# Improved Spatial and Temporal Resolution Black-Blood Dynamic Contrast-Enhanced Carotid Artery Wall MRI Using Compressed Sensing

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**Background:** Dynamic gadolinium contrast-enhanced (DCE) vessel wall imaging has been used to quantitatively assess the inflammatory status of carotid plaques [1]. However, there are several limitations underlying current techniques that may potentially compromise quantitative accuracy including: a) vessel wall blurring during high-spatial-resolution imaging due to arterial pulsation; b) inadequate signal difference between vessel wall and lumen; and c) relatively low temporal resolution (20-40 seconds). Recently, a black-blood DCE technique using ECG-triggering and saturation and double-inversion combined (SRDIR) preparation was proposed to overcome the first two limitations at the expense of temporal resolution [2]. Compressed sensing (CS) exploits the high degree of spatio-temporal correlation inherent within the DCE data to enforce data sparsity in appropriate "transform" domains [3]. This work aims to accelerate data acquisition using a combination of golden-angle radial acquisition and CS to improve temporal resolution of carotid wall DCE MRI.

**Methods**: The major modification in the SRDIR DCE sequence lies in the following two aspects. Bright-blood images are shared by the dark-blood images because the blood signal remains the same in different slices. In this way, temporal resolution can be increased while keeping the spatial coverage of vessel wall (Fig. 1). A 2D golden-angle radial sampling acquisition is applied in both bright-blood and black-blood scans. This permits a retrospective selection of the temporal resolution.

CS image reconstruction was performed using the Split Bregman method for $l_1$ regularized optimization problems [4]. The cost function is $\|Au - b\|_2^2 + \mu|\nabla u|_1 + \gamma|u - u_{ref}|_1$, i.e. the sum of a data fidelity term, a total variation (TV) sparsity penalty (enforcing sparsity in the finite-differences domain), and an l1-norm temporal sparsity term. *A* is the forward radial-sampling operator; *b* is the k-space data; *u* is the underlying image.

Volunteer data (n=4) were acquired at 3T (Siemens Magnetom Verio) using a 4-channel bilateral carotid coil, with the imaging slices centered at the carotid bifurcations. Imaging parameters included: spatial resolution = 0.58 x 0.58 x 3 $mm^3$, 6 contiguous slices for dark-blood scans and 1 additional slice for bright-blood scans, pulse triggering to avoid pulsation motions and inflow inconsistency, 30 projections/R-R, 8 heart beats/frame for dark-blood scans and 4 heart beats/frame for bright blood scans. A 15-minute continuous golden-angle radial sampling was conducted along with intravenous contrast (0.1 mmol/kg gadoversetamide) injection and saline flush (20 ml) both at 1 ml/s.

Through ROI analysis from the bright-blood and dark-blood image series respectively, signal intensity change of blood pool and vessel wall was captured, then converted to contrast agent concentration change, and finally used to calculate kinetic parameters.

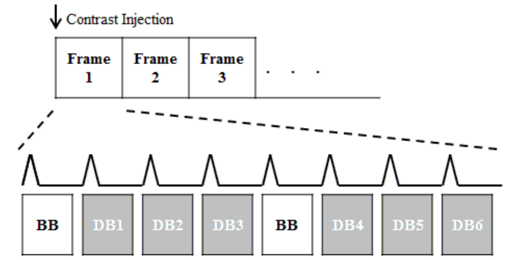


**Fig.1**"BB" stands for bright-blood scans while "DB" stands for dark-blood scans. The number refers to different slices. Bright-blood scans are shared by the dark-blood scans because the blood signal is theoretically the same in different slices. Hence, temporal resolution is increased while keeping the spatial coverage of vessel wall.

