Isotropic high-resolution 3D MRI of carotid arterial wall with imporved blood suppression using motion-sensitized dephasing SPACE

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Introduction:

Suppression of the intraluminal blood signal is essential for visualizing arterial wall. 2D turbo spin-echo (TSE) acquisition using double inversion-recovery (DIR) or inflow/outflow saturation band (IOSB) technique has been the method of choice for carotid atherosclerotic plaque imaging. Compared to their 3D counterpart, 2D techniques offer relatively low through-plane resolution and limited anatomic coverage. Two challenges of 3D techniques include poor blood signal suppression and long imaging times. Recently, a motion-sensitized dephasing (MSD) preparation scheme was used for blood suppression in conjunction with 3D balanced steady-state free precession (bSSFP) acquisition [1]. However, at 3.0T, bSSFP suffers from off-resonance artifacts mediated by main magnetic field inhomogeneity. Variable-flip-angle 3D TSE (SPACE) has been introduced as an alternative for T2-weighted fast imaging of carotid arterial wall at 3.0T due to its insensitivity to field inhomogeneities [2]. Although most intraluminal signal is suppressed via its inherent flow spin dephasing effect, residual blood signal is often observed in regions of slow or complex flow, particularly at the carotid bifurcation. In this study, we attempted to use a MSD preparation in SPACE (MSD-SPACE) to improve blood suppression efficiency. It was also hypothesized that MSD-SPACE could be more time efficient than multi-slice 2D IOSB TSE (mTSE) in achieving comparable wall-lumen contrast-to-noise ratio (CNR).

Methods:

Sequence: MSD-SPACE sequence was created by applying two identical trapezoidal gradient pulses right before and after the first refocusing pulse (180^o) in the readout, phase encoding, and slice-selective directions, respectively (amplitude 15 mT/m, duration 3 ms, 1^{th} gradient moment = 554 $mTms^2/m$).

Imaging: 7 healthy volunteers and 2 patients (2F/5M, age 48.7±14.9) with known carotid atherosclerotic disease participated in this study on a 3.0T system (Tim Trio, Siemens Medical Solutions, Erlangen, Germany) using a 4-channel bilateral carotid phase array surface coil (Machnet BV, Eelde, The Netherland). Following vessel scout, two scans, SPACE and MSD-SPACE, were successively performed to acquire coronal 3D images with the bilateral carotid bifurcations located in the slab center. The imaging parameters included: (1) for patients, TR/TE=1600/161 ms, ETL=66, FOV =180x124 mm^2, matrix=256x176, 56 0.70-mm-thick slices (resolution 0.70x0.70x0.70 mm^3), acquisition time (TA) =4.5 min; (2) for volunteers, TR/TE=1600/175 ms, ETL=70, FOV=160x116 mm^2, matrix=256x186, 80 0.63-mm-thick slices (resolution 0.63x0.63x0.63 mm^3), TA=6.4 min. Other common parameters: GRAPPA=2, average=2, BW=454 Hz/pixel, fat sat. On 5 healthy volunteers, T2-w mTSE was performed to acquire 16 transversal slices within two acquisitions for covering carotid bifurcation anatomy (resolution 0.55x0.55x3.0 mm^3, TR/TE=2500/54 ms, ETL=13, slice spacing=3 mm, average=2, TA=1.6 min).

Analysis: Conventional SPACE 3D data sets were inspected using multi-plane reformatting (MPR) on the scanner console to detect possible residual flow artifacts. From two 3D image sets of each subject, the identical longitudinal views of vessels, which showed artifacts in SPACE, were reconstructed. Using ImageJ (version 1.38x, NIH, USA), residual blood and adjacent vessel wall signal intensities were measured, respectively, and noise was measured in a consistent location of air region. The wall-lumen CNRs were calculated and compared between the two SPACE scans using paired t-test. One region free of residual blood in each subject was also analyzed using the same approach. Furthermore, 16 pairs of 2D artery cross-sectional images from MSD-SPACE and mTSE located at the same location on each subject were analyzed for measuring lumen, wall, sternocleidomastoid muscle signals and noise (standard deviation of a ROI in nearby muscle region). The average wall-lumen CNRs, CNR efficiency (CNR_{eff}) [1], and image quality factor (QF) [3] were calculated for each sequence and subject and then subjected to paired *t*-test.

