Three-Dimensional Black-Blood Vessel Wall Imaging with Diffusion-Prepared Segmented Steady-State Free Precession

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Introduction: Black-blood (BB) vessel wall MR imaging of thick imaging slabs containing large anatomical volumes may be helpful for assessing systemic diseases affecting the arterial wall (e.g. atherosclerosis). However, BB MR imaging of thick slabs is difficult to achieve with conventional inflow/outflow-based magnetization preparations (e.g. saturation band [1], double inversion-recovery (DIR) [2]) that rely on complete inflow (or equivalently outflow) of blood to the imaged slab to ensure BB image contrast. For this reason, slab-selective 3D BB MR vessel wall imaging, although potentially advantageous in respect to achievable signal-to-noise ratio, anatomical coverage, and spatial resolution over 2D BB MR vessel wall imaging, is difficult since residual blood signal can obscure depiction of the vessel wall.

We hypothesize that thick-slab 3D BB vessel wall imaging may be performed with use of a mild driven equilibrium Fourier transform (DEFT)-based diffusion preparation that relies on motion-induced dephasing of blood spins to suppress blood signal rather than complete blood inflow/outflow [3,4]. This study investigated a diffusion-prepared segmented 3D SSFP imaging sequence (3D DIFF-SSFP) for slab-selective BB MR imaging of the thoracic aorta and the carotid arteries. The wall-lumen contrast-to-noise ratio (CNR) efficiency of the developed 3D DIFF-SSFP imaging sequence was compared to that of known gold-standard T_2-weighted (T2W) DIR-prepared 2D fast spin-echo (FSE) aortic and carotid BB MR imaging protocols [5,6].

Methods: All MR imaging experiments were performed in a 1.5 T whole-body MR scanner (Sonata; Siemens Medical Systems, Germany). The 3D DIFF-SSFP imaging sequence consisted of a segmented 3D SSFP data acquisition block preceded by a chemically selective fat saturation pulse to suppress the appearance of perivascular fat, and by a DEFT preparation interspersed with diffusion gradients [4] to suppress the appearance of moving blood.

Using axially oriented imaging slabs, segmented 3D DIFF-SSFP BB MR imaging of the thoracic aorta (n = 7) and carotid arteries (n = 6) was performed in thirteen volunteers. *Aortic Imaging*: Signal reception was performed using six channel cardiac surface coils placed anterior and posterior to the thorax. Imaging parameters were: free-breathing acquisition, ECG gating (acquisition during diastole), TR = 1 R-R, FOV = 27.5 × 20.6 cm^2, matrix = 256 × 192, 53-71 segments per TR, BW = 1220 Hz/pixel, SSFP TR/TE = 3.8/1.9 msec, flip = 45°, slab thickness = 120 mm, 48 slices, slice thickness (SL) = 2.5 mm, slice oversampling = 25%, b-value = 0.69 ± 0.37 sec/mm^2, NEX = 3, imaging time = 480 sec ± 99 sec. *Carotid Imaging*: Signal reception was performed using two channel surface coils placed over the carotid arteries (Machnet BV, The Netherlands). Imaging parameters were: TR = 1 sec, FOV = 12 × 12 cm^2, matrix = 256 × 256, 65 SSFP segments per TR, BW = 560 Hz/pixel, SSFP TR/TE = 5.8/2.9 msec, flip = 45°, slab thickness = 30 mm, 20 slices, SL = 1.5 mm, slice oversampling = 20%, b-value = 10.90 ± 2.61 sec/mm^2, NEX = 2, imaging time = 192 sec.

In all thirteen subjects, fat-saturated T2W 2D DIR-FSE imaging was performed with readout and phase-resolutions equal to those used during segmented 3D DIFF-SSFP imaging (same FOV and acquisition matrix). Remaining DIR-FSE imaging parameters were closely matched to literature values [5,6]. Several equidistant 2D DIR-FSE imaging slices (aortic imaging: 12-24 5-mm thick slices, 0%-100% gap; carotid imaging: 5 2-mm thick slices, 200% gap) were sequentially acquired throughout the 3D DIFF-SSFP imaging volume so as to attain similar coverage. Wall-lumen CNR was calculated by dividing the mean signal difference between the arterial wall and lumen by the standard deviation of air signal measured outside of the body (σ_n). CNR-efficiency (EF_{CNR}), adapted from reference [7] and defined as

$$EF_{CNR} = \frac{CNR\sqrt{N_{SLICES}}}{\sqrt{TA}\sqrt{SL}}$$

sought to adjust measured CNR by the imaging time (TA) (in minutes), slice thickness (SL) (in millimeters), and the number of acquired imaging slices (N_{SLICES}).

