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High-Resolution Vessel Wall Magnetic Resonance Imaging of the Middle Cerebral Artery: Comparison of 3D CUBE T1-Weighted Sequence with and without Fat Suppression

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Statistical Analysis C
Data Interpretation D
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Background: Fat suppression is an important technique in magnetic resonance imaging (MRI). Comprehensive and quantitative assessment of the influence of fat suppression (FS) on T1-weighted imaging of intracranial vessel wall imaging is needed. In this study, we compared the three-dimensional (3D) variable-flip-angle turbo-spin-echo (CUBE) T1-weighted sequence with and without FS to investigate the differences between the 2 sequences in imaging of the middle cerebral artery (MCA) vessel walls.


Material/Methods: A 3D CUBE T1-weighted sequence with and without FS by 3.0T MRI was used to obtain intracranial vessel wall images of 105 MCA stenosis patients. The image signal intensity, signal-to-noise ratio, and contrast-to-noise ratio were calculated and compared. Two observers evaluated the image quality of the 2 sequences twice, and interobserver and intraobserver consistency were determined. Differences between the 2 sequences in the area of lumen and plaque were compared.

Results: The signal intensity, signal-to-noise ratio, and contrast-to-noise ratio of the 3D CUBE T1-weighted sequence without FS were higher, whereas the noise level was lower. In terms of subjective scores, the 3D CUBE T1-weighted sequence without FS performed better. No significant difference was observed in the measurement of the vascular lumen area between the 2 sequences, although there were statistically significant differences in the measurement of plaque area (i.e., the measurement obtained with 3D CUBE T1-weighted sequence without FS was larger).

Conclusions: 3D CUBE T1-weighted sequence without FS performed better for MCA vessel walls imaging than 3D CUBE T1-weighted sequence with FS.

MeSH Keywords: **Magnetic Resonance Imaging • Middle Cerebral Artery • Plaque, Atherosclerotic**

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Background

Intracranial atherosclerotic disease (ICAD) is one of the most common causes of intracranial arterial stenosis [1,2]. The middle cerebral artery (MCA) is an important branch of the intracranial carotid artery and is susceptible to ICAD, leading to lumen stenosis of the MCA and corresponding clinical symptoms. Therefore, it is clinically important to evaluate MCA stenosis caused by ICAD.

With the development of imaging technology, an increasing number of diagnostic imaging methods have been used to evaluate vascular stenosis caused by atherosclerotic diseases, and high-resolution vessel wall magnetic resonance imaging (HR VW-MRI) is considered one of the most reliable methods for detecting atherosclerotic plaques *in vivo*. HR VW-MRI is an MRI technique which is capable of displaying vascular lumen and vessel wall lesions using two-dimensional (2D) and three-dimensional (3D) imaging sequences and directly display and quantitatively measure the shape, structure, and lesion of the intracranial artery wall and lumen [3].

Currently, T1-weighted, T2-weighted, and proton density-weighted sequences are commonly used as scanning sequences for HR VW-MRI. The T1-weighted sequence is one of the most commonly used sequences for assessing intracranial arterial vessel walls. The 3D T1-weighted sequence can fully display the location, spatial distribution, size, shape, vascular remodeling, and signal characteristics of intracranial arterial plaques. Importantly, 3D imaging can cover a larger imaging area and even the whole brain in a similar scanning time as 2D imaging. Furthermore, 3D imaging can achieve isotropic resolution and visualize the morphology and distribution characteristics of intracranial arterial lesions from multiple perspectives through multi-planer reformation or curved planner reformation [4].

The generally accepted scanning standard is high-resolution cerebrospinal fluid suppression and blood suppression [4,5]. Some previous studies have applied the T1-fat suppression (FS) sequence in intracranial vascular wall imaging [6–9], whereas others have not [10–13], and it remains unclear whether the use of FS has an influence on HR VW-MRI of MCA [14]. Although it is generally known that FS reduces the signal-to-noise ratio (SNR) of MRI, there is no evidence that clearly demonstrates it. Therefore, it is necessary to perform a comprehensive and quantitative assessment of the influence of FS on the T1-weighted sequence of MCA vessel wall imaging. We hypothesized that the 3D variable-flip-angle turbo-spin-echo (CUBE) T1-weighted sequence without FS would perform better in terms of MCA imaging. In the current study, we compared image quality and relevant scanning results of 3D CUBE T1-weighted sequence with and without FS using subjective evaluation and objective indexes. The overall aim of this study

was to compare the performances of these 2 sequences of MCA vessel wall imaging.

