Multi-contrast Black-blood MRI of Carotid Arteries: Comparison between 1.5 and 3 Tesla Magnetic Field Strengths

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Introduction: Since introduction of 3 T scanners into clinical practice, advantages of high-field MRI have been extensively explored in many radiological applications. The purposes of this study were to compare black-blood multi-contrast carotid imaging at 3 T and 1.5 T; evaluate potential improvements in image quality, vessel wall signal-to-noise ratio (SNR), and black-blood contrast at 3 T; and assess compatibility between morphological measurements of carotid arteries at 1.5 T and 3 T.

Methods: Images of bilateral cervical carotid arteries were obtained from five healthy subjects and two atherosclerosis patients. MRI scans were conducted on 1.5 T (Signa TwinSpeed) and 3.0 T (Signa VH/i) whole body scanners of the same manufacturer (General Electric Healthcare Technologies, Milwaukee, WI) using bilateral four-element phased-array coils with identical geometry. A similar multi-contrast protocol providing T_1-, T_2- and PD-weighted black-blood images was used on both scanners. All scans were conducted using a 2D fast spin-echo (FSE) sequence with double inversion-recovery (DIR) preparation with slice thickness of 2 mm. The imaging sequence made available both standard single-slice and time-efficient multi-slice DIR acquisition modes (1). Images were obtained with the following parameters: TR(ms)/TE(ms)/echo train length/receiver bandwidth ($\pm$ kHz) = 800/10/10/20.8 for T_1-, 2500/50/12/31.3 for T_2-, and 2500/9/12/31.3 for PD-weighting. For black-blood imaging with long TR (PD- and T_2-weighted), a multi-slice DIR method was used with four slices per TR. Inversion times (TI) were calculated to achieve zeroing of the blood signal for specified values of blood T_1, TR, and the number of slices per TR (1). Based on literature values of blood T_1 (1200 ms at 1.5 T and 1550 ms at 3 T (2)), TI for PD- and T_2-weighted sequences was 272 ms at 1.5 T and 281 ms at 3 T, respectively. T_1-weighted images were obtained using the single-slice DIR technique with TI=335 ms and 349 ms for 1.5 T and 3 T, respectively. At 3 T, different options of scan time (1 or 2 signal excitations) and in-plane resolution (0.63, 0.42, and 0.31 mm) were additionally tested to evaluate advantages of an increased SNR. Wall and lumen SNR and wall-lumen contrast-to-noise ratio (CNR) were compared in 44 cross-sections of carotid arteries by paired t-test. Inter-scanner variability of lumen area (LA), wall area (WA), and mean wall thickness (MWT) measurements was assessed using Bland-Altman analysis.

Results: Artery wall SNR and lumen-wall CNR significantly increased (Table 1) at 3 T with gain factors of 1.5 for T_1-weighted and 1.7-1.8 for PD/T_2-weighted images. SNR and CNR gains for T_1-weighted images were significantly less than for PD- and T_2-weighted images ($P\leq0.01/0.03$ for SNR/CNR, respectively). At the same time, there were no statistically significant differences between SNR and CNR gains for PD- and T_2-weighted images (P=0.3 and 0.4). This observation is consistent with an increase of T_1 at 3 T. A two-fold reduction of scan time or 1.5-fold increase of in-plane resolution was achieved at 3 T without SNR penalties as compared to 1.5 T (Fig. 1). The quality of blood suppression was similar at both field strengths for single-slice DIR T_1-weighted imaging as indicated by comparison of SNR in the lumen (Table 1). However, the lumen SNR was larger at 3 T for multi-slice DIR PD/T2-weighted imaging (P=0.01/0.03). This result is due to a field-dependent increase of the residual flow signal, which appears stronger for multislice DIR than for single-slice DIR. Although a minor increase of the residual blood signal, overall quality of black-blood imaging was consistently higher at 3 T, as indicated by lumen-wall CNR (Table 1). Morphological measurements (LA, WA, and MWT) at both field strengths demonstrated good agreement (Fig. 2) with no significant bias (P>0.5), coefficient of variation <10%, and intraclass correlation coefficient >0.95.