Results & Discussion: BB vessel wall imaging with segmented 3D DIFF-SSFP was successfully performed in all subjects. Imaging results obtained in the thoracic aorta and in the carotid arteries are shown in Figures 1 and 2, respectively. Segmented 3D DIFF-SSFP imaging provided for clear depiction of the arterial wall and robust suppression of blood signal. Furthermore, slow moving blood observed in the carotid bifurcation during T2W 2D DIR-FSE imaging was well suppressed with segmented 3D DIFF-SSFP (Fig 2A & B). EF_{CNR} values are shown (Fig. 3). Statistical significant differences in EF_{CNR} were found between the 3D DIFF-SSFP and 2D DIR-FSE sequences for both aortic and carotid wall imaging (*t*-test, $p < 0.01$). As observed, EF_{CNR}s were larger with 3D DIFF-SSFP than with 2D DIR-FSE.

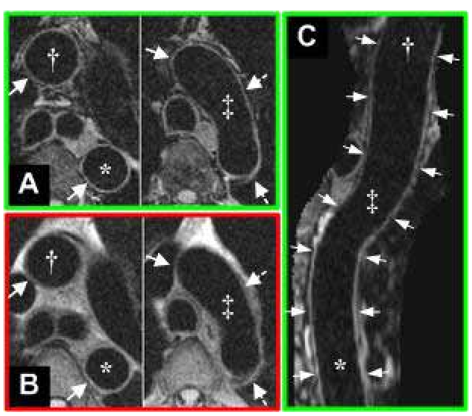


Figure 1. A, 3D DIFF-SSFP images acquired through the thoracic aorta (†: ascending aorta; ‡: arch; *: descending aorta). **B**, T2W 2D DIR-FSE images at the slice positions in A. Note the similar (solid arrows) and improved (dashed arrows) depiction of the aortic wall with 3D DIFF-SSFP. **C**, Curved reformation through the 3D DIFF-SSFP slab depicts the aortic wall throughout the length of the thoracic aorta.

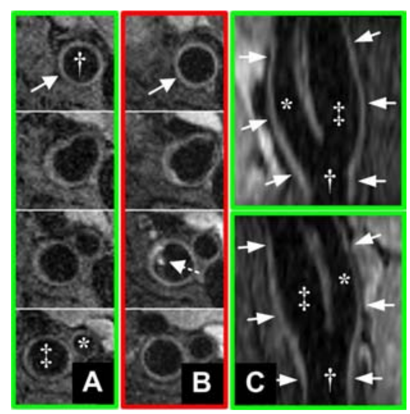
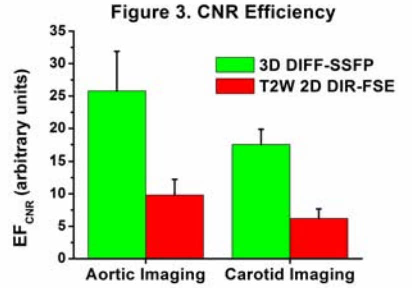


Figure 2. A, 3D DIFF-SSFP and **B**, T2W 2D DIR-FSE images of the carotid wall (solid arrows) acquired through the carotid bifurcation (†: common carotid; ‡: internal carotid (ICA); *: external carotid). Blood signal is encountered in the ICA lumen (dashed arrow) with 2D DIR-FSE but not with 3D DIFF-SSFP at the same location. **C**, 3D DIFF-SSFP reformations provide for in-plane depiction of the carotid arteries.

Conclusion: Diffusion-prepared segmented 3D steady-state free precession imaging is a promising MR imaging sequence for black-blood (BB) vessel wall imaging of the aorta and carotid arteries. The DIFF-SSFP sequence facilitates 3D BB MR imaging of thick slabs with good wall-lumen CNR efficiency. With reformation, the vessel wall can be viewed along arbitrarily prescribed imaging slices. Future work may consist of validating the segmented 3D DIFF-SSFP technique in other vascular territories, comparing its CNR efficiency with time-efficient multi-slice BB FSE imaging protocols, and applying the technique for rapid assessment of atherosclerotic plaque burden over large anatomical regions.

Figure 3. CNR Efficiency



References: [1] Felmlee et al. Radiology 1987;164:559-564 [2] Edelman et al. Radiology 1991;181:655-660 [3] Okada et al. J Comput Assist Tomogr 1998;22:364-371 [3] Sirol M et al. Circulation 2004;109:2890-2896 [5] Fayad et al. Circulation 2000;101:2503-9 [6] Yuan et al. Circulation 2001;104:2051-6 [7] Mani et al. Radiology. 2004;232:281-8