Material and Methods

Patients

The study procedures and informed consent were reviewed by the Ethics Committee of our college. All patients who participated in this study provided written informed consent before undergoing non-invasive HR VW-MRI examination.

A prospective study conducted in this study from March 2019 to July 2019, in which 129 MCA stenosis patients were enrolled. Clinical data (age, sex, neurological clinical symptoms, and clinical history) were recorded for all patients. Patients were diagnosed with MCA stenosis by neurologists according to the atherosclerotic intracranial arterial stenosis diagnostic criteria [15].

The exclusion criteria were: (1) contraindications to MRI, (2) MCA dissection or Moyamoya disease, (3) generation of motion artifacts during MRI examination that affected the diagnosis, and (4) implantation of a stent in the head or carotid artery.

Scanning protocol

A 3.0-T MRI scanner (GE Discovery MR750; GE Healthcare, Global Diagnostic Imaging, WI, USA) performed HR VW-MRI of the MCA, with an 8-channel head coil. All subjects were scanned using the same parameters (Table 1). We used the FS technique of frequency-selective fat saturation (FatSat).

A 3D time-of-flight (TOF) MRA image from each patient was used as the positioning image for scanning the 3D CUBE T1-weighted sequence with and without FS. The imaging range included the MCA M1 segment. In patients with MCA stenosis, MRA results were used to assess MCA stenosis and the select responsible vessels to be scanned. All source data obtained after scanning were uploaded to a GE workstation (Advantage Workstation 4.6, GE Healthcare), and 2 observers conducted further image analysis and comparisons.

Imaging processing and objective evaluation

To select the regions of interest (ROI; mm²): we imported the source images of the 3D CUBE T1-weighted sequence with and without FS into the workstation in “comparison mode” and ensured that the ROIs of the 2 sequences were at the same level. To more accurately evaluate image noise, we drew an area equal to 250 mm² within the brain white matter (ROI_w) and obtained its standard deviation as the noise of the image [16]. In patients with MCA stenosis, the vessel wall at the narrowest

Table 1. Vessel wall imaging protocol with a GE Discovery 3.0T MRI scanner.

Parameter	3D TOF MRA	3D CUBE T1 with FS	3D CUBE T1 without FS
TR (ms)	min	1140.0	1140.0
TE (ms)	min	min	min
Slice thickness (mm)	1.4	1.0	1.0
FOV (cm)	22.0	18.0	18.0
NEX	3	1	1
Bandwidth	31.25	62.5	62.5
Locs per slab	32	60	60
Matrix size	320×256	320×288	320×288
Scan duration (minutes)	3: 57	3: 50	3: 50

Locs per slab, total number of locations (slices) generated from a slab; 3D – three dimensional; TR – repetition time; TE – echo time; SNR – signal-to-noise-ratio; FOV – field of view; NEX – number of excitations; TOF – time of flight; MRA – magnetic resonance angiography; FS – fat suppression.

vascular cross-section of MCA was used to draw the ROI_v, and the lumen and plaque of interest were drawn separately (ROI_L and ROI_{PQ}, mm²) (Figure 1). All cases were reviewed in random order. The GE workstation automatically calculated the signal intensity (including the vascular cross-section S_v, brain white matter S_B, vessel lumen S_L, plaque S_{PQ}) and noise standard deviation (σ_N) of each ROI. SNR=S/σ_N, contrast-to-noise-ratio (CNR)=(SNR_B-SNR_V or _L or _{PQ})/σ_N.

Subjective imaging assessment

Subjective evaluation of the images was performed on the GE workstation. First, the 2 observers evaluated all images independently according to predetermined scoring criteria. The 2 observers were blinded to the other sequencing images when analyzing the images. After 4 weeks, the 2 observers assessed the image quality again. Parameter information of the images and clinical information were removed before the assessment, and the assessment order was randomized. The image quality score was divided into the following 5 components: noise, lumen visualization, vascular wall visualization, contrast resolution between the vessel wall and surrounding structures, plaque visualization, and contrast resolution between the plaque and vessel wall. A 5-point scale was defined as 1 (very poor), 2 (poor), 3 (adequate), 4 (good), and 5 (excellent).

