Single-point fat-water separation using a fuzzy C-means algorithm

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Introduction: Field map estimation is an essential step in all Dixon-based fat-water separation techniques [1]. While multi-point approaches, where images are acquired with different echo times (TEs), can accurately calculate the field map, a single-point (1-pt) fat-water separation is highly desirable when scanning speed is the most import factor [2]. The bias-corrected fuzzy C-means (BCFCM) clustering technique [3], previously used for segmenting MR brain images, simultaneously compensates for intensity inhomogeneities while segmenting the image. We expect that the BCFCM algorithm can be used to, at least roughly, estimate the field map and separate fat-water signals from phase images acquired at a single TE. The performance of the proposed BCFCM-based 1-pt method is demonstrated with a set of volunteer ankle images.

Algorithm: The proposed 1-pt fat-water separation approach is described as follows: 1) combine the complex images from all channels and unwrap aliased phase; 2) generate raw fat-like and water-like masks using BCFCM; 3) generate a raw field map by shifting the phase values of the fat-like pixels; 4) generate a refined field map by smoothing the raw field map; 5) perform fat-water separation by using the field-corrected phase information.

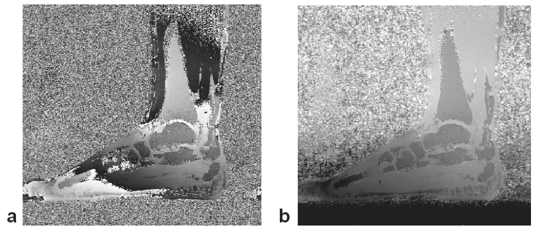

Figure 1. The wrapped (a) and the unwrapped (b) phase images of the channel-combined complex images at central sagittal position.

Methods: The product IDEAL pulse sequence [4] was used to acquire sagittal images of an ankle (flip angle = 10°, field view = 26 cm × 26 cm × 6.4 cm, slice thickness = 1 mm, matrix size = 512 × 512 × 64); three echoes were acquired, such that the phase offsets between fat and water are equal to $5\pi/6$, $3\pi/2$ and $13\pi/6$, denoted as S_{c-}, S_c and S_{c+}, respectively. Only the S_c data set was used to evaluate the proposed 1-pt technique. The fat and water images generated by the product IDEAL reconstruction were used as a reference. Images were also generated using data from two echoes. All experiments were performed on a GE 3.0-T whole-body MRI scanner using an eight-channel ankle coil.

The field maps were estimated from channel-combined images generated from the complex sum of all channels. Phase unwrapping was performed using the PUROR algorithm [5]. The field maps were used to calculate separated fat and water images on a channel-by-channel basis based on the phase information [6]. The final channel-combined fat-water images were generated using the sum of squares method. All processing was performed using MATLAB (USA); the BCFCM algorithm was coded in MATLAB by Dr. Dirk-Jan Kroon.

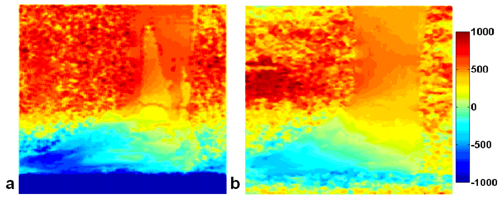

Figure 2. The field map (Hz) generated from the Sc data set (a) and all three data sets (b).

Results: Figure 1 demonstrates that the phase unwrapping technique successfully removed the phase aliasing for the channel-combined images. Applying the BCFCM algorithm directly to the sagittal images (Fig. 1b) would have resulted in severe artifacts in the region of the distal foot. Instead, we applied BCFCM in the axial plane for analysis, but have displayed the data in the sagittal orientation. Shown in Fig. 2 are field maps of the ankle generated using the central echo only (a) and using all three echoes (b) of the IDEAL data acquired. The 1-pt field map agrees well with the 3-pt field map in the vicinity of the inferior tibiofibular, talocrural, and talocalcaneal joints. Differences between the 1-pt and 3-pt field maps are most pronounced around the toes and sole of the foot; these are attributed to large field inhomogeneities, due to inadequate shimming and/or susceptibility variations. Figure 3 reports the fat-water images separated using the 1-pt and the IDEAL methods. While higher SNR was observed for the IDEAL method, overall, Fig. 3 clearly demonstrates the success of the proposed 1-pt technique. Using two echoes, with the BCFCM algorithm, resulted in fat-water separation with higher SNR than the 1-pt analysis, as expected (detail not shown).

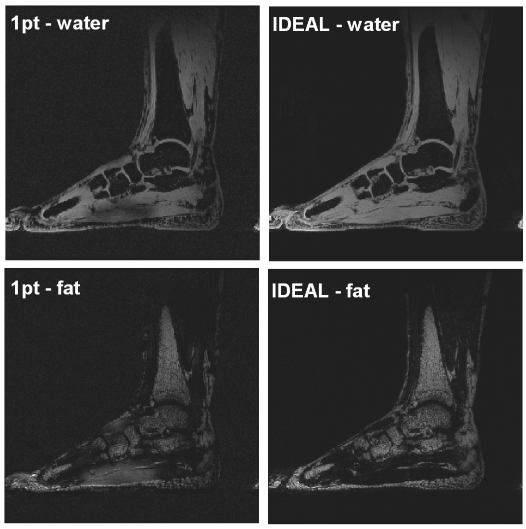

Figure 3. Water (top) and fat (bottom) images obtained using the 1-pt method (left) compared to IDEAL (right).

Discussion: This report is the first to demonstrate that fat-water separation is achievable from single-echo imaging and BCFCM analysis. While the data processing was performed in the axial plane, a smooth sagittal field map was generated over the entire field of view in the superior/inferior direction. In the current experiment the 1-pt technique was applied to a data set acquired using the IDEAL technique, which provided a reference for comparison. Ultimately, for rapid fat-water separation faster single–echo sequences (e.g. SSFP) are expected to provide an optimal compromise between rapid scan time, accuracy, and SNR.

References: [1] Dixon, Radiology 153:189-194, 1984. [2] Yu, et al., MRM 55:413-422, 2006. [3] Ahmed, et al., IEEE Med Imag 21: 193-199, 2002. [4] Reeder, MRM 51: 35-45, 2004. [5] Liu and Drangova, MRM 68: 1303-1316, 2012. [6] Liu, et al., ISMRM 3289, 2012.