Water fat opposed phase (WFOP) sequence is a robust fat suppression technique under the presence of B0 inhomogeneity in abdominal MRI at 3.0 T.

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Introduction: MR imaging at 3T can make use of good frequency separation between fat and water, although magnetic field (B0) inhomogeneity and RF field (B1) inhomogeneity result in unexpected behavior of excited spins, which appear as insufficient fat suppression or unwanted signal loss. When obtaining spin-echo T1-weighted images (SE-T1W), chemical-shift-selective (CHESS) pulse is convenient for its relatively low SAR, but this technique is susceptible to both B0 and B1 inhomogeneity. Spectral adiabatic inversion recovery (SPAIR) is preferred for clinical usage at 3T because of its robustness to B0 and B1 inhomogeneity, but is sometimes ineffective for suppression of superficial adipose tissue or intra-orbital fat. Water fat opposed phase (WFOP) sequence is an asymmetric spin-echo (SE) sequence combined with CHESS pulse which was proposed almost 20 years ago [1]. Following CHESS, excitation and refocus pulses, echo center for the WFOP sequence is offset by means of readout gradient so that the echo is formed with fat and water in opposite phase. This study aimed to optimize the WFOP sequence and evaluate its robustness in abdominal MRI at 3T by comparing it to conventional SE-T1W with CHESS or SPAIR pulse.

Materials and Methods: Axial pelvic SE-T1W images were obtained with the WFOP sequence and compared with conventional SE-T1W with CHESS or SPAIR pulse. The CHESS pulse flip angle for WFOP sequence was varied between 90-110°. SE-T1W images without fat suppression were also obtained. The following parameters were identical for all sequences: TR/TE = 600/15ms, flip angle = 90/180, matrix = 320*320, FOV = 30x40cm, 5slices, slice thickness/gap = 7mm/7mm, readout BW = 163Hz/pixel. Images were acquired using a 3T MR whole-body research system equipped with 16-channel body array coil and 32-channel spine array coil. 7 healthy volunteers (3 males, 4 females) were included. Images were post-processed by in-house software using Matlab (Mathworks, Nattick, Mass) so as to calculate the following four quantitative values.

1. Mean and standard deviation of signal intensity (SI) of all voxels
2. Mean and standard deviation of SI of fat voxels
3. Inhomogeneity index = (number of voxels exceeded mean + 2SD of the SI of total volume) / number of voxels of fat in total volume
4. Mean relative SI drop of fat = 1 - (signal intensity of fat with fat suppression / signal intensity of fat without fat suppression)

Binary images for voxels that exceeded the threshold of mean + 2/2.5/3SD were created. The correspondence of the binary images with "bright fat" due to incomplete fat suppression was visually evaluated. Qualitative analysis was performed by two radiologists, who independently evaluated the overall quality of the images by using a five-point scale: 5-excellent: homogenous, 4-good: diagnostic but slightly inhomogeneous, 3-moderate: diagnostic but noisy, 2-poor: inhomogeneous, 1: not evaluable: nondiagnostic.

Results: Binary images using a threshold of mean + 2SD best corresponded with visually evaluated "bright fat" in grayscale images (Fig.1). Using this measure, the inhomogeneity index was lowest for WFOP compared to CHESS and SPAIR (Fig.2). The inhomogeneity index was lowest for WFOP with a 90° CHESS pulse.

Mean relative SI for all voxels was similar across all sequences (Fig. 2). SPAIR image quality was rated highest by visual evaluation although its mean SI of suppressed fat was highest. The average visual evaluation score for WFOP was lower as those for CHESS or SPAIR (Fig.2). Signal drop from T2* dephasing was present in the WFOP images due to the offset of the RF echo relative to the readout gradient echo. In several cases, chemical shift of the 2nd kind degraded images with WFOP at the interface between fat and soft tissue (Fig. 3).

Discussion: The combined effect of CHESS pulse + WFOP chemical shift (of the 2nd kind) effectively works for robust fat suppression. In several cases, WFOP was effective at reducing SI in voxels of "bright fat" even in the presence of B0 inhomogeneity, which were not efficiently suppressed by other sequences.

The fat suppression effect of WFOP might be caused not only by the primary mechanism of the cancellation of water and fat magnetization vectors due to their opposed phase, but also from the offset of the RF and readout gradient echoes which results in intravoxel spin dephasing (T2* decay). This secondary source of signal loss also affects water, as noted above. However, since a majority of fat lies in the periphery, where B0 inhomogeneity is typically highest, and T2* for tissue water is generally longer than T2* for fat, this secondary source may contribute to a greater reduction of fat signal than water signal creating an additional fat suppression effect.

Conclusion: The combination of WFOP with 90° CHESS pulse robustly suppressed fat in SE-T1W abdominal images. WFOP produces images with uniform fat suppression across the entire field-of-view.

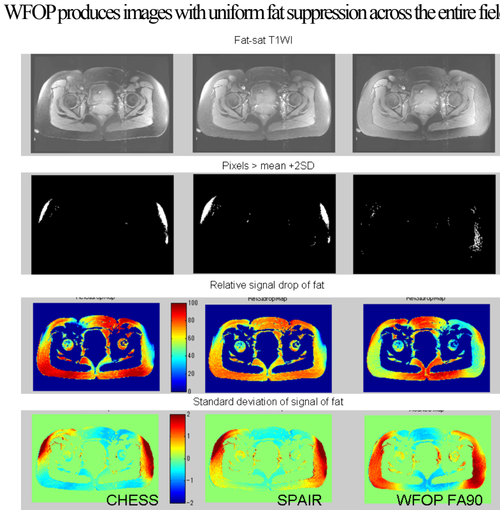

Figure 1

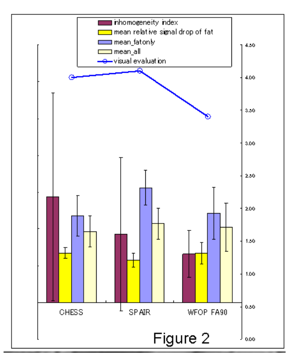

Figure 2

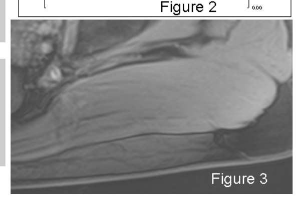

Figure 3

Reference: [1] Chan TW, Listerud J, Kressel HY. R Combined chemical-shift and phase-selective imaging for fat suppression: theory and initial clinical experience. Radiology. 1991 Oct;181(1):41-7.