Statistical analysis

All statistical analyses were performed using MedCalc 19.0.7 (MedCalc Software bvba, Ostend, Belgium). Continuous variables are described as mean±standard deviation, and classified variables are expressed as count (percentage). The Kolmogorov-Smirnov test was used to determine whether the continuous variables were normally distributed. The intraclass correlation

coefficient (ICC) was used to quantify the intraobserver and interobserver reproducibility. An ICC value >0.75 was used to indicate a high level of reproducibility, 0.40≤ ICC ≤0.75 denoted moderate reproducibility, and ICC <0.4 denoted low reproducibility. The Wilcoxon signed-rank test was used to verify the differences in measurement and enumeration data. All statistical methods used P<0.05 as the threshold for determining statistically significant differences.

Results

In this study, 122 of 129 patients with MCA stenosis completed the examination (7 patients were unable to complete the MRI examination due to physical condition). Assessment of the original data revealed that a total of 17 participants could not complete the diagnosis because of poor image quality caused by motion artifacts. Finally, a total of 105 patients with MCA stenosis were included in this study. Of the 105 patients, 68 were men (64.76%) and 37 women (35.24%), with an average age of 61.9 years (range, 31–74 years). The clinical histories of the patients included hypertension (68 cases, 64.76%), diabetes (38 cases, 36.19%), hyperlipidemia (52 cases, 49.52%), and smoking (49 cases, 46.67%).

Results of objective measurement of images

Compared with 3D CUBE T1-weighted sequence with FS, 3D CUBE T1-weighted sequence without FS had higher signal intensity and a higher SNR of brain white matter, vascular cross-section, lumen, and plaque, and they had a higher CNR of vascular cross-section, lumen, and plaque. In addition, the noise level of the 3D CUBE T1-weighted sequence without FS was lower. The differences were statistically significant (Table 2).