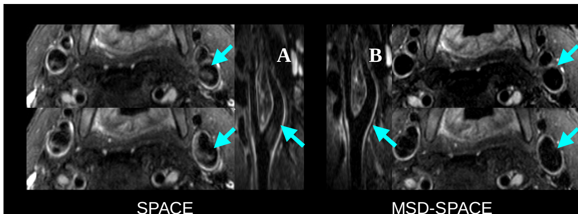

Figure 1. MPR images from a healthy volunteer SPACE data sets. Residual blood signals in SPACE images (A, arrows) were suppressed in MSD-SPACE images (B, arrows).

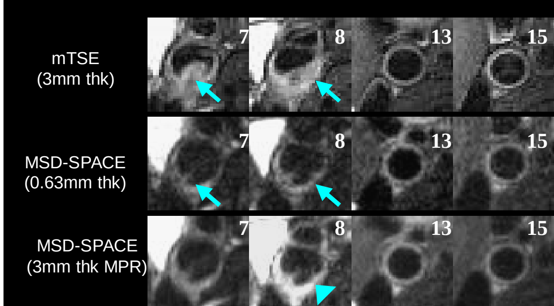

Figure 2. Sample carotid cross-section from mTSE and MSD-SPACE scans in a healthy volunteer. Flow artifacts in the mTSE images are suppressed in the thin-section MSD-SPACE images (arrows). The wall details may be obscured when visualized in a thicker section due to partial volume effect (arrowhead). (Numbers in the corners indicate slice positions).

Results:

Residual blood signals were visually detected in 4 subjects (1 patient, 3 volunteers, 6 locations), mostly at the bifurcation, in the conventional SPACE images (arrows in Fig. 1 A) which were dramatically suppressed in MSD-SPACE images (arrows in Fig. 1 B). MSD preparation significantly improved wall-lumen CNR in these regions, but did not affect CNR in artifact-free regions (Table 1). The CNR_{eff} and QF in MSD-SPACE were significantly higher than those in mTSE (Table 1). MSD-SPACE also showed better blood suppression than IOSB mTSE (arrows in Fig. 2).

Discussion and Conclusion:

A MSD preparation improved blood suppression in carotid artery wall imaging using SPACE at 3T, resulting in substantially reduced plaque-mimicking artifacts and wall-lumen CNR improvement. MSD-SPACE has markedly higher wall-lumen CNR efficiency than multi-slice 2D black blood TSE. As a 3D sequence, SPACE achieved superior spatial resolution (through-plane resolution = 0.63 mm/3 mm using SPACE/mTSE) and shorter scan time for covering major carotid artery anatomy (for covering 16 ~ 18cm-long vessel, 4-6 min/10-12 min using SPACE/mTSE). With isotropic resolution in all three directions, the arterial wall and plaque can be visualized in any angle, particularly along the vessel axis. 3D MSD-SPACE is a promising technique for plaque screening in the carotid arteries at 3.0T.

Table 1 CNR comparison between MSD-SPACE and SPACE; and CNR, CNReff, and QF comparison between MSD-SPACE and mTSE

CNR in regions with flow artifacts		*CNR in artifact-free regions*		*CNR*		*CNR_{eff}*		*QF*	
SPACE	*MSD-SPACE*	*SPACE*	*MSD-SPACE*	*MSD-SPACE*	*mTSE*	*MSD-SPACE*	*mTSE*	*MSD-SPACE*	*mTSE*
21.2± 15.4	*26.0± 16.3*	*16.2± 8.4*	*16.0± 7.0*	*6.0± 2.5*	*5.5± 0.9*	*84.9± 35.0*	*13.6± 2.2*	*103.2± 13.3*	*19.6± 1.9*
P < 0.05 (n=6)		*P = 0.88 (n=4)*		*P = 0.62 (n=5)*		*P < 0.01 (n=5)*		*P < 0.01 (n=5)*	

References: [1] Koktzoglou et al. JCMR (2007); 9:33-42. [2] Chung et al. Proc ISMRM 15th (2007); 683. [3] Mani et al. Radiology (2004);232:281-8.