**Table 1** Kinetic Parameters for Radial and Cartesian Method

| Method | Ktrans($min^{-1}$) | Kep($min^{-1}$) | Vp |
|---|---|---|---|
| Cartesian | 0.082±0.025 | 0.085±0.013 | 0.193±0.014 |
| Radial | 0.054±0.002 | 0.101±0.004 | 0.141±0.025 |

**Results:** As shown in Fig. 2, the proposed method achieves a significant SNR improvement (3.4 fold increase) compared to non-accelerated radial regridding method. In dark-blood image series, the vessel wall was well preserved (Fig. 2). In order to verify the accuracy, we compared the proposed approach with conventional Cartesian single-slice carotid DCE method using exactly same contrast injection protocol. The time curves of blood and vessel wall for two methods follow similar dynamics (see Fig. 3). Kinetic parameters for the two methods are in the same range (Table 1).

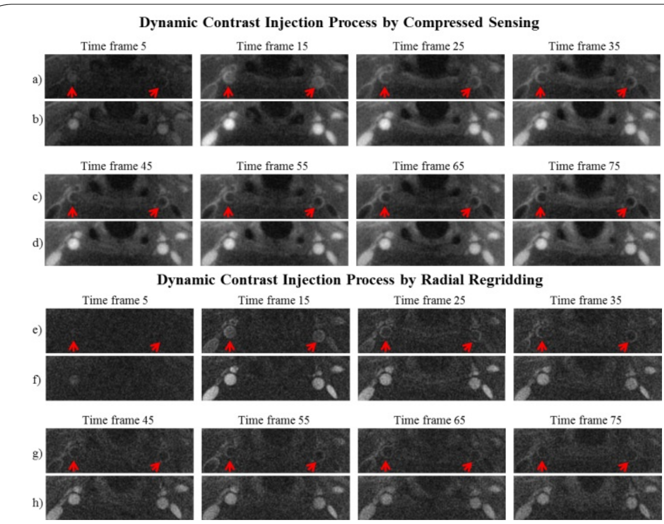


**Fig.2** Dark-blood (a, c) and bright-blood (b, d) images by compressed sensing compared with dark-blood (e, g) and bright-blood (f, h) images by radial regridding throughout the dynamic contrast injection process.

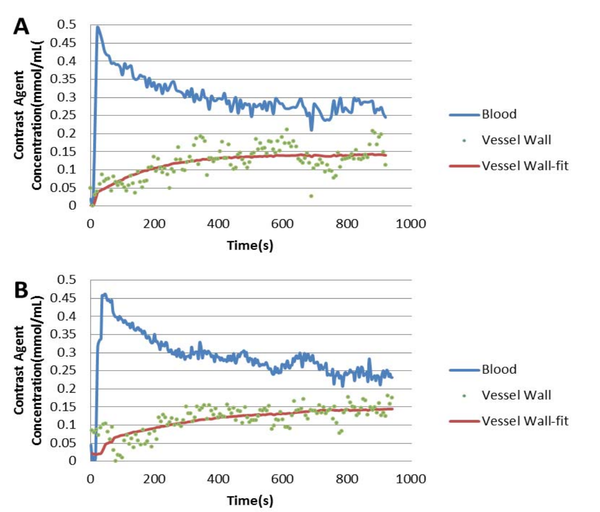


**Fig.3** Contrast agent concentration (mmol/mL) vs. time(s) curves of blood and vessel wall for (A), the result of the conventional Cartesian method and (B), the result of the radial compressed sensing method.

**Conclusions:** In this study, a combination of compressed sensing and golden-angle radial imaging was applied to improve the temporal resolution of carotid wall DCE MRI from ~20s to ~ 8s. This significant level of improvement in temporal resolution for the SRDIR DCE approach may have many clinical benefits in terms of more accurate quantitative assessment of the inflammatory status of carotid plaques, an important biomarker for detecting the vulnerability of the plaque.

**Reference**

[1].Kerwin, W.S., et al., Radiology, 2006. 241(2): p. 459-468. [2].Fan, Z., et al., Journal of Cardiovascular Magnetic Resonance, 2013. 15(Suppl 1): p. P246. [3].Jung, H., et al., MRM, 2009. 61(1): p. 103-116. [4].Goldstein, T. and S. Osher, SIAM Journal on Imaging Sciences, 2009. 2(2): p. 323-343.