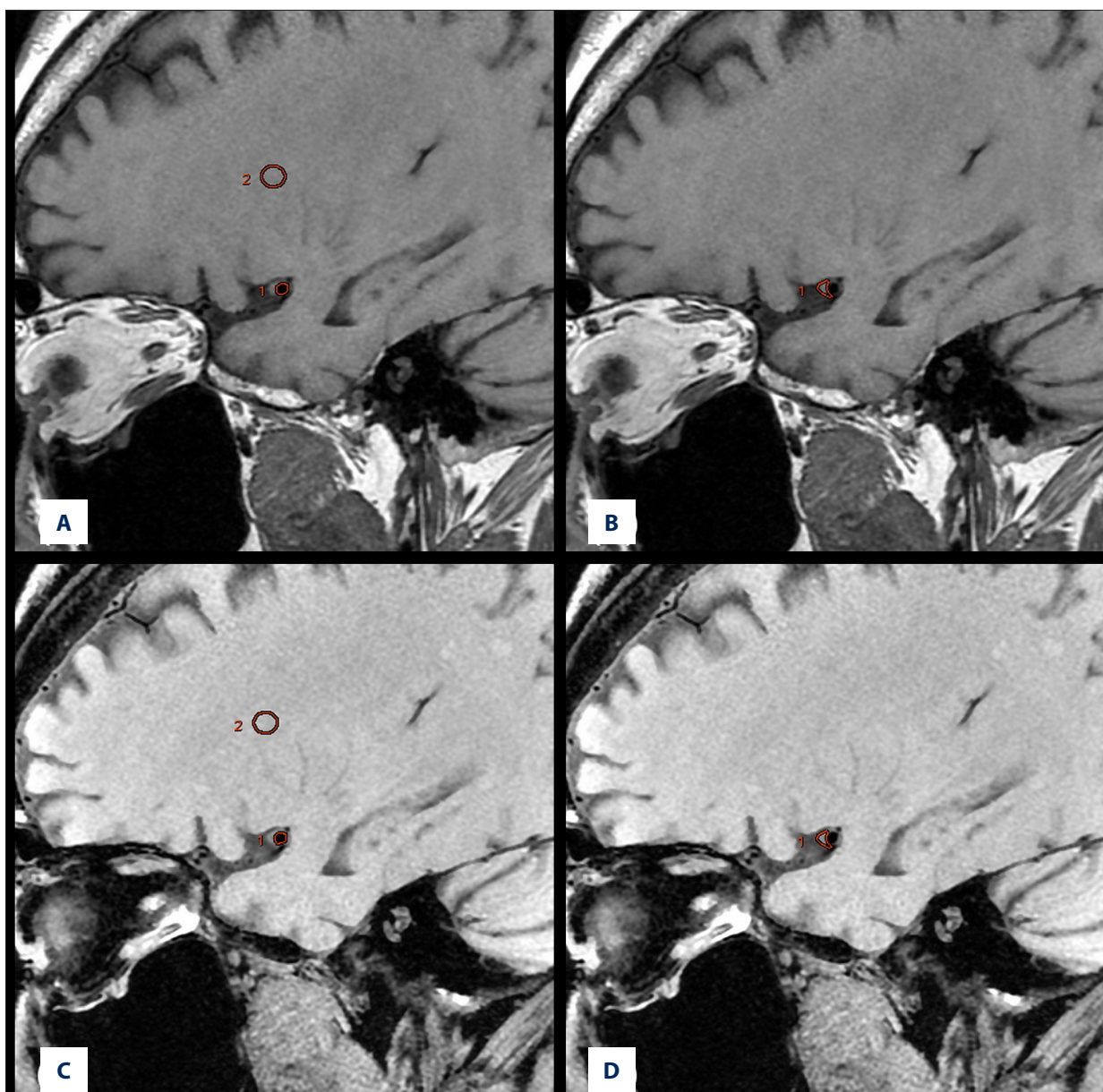


Figure 1. Typical images of a patient with MCA stenosis. (A, B) 3D CUBE T1 sequence without fat suppression. (C, D) 3D CUBE T1 sequence with fat suppression. Two ROIs for signal intensity measurements are separately depicted as circles in the lumen (circle 1) and brain white matter (circle 2) on images A and C. An ROI for signal intensity measurement is depicted as a circle (circle 1) in the plaque on images B and D.

There was no significant difference in the vascular cross-section (T1 vs. T1-FS: 15.97 ± 4.67 vs. 15.67 ± 4.90 mm², $P > 0.05$) and lumen area (T1 vs. T1-FS: 3.43 ± 2.35 vs. 3.34 ± 2.36 mm²; $P > 0.05$) between the 2 sequences in patients with MCA stenosis, whereas there was a difference in the measurement of the plaque area (T1 vs. T1-FS: 7.67 ± 3.3 vs. 7.25 ± 3.28 mm², $P < 0.05$).

Results of subjective evaluation of images

The subjective scores indicated no significant difference between the 2 sequences in the display scores of the vascular lumen. However, the noise score was significantly higher in the 3D CUBE T1-weighted sequence without FS. For other scores, the 3D CUBE T1-weighted sequence without FS scores were slightly higher than the 3D CUBE T1-weighted sequence with FS scores (Table 3). There was a high level of consistency between the 2 observers in subjective scores (Table 4).

Table 2. Comparison of signal characteristics between the two sequences.

Group	Signal characteristics	3D CUBE T1 without FS	3D CUBE T1 with FS	p
MCA stenosis patients (N=105)	σ_N	34.72±2.82	39.66±3.93	0.000
	S_B	1049.99±16.80	803.25±96.95	0.000
	S_V	523.09±139.50	428.02±113.79	0.000
	S_L	251.98±98.52	192.57±69.26	0.000
	S_{PQ}	635.52±120.70	522.84±103.02	0.000
	SNR_B	30.37±3.96	20.29±2.56	0.000
	SNR_V	14.29±3.02	10.89±1.89	0.015
	SNR_L	6.88±2.11	4.94±2.32	0.005
	SNR_{PQ}	17.91±2.85	13.21±1.70	0.002
	CNR_V	16.38±5.09	9.39±2.39	0.002
	CNR_L	23.88±5.21	15.23±2.37	0.000
	CNR_{PQ}	12.47±5.37	7.04±2.77	0.016

MCA – middle cerebral artery; FS – fat suppression; S – signal intensity; SNR – signal-to-noise-ratio; CNR – contrast-to-noise-ratio; N – noise; B – brain white matter; V – vascular cross-section; L – lumen; PQ – plaque.

Table 3. Comparison of image quality between two sequences datasets as scored by two readers.

