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Original contribution

Identification of carotid lipid-rich necrotic core and calcification by 3D magnetization-prepared rapid acquisition gradient-echo imaging☆

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ABSTRACT

Background and purpose: This study sought to investigate the feasibility of three-dimensional MPRAGE in identifying the lipid-rich necrotic core (LRNC) and calcification (CA) of carotid atherosclerotic plaques.

Materials and methods: Twelve patients (mean age 68.4 ± 11.8 years; 7 males) with carotid atherosclerotic plaques on ultrasound were included and underwent multicontrast magnetic resonance (MR) vessel wall imaging. The contrast enhanced T1W (CE-T1W) images were considered as reference for identifying LRNC. The signal intensity of LRNC, CA, sterno-cleidomastoid muscle and fibrous tissue (FT) was measured on CE-T1W, T1W, T2W, and MPRAGE images, respectively. The relative signal intensity (rSI) of LRNC and CA against muscle or FT was compared among four sequences. Area under the curve (AUC) of rSIs of LRNC, CA and FT against muscle on MPRAGE, T1W and T2W images in discriminating the LRNC or CA from FT and the other plaque component was calculated.

Results: Of 352 slices, 88 (25.0%) had LRNC, 31 (8.8%) had CA, 14 (4.0%) had both LRNC and CA, and 247 (70.2%) had no components. Among four imaging sequences, MPRAGE images showed the lowest rSI of LRNC (0.34 ± 0.18) and CA (0.20 ± 0.16) against muscle, followed by T1W (0.48 ± 0.18 and 0.33 ± 0.21), CE-T1W (0.58 ± 0.23 and 0.40 ± 0.21) and T2W (0.71 ± 0.47 and 0.43 ± 0.40) images. In addition, the MPRAGE images showed the lowest rSI of LRNC (0.57 ± 0.26) and CA (0.33 ± 0.23) against FT. MPRAGE showed greater AUC than T2W and T1W in discriminating the LRNC (0.827 vs. 0.703 vs. 0.635) and CA (0.917 vs. 0.838 vs. 0.825).

Conclusion: MPRAGE sequence might be a potential non-contrast enhanced imaging tool for identification of carotid LRNC and CA.

1. Introduction

Lipid-rich necrotic core (LRNC) plays a key role in the progression and vulnerability of atherosclerotic plaques. Previous study showed the presence of LRNC in carotid atherosclerotic plaque could speed plaque growth and the progression of luminal stenosis [1]. It has been demonstrated that the presence and size of LRNC are significantly associated with ischemic cerebrovascular events [2]. Characterization of carotid LRNC prior to plaque rupture is important.

Multi-contrast cardiovascular magnetic resonance has been used to identify characteristics of plaque components. Previous studies reported that LRNC can be identified by using T2-weighted (T2W) or contrast-enhanced T1-weighted (CE-T1W) imaging sequence after combining with T1W imaging and TOF MR angiography [3–5]. LRNC without IPH appears varied signal intensity on T2W images from isointense to hypointense [3,4], which may lead to underestimation in quantification of LRNC. A study by Cai et al. has shown that the CE-T1W imaging was better than T2W imaging in quantification of LRNC validated by histology [4]. However, CE-T1W imaging might not be applicable for patients with renal dysfunction. Therefore, it is suggested to propose a non-contrast imaging approach that has a better performance than T2W imaging in characterizing LRNC.

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Histologically, LRNC is usually composted of cholesterol crystal, debris of apoptotic cells, particles of calcium, etc. Previous study showed that the T1 value of LRNC and fibrous tissue in the vessel wall was 519 ms and 596 ms, respectively [6]. As such, it is challenging to distinguish LRNC from fibrous tissue using traditional T1W imaging. It is well established that heavily T1 weighted imaging displays better contrast than traditional T1W imaging, particularly for tissues with small differences in T1 values [7]. Three-dimensional MPRAGE, as a heavily T1-weighted sequence, has been largely used to delineate white/gray matter of brain [8]. A previous study also showed that single-sequence T1W turbo field echo MRI which was technically comparable to MPRAGE was promising to quantify LRNC in carotid atherosclerotic plaque [9].

We hypothesized that MPRAGE might enhance the contrast among LRNC, calcification (CA) and fibrous tissue (FT) and can be possibly used to identify LRNC. In this study, we investigate the feasibility of three-dimensional MPRAGE in identifying carotid LRNC and CA.

2. Methods

2.1. Study sample

Twelve asymptomatic patients with carotid atherosclerotic plaques on ultrasound were included in this study. Patients with a history of radiotherapy and confirmed muscle diseases were excluded. All recruited subjects underwent carotid multicontrast MR vessel wall imaging. The study protocol was approved by the local Institution Review Board prior to the initiation of this study and the written consent was obtained from each subject.

