8 ms/3.2 ms)[1].

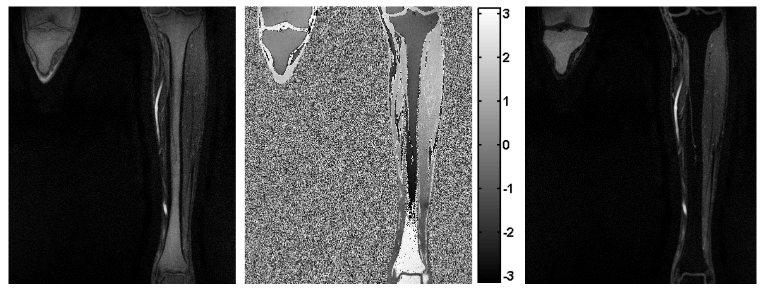

Fig. 1. Magnitude of one source image (left), phase difference between two source images (middle), and water image (right) produced from a bipolar dual-gradient-echo acquisition.

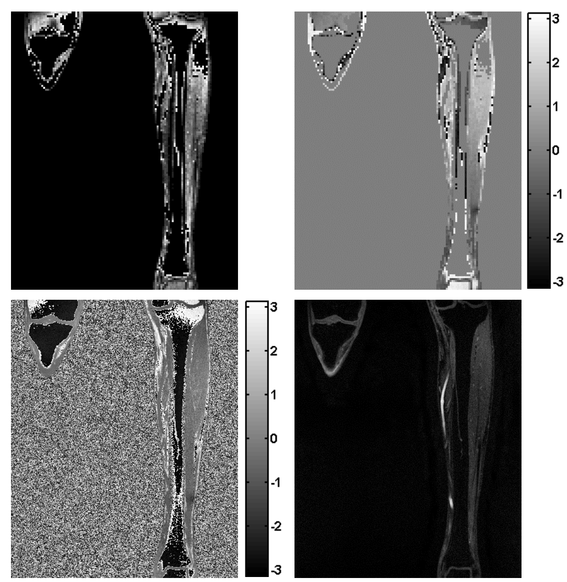

Fig. 2. Magnitude (top left) and phase difference (top right) from Fig. 1 after image decimation and voxel selection, which serve as basis for the proposed automatic virtual shimming, and resulting phase difference (bottom left) and water image (bottom right).

Fig. 3. Coronal maximum intensity projections of water images produced without (left) and with (right) the proposed automatic virtual shimming.

Results: The demanding case of a patient with an amputated lower right leg is illustrated in Figs. 1-3. The phase difference between the two source images in Fig. 1 indicates a large main magnetic field offset between the two legs, causing a complete swap of water and fat signal in one of them. The selected voxels shown in Fig. 2 were obtained with a non-optimized upper bound of 30% of the maximum signal amplitude, yielding constant gradients of 7 µT/m, 9 µT/m, and -21 µT/m in x, y, and z direction, respectively, and a resonance frequency offset of 43 Hz. As also evident from Fig. 3, the virtual shimming led to a suppression of the swap in this case. Similarly, all swaps in the other cases were successfully removed.

Discussion: The proposed approach restricts the fitting to voxels containing non-contrast-enhanced water only. These sufficed in all considered cases for a robust estimation, even if some voxels were misclassified. Alternatively, voxels containing fat only could be included as well by fitting to the phase difference raised to an appropriate power, such that the chemical shift difference between water and fat is mapped to a phase difference of 2π for the given echo spacing[6]. However, this failed at eliminating all swaps in one of the cases. A more extensive evaluation is required to thoroughly compare both options.

References: 1. Leiner T, et al. Eur Radiol 2013; 23:2228-2235. 2. Ho KY, et al. Radiology 1998; 206:683-692. 3. Xiang QS. Proc ISMRM 2012; Workshop on Fat-Water Separation. 4. Ahn CB, et al. IEEE TMI 1986; 6: 32-36. 5. Eggers H, et al. MRM 2011; 65:96-107. 6. Ma J, et al. MRM 2008; 60:1250-1255.