Characteristics	Reader 1, 1 st			Reader 2, 1 st			Reader 1, 2 nd			Reader 2, 2 nd		
	3D CUBE T1 without FS	3D CUBE T1 with FS	p	3D CUBE T1 without FS	3D CUBE T1 with FS	p	3D CUBE T1 without FS	3D CUBE T1 with FS	p	3D CUBE T1 without FS	3D CUBE T1 with FS	p
Noise	4.73±0.54	4.04±0.61	0.000	4.68±0.37	4.05±0.58	0.001	4.74±0.38	4.06±0.57	0.000	4.72±0.37	4.04±0.59	0.001
Vessel wall visualization	4.70±0.57	4.37±0.71	0.000	4.68±0.36	4.26±0.66	0.000	4.71±0.37	4.39±0.67	0.000	4.67±0.39	4.26±0.68	0.000
Lumen visualization	4.84±0.41	4.81±0.45	0.280	4.88±0.19	4.83±0.46	0.109	4.86±0.33	4.80±0.42	0.170	4.83±0.17	4.82±0.46	0.401
Vessel wall and surrounding tissue resolution	4.68±0.56	4.15±0.63	0.000	4.67±0.41	4.20±0.71	0.000	4.70±0.56	4.16±0.42	0.000	4.68±0.40	4.23±0.75	0.000
Plaque visualization	4.65±0.60	4.33±0.71	0.000	4.58±0.56	4.40±0.71	0.025	4.66±0.54	4.38±0.75	0.000	4.59±0.52	4.40±0.71	0.025
Plaque and Vessel wall resolution	4.58±0.64	4.25±0.70	0.000	4.56±0.54	4.35±0.75	0.033	4.59±0.77	4.27±0.63	0.000	4.57±0.50	4.37±0.57	0.033

MCA – middle cerebral artery; FS – fat suppression.

Discussion

To the best of our knowledge, no previous studies have reported the effect of FS on 3D CUBE T1 sequence in vessel wall imaging in detail. The present study assessed the influence of the use of fat suppression on the image quality of 3D CUBE

T1 sequences in depicting the MCA. Although expert consensus has recommended that fat suppression is not necessary for intracranial vessel wall imaging [14], it is still important to perform a comprehensive and quantitative assessment of the influence of fat suppression on the image. In the present study, we compared a 3D CUBE T1-weighted sequence with

Table 4. ICC values of intraobserver, and interobserver reproducibility for two sequences.

Characteristic	3D CUBE T1 without FS-ICC (95% CI)		3D CUBE T1 with FS-ICC (95% CI)		3D CUBE T1 without FS-ICC (95% CI)		3D CUBE T1 with FS-ICC (95% CI)	
	Reader 1 1 st vs. 2 nd	Reader 2 1 st vs. 2 nd	Reader 1 1 st vs. 2 nd	Reader 2 1 st vs. 2 nd	1 st Reader 1 vs. 2	2 nd Reader 1 vs. 2	1 st Reader 1 vs. 2	2 nd Reader 1 vs. 2
MCA stenosis patients (n=105)								
Noise	0.97 (0.98–0.99)	0.97 (0.95–0.98)	0.98 (0.98–0.99)	0.94 (0.91–0.95)	0.76 (0.57–0.80)	0.78 (0.61–0.81)	0.79 (0.72–0.85)	0.78 (0.71–0.83)
Vessel wall visualization	0.96 (0.94–0.98)	0.98 (0.97–0.98)	0.96 (0.94–0.98)	0.99 (0.98–0.99)	0.74 (0.56–0.80)	0.75 (0.57–0.82)	0.78 (0.59–0.82)	0.76 (0.51–0.79)
Lumen visualization	0.98 (0.97–0.98)	0.94 (0.92–0.96)	0.99 (0.99–0.99)	0.98 (0.97–0.98)	0.77 (0.65–0.82)	0.78 (0.68–0.84)	0.79 (0.66–0.81)	0.78 (0.63–0.80)
Vessel wall and surrounding tissue resolution	0.99 (0.98–0.99)	0.99 (0.99–0.99)	0.99 (0.99–0.99)	0.99 (0.99–0.99)	0.75 (0.59–0.81)	0.75 (0.62–0.83)	0.75 (0.60–0.73)	0.76 (0.69–0.77)
Plaque visualization	0.98 (0.97–0.98)	0.98 (0.97–0.98)	0.98 (0.97–0.98)	0.98 (0.97–0.98)	0.82 (0.73–0.87)	0.81 (0.71–0.85)	0.76 (0.65–0.84)	0.78 (0.68–0.87)
plaque and Vessel wall resolution	0.98 (0.98–0.99)	0.97 (0.97–0.98)	0.98 (0.97–0.98)	0.94 (0.90–0.95)	0.81 (0.71–0.87)	0.74 (0.57–0.77)	0.76 (0.61–0.82)	0.73 (0.57–0.77)

MCA – middle cerebral artery; ICC – intraclass correlation coefficient; CI – confidence interval; FS – fat suppression.

and without FS for imaging the MCA vessel walls. Based on the signal intensity measurements, as well as qualitative evaluation by 2 observers, our results indicate that the 3D CUBE T1-weighted sequence without FS visualizes the intracranial vessel walls better than when using FS.