2.2. Phantom study

The phantom study was performed on a 3.0 T MR scanner (Achieva TX, Philips Healthcare, The Netherlands) with a 32-channel head coil (Achieva TX, Philips Healthcare, The Netherlands). A phantom consists of tubes containing diluted gadopentetic acid with varied T1 value from 200 ms to 1900 ms was scanned using T1W and MPRAGE protocol. The parameters of T1W and MPRAGE imaging are same as the in-vivo sequence. The phantom was also performed using a 2D inversion recovery turbo spin-echo (TSE) sequence with the following parameters: repeat time (TR)/echo time (TE) 10,000/8.7 ms; TSE factor 8; fourteen inversion times (100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1500, 2000, 2500, 3000 ms), FOV 140 × 140 mm^2; spatial resolution 1 × 1 mm^2. The mean T1 values were calculated on two-dimensional inversion recovery TSE images and the signal intensity were measured for each region of interest in the same location on T1W and MPRAGE images.

2.3. Carotid MRI

Carotid MRI was performed on a 3.0 T MR scanner (Achieva TX, Philips Healthcare, The Netherlands) with a dedicated 4-channel carotid coil (Machnet BV, Roden, Netherlands). The MR imaging protocol included TOF, T1W, T2W, CE-T1W, MPRAGE imaging sequences. The imaging parameters are detailed as follows (Table 1): TOF: turbo field echo (TFE); TR/TE 20/5 ms; flip angle 20°; T1W: TSE; TR/TE 800/10 ms; flip angle 90°; T2W: TSE; TR/TE 4800/50 ms; flip angle 90°; CE-T1W: TSE; TR/TE 800/10 ms; flip angle 90°; and MPRAGE: TFE; TR/TE 9/5.5 ms; flip angle 15°. The FOV of TOF, T1W and MPRAGE sequence is 140 × 140 × 48 mm^3 and the FOV of T2W and CE-T1W sequence is 140 × 140 × 40 mm^3. All sequences had the same spatial resolution 0.6 × 0.6 × 2 mm^3.

2.4. Image analysis

All MR images were interpreted by two reviewers with > 5 years' experience in neurovascular MRI using custom designed software "CASCADE" (University of Washington, Seattle, USA) [10]. The MR image quality was assessed with a 4-point scale: 1 = poor; 2 = adequate; 3 = good; and 4 = excellent [11]. The slices with image quality < 2 or intraplaque hemorrhage were excluded. The contours for lumen, outer wall, ROI in the sternocleidomastoid muscle at each axial location were outlined on T1W images and mapped to MPRAGE and the other contrast weighted images. The presence or absence of LRNC and CA at each axial location was determined according to the published criteria [12]. The LRNC shows isointense on TOF and T1W images and hypointense on CE-T1W images. The CA shows hypointense on TOF and T1W images. CE-T1W images were considered as reference in identifying LRNC because of its better agreement with histology than T2W images [4]. The signal intensity (SI) was measured for the FT, LRNC, CA, and muscle on the images of each imaging sequence. The FT was the part of vessel wall without any plaque component.

Table 1
MR imaging parameters for multi-contrast sequences.

	TOF	T2W	MP-RAGE	T1W	CE-T1W
Acquisition sequence	TFE	TSE	TFE	TSE	TSE
Blood suppression	–	MDIR	QIR	QIR	QIR
TR/TE (ms)	20/5	4800/50	9/5.5	800/10	800/10
Flip angle (deg)	20	90	15	90	90
FOV	140 × 140				
Resolution (mm)	0.6 × 0.6				
Slice number	48	20	48	20	20
NSA	1	1	1	1	1
Scan time (min)	2′04	3′40	3′18	6′11	6′11

TFE: turbo field echo; TSE: turbo spin echo; QIR: quadruple inversion recovery; MDIR: multi-slice double inversion recovery; TR: repetition time; TE: echo time; FOV: field of view; NSA: the number of signal averages performed during the scan.

2.5. Statistical analysis

The relative SI (rSI) of plaque components, including LRNC and CA, against muscle or FT was calculated according to minimum SI of plaque components versus the mean SI of muscle or FT. There is only one rSI value for each plaque component on every axial image when it has corresponding component. The rSI of plaque components against muscle or FT was compared among CE-T1W, T1W, T2W, and MPRAGE sequences by using repeated-measures analysis of variance with mixed procedure and Bonferroni adjustment for post hoc comparisons. A p value < 0.0083 (0.05 divide by the times of comparisons) was considered statistically significant.

The rSI of FT against muscle was also computed on T1W, T2W and MPRAGE sequences. For discriminating one from other plaque component and FT, the area under the curve (AUC) and corresponding 95% confidence interval (CI) of the rSIs of plaque components and FT against muscle were calculated by receiver operating characteristic (ROC) curve on T1W, T2W and MPRAGE sequences. A p value < 0.05 was considered statistically significant.

All statistical analyses were performed using SPSS 16.0 (SPSS Inc., Chicago, IL) and SAS (SAS Inc., North Carolina, NC).

3. Results

3.1. Phantom study

The T1 values of tubes in the phantom were 212 ms, 296 ms, 404 ms, 502 ms, 754 ms, 954 ms, 1004 ms and 1899 ms. When the signal intensity of the tube with T1 value of 1899 ms was considered as a reference, the contrast of signal intensity between different T1 value and the reference was calculated on T1W and MPRAGE images. The contrast of signal intensity on T1W images were 64.6%, 60.5%, 57.6%,