# 3D $T_2$-Weighted Black Blood Vessel Wall Imaging with Uniform Fat and Water Separation

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**Introduction:** High-resolution vessel wall imaging is critical to assess atherosclerotic plaque morphology and tissue composition. Often vessel wall images are acquired with black blood imaging to increase the lumen to wall contrast. Commonly used black-blood preparations such as inflow suppression and double inversion recovery are optimized for 2D axial imaging and, when used for 3D imaging, can produce sub-optimal blood suppression (1). Recent developments in motion-sensitizing driven equilibrium (MSDE) preparations have enabled black-blood imaging with good blood suppression in both 2D (2) and 3D acquisitions (3).

Evaluation of plaque composition is aided by the acquisition of vessel wall images with and without fat suppression (4). Current black blood imaging techniques use fat saturation, which can suffer from non-uniform saturation in the presence of $B_0$ and/or $B_1$ inhomogeneities. Additionally, images acquired with and without fat suppression from separate acquisitions are prone to mis-registration. In this work, we have integrated a modified 2-point chemical-shift technique (5) with 3D FSE based acquisition (6) and MSDE preparation to reconstruct high-resolution 3D $T_2$-weighted black blood vessel wall images with and without fat suppression from a single acquisition.

**Methods:** An investigational version of 3D-FSE, which uses variable refocusing flip angles and extended echo trains (6), was used in our study. The sequence was modified to acquire two echoes with fat and water in-phase and out-of-phase respectively in two sequential repetitions. The two echoes were then processed with a modified 2-point Dixon method (5) that reconstructs separate fat and water images. This reconstruction uses an efficient and robust phase-correction algorithm and has been shown to produce images with uniform fat and water separation even in the presence of $B_0$ inhomogeneities (7).

An MSDE preparation module using $90_x$, $180_y$, $90_{-x}$ and motion sensitizing gradients was inserted in front of the modified 3D-FSE acquisition. The motion sensitizing gradients induce additional phase in moving tissue while preserving the static tissue signal. The $90_{-x}$ at the end returns the static tissue signal to the longitudinal axis, while the residual transverse magnetization of the moving tissue is dephased using killer gradients.

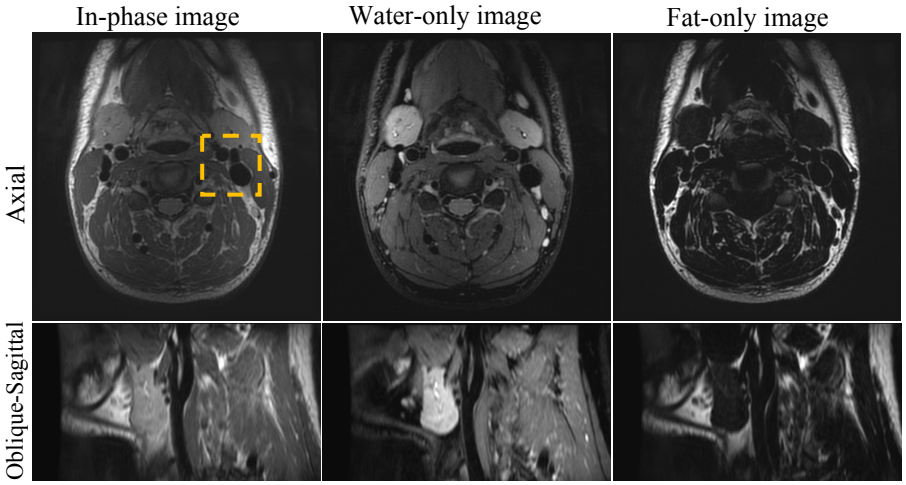


Fig. 1. Normal volunteer images without (in-phase) and with (water-only) fat suppression acquired from the same acquisition. Note the uniform fat suppression and black blood throughout the volume.

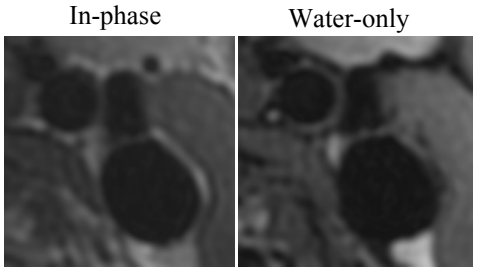


Fig. 2. Enlarged regions of the vessel cross-section from fig. 1.

The sequence was tested on 3 normal volunteers' carotid vessels with IRB approval and informed consent. All images were acquired on a Signa HDxt 3T scanner (GE Healthcare) using a 4-channel phased array coil (Nova Medical). The motion sensitizing gradients were empirically set to induce a velocity encoding of 2.9 cm/sec, such that the signal from the carotid arteries and the jugular veins was sufficiently suppressed. The duration between $90_x$ and $90_{-x}$ was approximately 8.2 ms. The acquisition parameters were: Axial orientation, FOV = 160×160 $mm^2$, $N_x \times N_y$ = 192×192, slice thickness = 2 mm, No. of slices = 48, $TE_{eff}$ = 63 ms, ETL = 52, TR = 2 R-R intervals with peripheral gating (~1800 ms), scan time = 4:30 minutes with an auto-calibrated parallel imaging (8) factor of 1.8 along phase encoding (R/L) direction. Using peripheral gating, the acquisition was timed to systole to achieve maximum dephasing of the blood signal.

**Results:** The acquisition produced black blood images with uniform fat and water separation. The acquired in-phase image and the reconstructed water-only and fat-only images are shown in the acquired axial plane and reformatted oblique-sagittal orientation in fig. 1. The oblique-sagittal images show the entire left carotid artery in the S/I direction completely devoid of the blood signal. The vessel cross-section clearly delineates the carotid arterial wall with uniform fat suppression (fig. 2).

**Discussion:** This technique provides both fat-suppressed (water-only) and non-fat-suppressed (in-phase) images from the same acquisition, which allows for perfect co-registration, while simultaneously providing black blood contrast. The uniform fat suppression better delineates the vessel wall and in addition, this technique also generates fat-only images that could aid in better characterization of the fat content in plaque. Enhancements to acquire both in-phase & out-of-phase images in the same repetition could further decrease the total acquisition time or increase the spatial resolution.

**Reference:** 1) Balu et. al. JMRI 27: 918-924 (2008); 2) Wang et. al. MRM 58: 973-981 (2007); 3) Balu et. al. MRM 64: xxx-xxx (2010); 4) Yuan et. al. Circulation 104: 2051-2056 (2001); 5) Ma. MRM 52: 415-419 (2004); 6) Busse et. al. MRM 60: 640-649 (2008); 7) Ma et. al. JMRI 31: 889-894 (2010) 8) Beatty ISMRM 07; p. 1749.