HR VW-MRI of the carotid artery requires the use of FS technique because the adjacent tissues of the carotid arteries contain fat, which displays a high signal on the T1-weighted sequence. When the high signal of fat is suppressed, the carotid artery wall can be displayed more clearly [17]. Some previous studies have used FS technique in HR VW MRI of intracranial arterial; those experiments might have referred to the techniques of carotid vessel wall imaging. However, the intracranial arterial blood vessel has no fat content and is very different from the cervical internal carotid artery and other large arteries [18,19]. For intracranial scanning, MCA is not affected by clivus bone marrow [20].

Common FS techniques consist of the following various modalities: short tau inversion recovery, spectral attenuated inversion recovery, FatSat, water-selective excitation, and Dixon technique [21], and each is based on a different physical phenomenon. In this study, we used FatSat technique to suppress the fat signal. This technique takes advantage of the difference in the precession frequency of water and fat to selectively apply presaturation pulses to fat, with the goal of fat suppression. It is widely used in clinical practice and is one of the most commonly used methods of fat inhibition by high-field

magnetic resonance [22]. We selected the FatSat technique for FS mainly because it is suitable for almost all MRI sequences and only slightly increases the scanning time.

Both the SNR and CNR of the source images of the 3D CUBE T1-weighted sequence with FS are lower because the application of FS technology increases imaging noise. The M1 segment of MCA is 3.0–5.0 mm in diameter on average, and is located along the cerebral sulcus, traveling tortuously [23]. To accurately evaluate the MCA vessel wall, plaque characteristics, and the signal characteristics of both, higher resolution and the relative SNR are required [24,25]. The increase in noise and decrease in signal intensity, SNR, and CNR affected the evaluation of image quality and vascular wall details, leading to a difference in scores between the 2 observers for the 2 sequence images, except for the visualization of the vascular lumen.

From the subjective evaluation, the 2 sequences showed no significant difference in the inhibition of blood flow, and the boundary between the vascular lumen and vessel wall could be distinguished. Therefore, there was no statistically significant difference in the measurement of vascular lumen area between the 2 sequences. However, from the perspective of plaque and vessel wall visualization, the increase in noise and the decrease in signal intensity affected the detailed observation of MCA vessel wall imaging, including the resolution of the plaque and vessel wall and the resolution of the vessel wall and surrounding tissues. Because the 3D CUBE T1-weighted

sequence without FS has a high SNR, high CNR, and low noise, it can better display the plaque and distinguish the boundary between the plaque and the vessel wall. Accordingly, the differences were noted in the measurements of plaque area by the 2 observers.

In this study, although the subjective score of blood vessel wall and the surrounding tissue comparison of the 3D CUBE T1-FS sequence was slightly lower, there was no significant difference in the cross-sectional area between the 2 objectively measured blood vessels. This may be because vascular sections are relatively easy to measure as compared with plaques, which offsets the disadvantage of local vascular walls being indistinguishable from surrounding tissues.

There are some limitations to our study. Currently, the most widely accepted scanning scheme for HR VW-MRI is multi-sequence scanning using the T1-weighted sequence, T2-weighted sequence, and proton density-weighted sequence, as well as the T1-enhanced sequence. In the current study, only the T1

sequence was selected for study. The T1-enhanced sequence may provide a more accurate display of the vascular lumen and plaque. However, injection of contrast medium is invasive and there is a risk of gadolinium deposition in the brain. Most patients enrolled in this study refused the minimally invasive examination, and the application of the contrast agent was beyond our scope and budget. Fat suppression technology leads to decreased SNR and CNR of images. This phenomenon may exist in the T1-enhanced sequence. Therefore, further studies on the evaluation of T1-enhanced sequence with and without FS will be necessary. In addition, other vascular stenoses caused by intracranial atherosclerotic diseases, including basilar artery stenosis, should be evaluated in future studies.

Conclusions

When using high-resolution vessel wall MRI of the MCA, the 3D CUBE T1-weighted sequence without FS performed better than the 3D CUBE T1-weighted sequence with FS.

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