

LONGITUDINAL RELAXATION TIME AND APPARENT DIFFUSION COEFFICIENT IN HUMAN CAROTID PLAQUE AT 3T: PHANTOM VALIDATION AND HISTOLOGICAL COMPARISON

Hideki Ota¹, Mika Watanabe², Tatsuo Nagasaka³, Makoto Obara⁴, and Hajime Tamura⁵

¹Diagnostic Radiology, Tohoku University Hospital, Sendai, Miyagi, Japan, ²Pathology, Tohoku University Hospital, Sendai, Miyagi, Japan, ³Radiology, Tohoku University Hospital, Sendai, Miyagi, Japan, ⁴Philips Electronics Japan, Tokyo, Japan, ⁵Health Sciences, Tohoku University Graduate School of Medicine, Sendai, Miyagi, Japan

AUDIENCE: Researchers, radiologists, and clinicians imaging/treating patients with carotid atherosclerotic disease.

PURPOSE: Multicontrast, high-resolution carotid MR imaging has been validated with histology and used to evaluate atherosclerotic plaque characteristics. However, this technique depends on evaluation of plaque components by experienced reviewers and/or semi-quantification of relative contrast of plaque components to adjacent muscle.¹ Current MR scanner enables measurement of longitudinal relaxation time (T1) and water proton apparent diffusion coefficient (ADC) with high-spatial resolution in clinically acceptable acquisition time. This study aimed to evaluate the use of quantitative T1 and ADC for segmentation of carotid plaque components.

METHODS: A clinical 3T MR scanner (Intera Achieva 3.0T Quasar Dual, Philips) with 2-ch SENSE Flex-S was used.

Sequence optimization and phantom study.

For T1 measurement, Double Angle Look-Locker (DALL)² integrated into a 3D imaging acquisition was performed. Detailed parameters were: flip angles = 6° and 12°, SENSE factor = 2, half scan factor = 0.625, k-space segmentation, total imaging time = 8 min, time of inversion recovery (TIR) = 3000 ms, TR = 12.2 ms, TE = 5.2 ms, TI = 41-2847ms in 10 TR intervals, 24 points were acquired, slab/slice thickness = 16/2.2 mm, acquisition matrix = 256x248 and FOV = 160 mm. We modified the original DALL calculation.² R1 (= 1/T1), flip angle (α) and efficiency of inversion pulse (β) were derived by fitting data using least-squares method into the following equation:

$$p \sin(\alpha) \left(\frac{(1 - \text{Er}1)(1 - f^{m-1})}{1 - f} - \frac{f^{m-1}((1 + \beta)(1 - f) e^{-R1 T10} - (1 - f) - \beta (\cos^m(\alpha) + \text{Er}1^{1-m} (1 - \cos(\alpha) - f^m)) e^{-R1 TIR})}{(1 - f)(1 + \beta \cos^m(\alpha) e^{-R1 TIR})} \right)$$

where $\text{Er}1 = e^{-R1 TIR}$, $f = \text{Er}1 \cos(\alpha)$ and m = the number of α pulses before TI. Diluted gadolinium solutions were imaged with DALL and inversion-recovery fast spin echo (IR-FSE) sequence (TR/TE = 10000/35 ms, TI = 100, 250, 500, 1000, 2000, 5000 ms). With the reference of IR-FSE as the gold standard, our modified DALL calculation was compared to the original DALL calculation.

Diffusion weighted imaging (DWI) was acquired with following parameters: single-shot spin-echo echo planar imaging with fat suppression and outer volume suppression³ (OVS-DWEPI), b values = 10 and 500 s/mm², TR/TE = 4000/63 ms, transverse acquisition, number of slices = 8, slice thickness/interval = 2.2/2.2 mm, FOV = 80 mm x 30 mm, acquisition matrix = 64x24, MPG in z-axis direction, imaging time = 5 min 12 sec. ADC was calculated by the following equation: $\text{ADC} = \text{Log}[s10/s500]/490$ [mm²/s], where s10 and s500 is signal intensity imaged with b = 10 and 500 s/mm² respectively. A polyvinyl alcohol solution phantom was imaged with OVS-DWEPI and standard DWEPI. ADC values by OVS-DWEPI were compared to those by standard DWEPI.

Patient study.

Two patients with carotid stenosis were included. Patients underwent MR examination before carotid endarterectomy. MR imaging protocols included DALL, OVS-DWEPI as well as 3D TOF, pre-contrast T1W, T2W, magnetization prepared rapid acquisition with gradient echo and CE-T1W images. Rigid-body transformation was used for image registration. Serial axial sections of the endarterectomy specimen were taken. Carotid bifurcation and the slice with the most severe stenosis were used as landmarks for matching MR images to histological specimens. Areas of lipid core without hemorrhage, hemorrhage and fibrous tissue were evaluated on histological cross-sections; the corresponding areas were manually outlined on the R1 and ADC maps.

RESULTS:

Phantom study.

R1 values by our method agreed well with those by IR-FSE. The original calculation² underestimated R1 values when R1 > 3 s⁻¹. ADC values by OVS-DWEPI were 4.1% higher than those by standard DWEPI.

Patient study

ADC vs. R1 plots demonstrated distribution of lipid-core without hemorrhage (L in dark green), hemorrhage (H in red) and fibrous tissue (F in green) (Figure). Lipid-core without hemorrhage (R1 = 0.5-0.9 s⁻¹, ADC = 0.5-1.5x10⁻³ mm²s⁻¹), hemorrhage (R1 ≥ 1.5 s⁻¹, ADC = 0.8-1.3x10⁻³ mm²s⁻¹) and fibrous tissue (R1 = 0.2-0.8 s⁻¹, ADC = 1.5-2.5x10⁻³ mm²s⁻¹) were separated on the plots.

DISCUSSION:

DALL sequence imaged by 3T scanner with B1 inhomogeneity gives reliable R1 values. ADC values in our technique demonstrated slight overestimation when compared to standard EPDWI. However, the overestimation might be acceptable in the clinical setting. Although the number of included patients was limited, our preliminary study indicates combination of ADC and R1 may be useful for segmentation of carotid plaque components.

CONCLUSION:

Measurement of R1 and ADC in carotid atherosclerotic plaque is possible. These parameters may be useful to characterize atherosclerotic carotid disease.

REFERENCES:

1. Saam T, et al. Quantitative evaluation of carotid plaque composition by in vivo MRI. *Arterioscler Thromb Vasc Biol* 2005;25:234-239.
2. Wade, T & Rutt, B. *Proc Intl Soc Magn Reson Med*. 2008, p1246.
3. Wilm BJ, et al. Reduced Field-of-View MRI Using Outer Volume Suppression for Spinal Cord Diffusion Imaging. *Magn Reson Med*. 2007;57:625-630

