HIGH-RESOLUTION 3D DIFFUSION MRI: DETECTION OF LIPID-RICH NECROTIC CORE IN PLAQUES WITHOUT CONTRAST MEDIA

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Target audience: MR scientists interested in diffusion-weighted MRI; physicians interested in atherosclerosis and stroke.

Purpose: Large lipid-rich necrotic core (LRNC) is a well-known feature of rupture-prone atherosclerotic plaque[1, 2], which is the major cause of both stroke and transient ischemic attack[3]. Plaque lipid content has also been used clinically to monitor disease progression and the results of therapeutic interventions[4]. Although contrast-enhanced (CE) MRI was shown possible for LRNC detection[5], patients with atherosclerosis often have concomitant renal disease[6] which makes CE MRI undesirable. Diffusion MRI (DWI and ADC mapping) showed great promises for discriminating LRNC from fibrous tissue with excellent contrast *ex vivo*[7] and *in vivo*[8]. However, conventional 2D EPI-based methods have suboptimal image quality due to susceptibility-induced distortion and blurring. It also has inadequate spatial resolution (in-plane pixel size ≥1.0x1.0 mm^2) for imaging plaques, causing partial volume effect and inaccuracies in ADC measurements. **The purpose of this work is to develop a novel diffusion MRI method for noncontrast carotid plaque characterization that provides (1) 3D imaging capability, (2) high spatial resolution (0.6x0.6x2 mm^3), and (3) reliable image quality.**

Methods:

Pulse sequence: Diffusion weighting was implemented with a driven equilibrium preparation module, allowing segmented high resolution 3D acquisition. Diffusion preparation was separated from the imaging readout, therefore avoiding instability of phase errors typically plagued multi-shot EPI, while maintaining CPMG condition for the readout (**Figure.1**). Bipolar diffusion sensitizing gradients were used to compensate for 1st-order motion and to reduce eddy currents. Pulse-triggering were utilized for minimizing pulsatile motion. Imaging readout was designed based on 3D TSE for good and consistent image quality at 3T. Reduced field-of-view (rFOV) with inner-volume refocusing pulses was developed to reduce scan time. Arterial blood was suppressed with DIR and FSD[9] for avoiding partial volume effect caused by blood and better vessel wall visualization.

In vivo imaging: Healthy volunteers (n = 12; 3 M, 9 F; aged 23-48 y/o) and patients suspected of carotid atherosclerosis (n = 3; 2M, 1F; aged 58-81 y/o) were scanned on a 3T scanner (Siemens Magnetom Verio) with the following parameters: 3D transverse slab with in-plane resolution = 0.6x0.6 mm^2; slice thickness = 2 mm; diffusion weightings of b = 30 and 300 s/mm^2 along the slice direction; total scan time = 5.5'±0.6'.

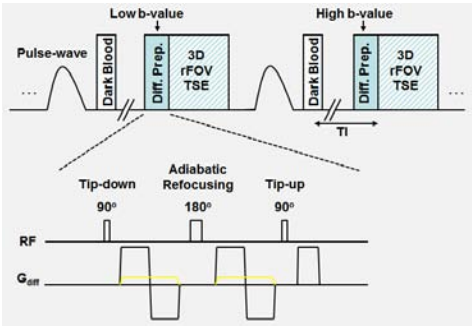

Figure 1. Interleaved high and low b-value diffusion prepared 3D rFOV TSE with 1st-order motion compensation and dark blood.

Results:

Figure 2: Panels (**A, B**) are representative DWI of carotid vessel wall from healthy subjects at b = 300 and 30 s/mm^2, respectively. Arterial blood suppression was effective throughout the slices with clear visualization of vessel wall at both b-values. No visible susceptibility-induced artifacts were observed. Successful 1st-order motion compensation was achieved as there was no apparent signal loss due to motion. Panel (**C**) is the ADC map of the corresponding slice. Panel (**D**) shows the comparison in which the ADC measurements of carotid vessel wall in healthy subjects, averaged at 1.53±0.23×10^{-3} mm^2/s, were consistent with previous studies.