Conclusions: This study demonstrated significant improvement in SNR, CNR, and image quality; capability of reducing scan time and increasing spatial resolution; and compatibility of morphologic measurements at 3 T in comparison to 1.5 T for high-resolution black-blood imaging of carotid arteries.

References: [1] Yarnykh VL, Yuan C. *JMRI* 2003;17:478-483. [2] Noeske R. et al. *MRM* 2000;44:978-982.
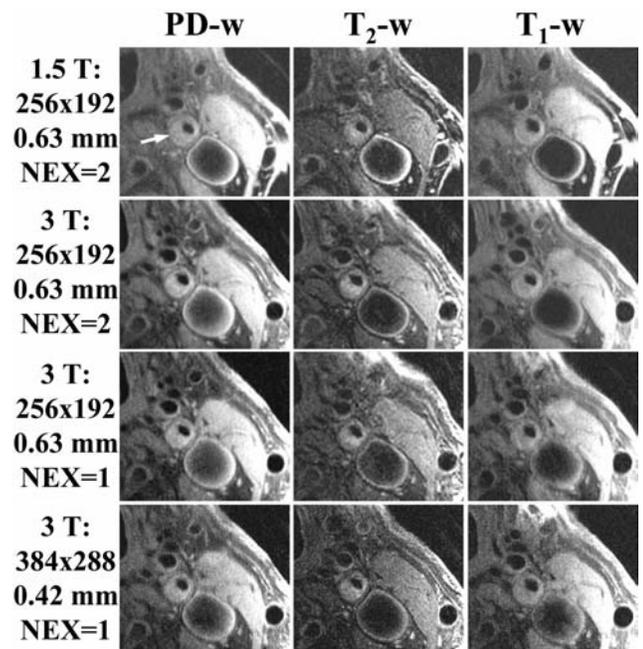
Fig. 1. Transverse multi-contrast black-blood images of the atherosclerotic plaque in the left internal carotid artery (marked by the arrow) obtained on 1.5 T and 3 T scanners with different protocol parameters. Image parameters (field strength: matrix size, in-plane resolution, and the number of excitations (NEX)) are given on the left side to each row. This figure compares a standard 1.5 T protocol (top row) with three protocol options for 3 T (other rows). The second row represents the same parameters as in the 1.5 T protocol and illustrates improvements in SNR and CNR. The third row demonstrates 3 T images obtained twice-faster than 1.5 T images with the same resolution. The fourth row shows the feasibility of improving image resolution (1.5 times) with still faster acquisition (also 1.5 times). Despite slightly increased noise level, these images still provide diagnostic quality and clear definition of the plaque and neck vasculature.
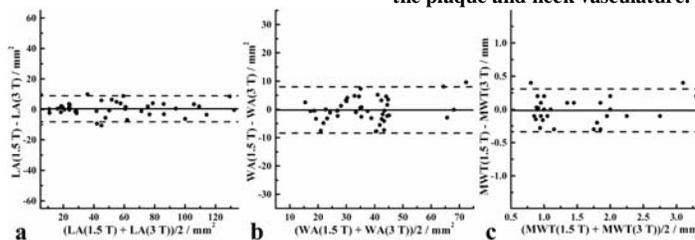

Fig. 2. Bland-Altman plots comparing morphological parameters of carotid arteries measured from 1.5T and 3T images: (a) lumen area (LA); (b) wall area (WA), and (c) mean wall thickness (MWT). Solid and dashed lines represent the mean difference and limits of agreement, respectively.

Table 1. Properties of multi-contrast black-blood carotid artery images at 1.5 T and 3 T (NEX=2, 0.63 mm in-plane resolution, see Fig. 1)

Para-meter	T_1-weighted			PD-weighted			T_2-weighted		
	1.5 T	3 T	P	1.5 T	3 T	P	1.5 T	3 T	P
SNR$_{wall}$	15.6±3.0	23.0±2.6	<.0001	17.1±3.4	28.3±5.3	<.0001	9.9±2.4	16.8±2.4	<.0001
SNR$_{lumen}$	1.2±1.1	1.6±1.2	0.20	2.3±1.6	3.3±2.4	0.011	1.3±1.3	1.9±1.4	0.032
CNR	14.4±2.8	21.4±2.8	<.0001	14.7±3.0	25.0±5.8	<.0001	8.6±2.3	14.9±2.6	<.0001