Table 1: DWI image quality was quantified with relative SNR and relative CNR by region-of-interest analysis.

Figure 3: Panel (**A**) is the DWI of a carotid plaque at b = 300 s/mm^2. Panel (**B**) is the post-contrast T1-weighted image at the corresponding slice location. Note that the LRNC area in the DWI with reduced diffusion (hyperintense) matched the area in the post-contrast T1-weighted image with low contrast uptake (hypointense). Panel (**C**) shows the ADC measurements in plaques based on region-of-interest analysis. The mean ADC in the LRNC area was significantly lower (0.61±0.23×10^{-3} mm^2/s) than that of the fibrous plaque tissue (1.32±0.4×10^{-3} mm^2/s) with p<0.01.

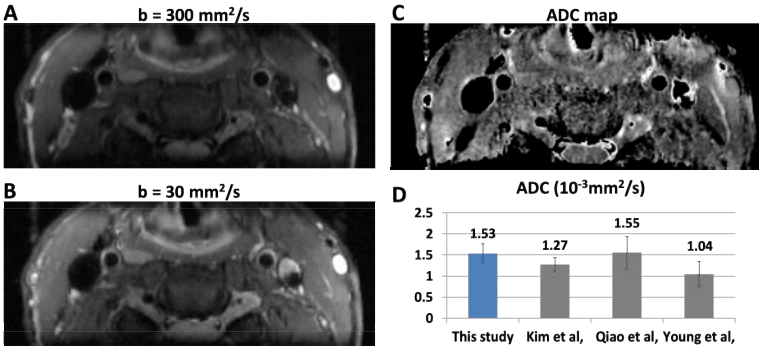

Figure 2. Results from healthy subjects.

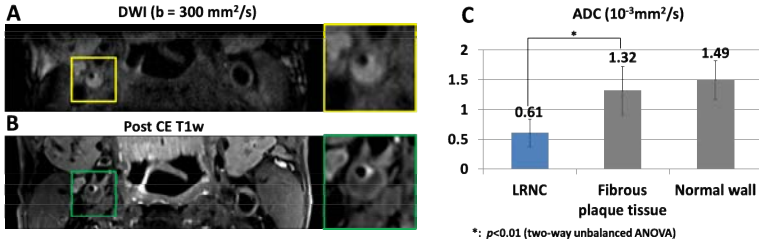

Figure 3. Results from patients with carotid atherosclerosis.

Discussion: **Diffusion-prepared TSE allows, for the first time, 3D diffusion MRI of the carotid arterial wall *in vivo* with high spatial resolution and excellent image quality.** LRNC findings from the new 3D diffusion MRI and conventional contrast-enhanced MRI demonstrated good agreement. ADC measurements in the healthy carotid wall were consistent with previous studies. ADC measurements in plaques were capable of differentiating LRNC from fibrous plaque tissue and normal wall.

Table 1. Image quality quantifications.

Image Quantification	b = 30	b = 300
Wall rSNR	14.9±2.8	11.6±2.1
Wall rCNR	13.2±2.6	9.9±1.9

rSNR = Wall/Noise; rCNR = (Wall-Lumen)/Noise

Conclusion: **Diffusion-prepared 3D MRI can detect lipid-rich necrotic core in carotid plaque *in vivo* without the use of gadolinium-based contrast agents, allowing carotid plaque characterization in patients with renal disease.**

References: [1] Stary HC, *et al*. ATVB; 1999:27. [2] Li ZY, *et al*. Circ J; 2008:72. [3] Aronow WS, *et al*. Am J Cardiol; 1999:83. [4] Corti R, *et al*. Circ; 2001:104. [5] Cai J, *et al.* Circ; 2005:112. [6] Bongartz, *et al.* Eur J Radiol; 2008:66. [7] Qiao Y, *et al*. ATVB; 2007:27. [8] Kim SE, *et al.* JMRI. 2011:30. [9] Fan Z, *et al.* JMRI. 2010:31.