Authorized translation from:
Hattori N, et al.: Comparison of the Contrast between the Imaging Methods for the Carotid Plaque. MEDIX 60, p22-25, issued in Mar, 2014 (in Japanese)

Research Paper

Comparison of the Contrast between the Imaging Methods for the Carotid Plaque

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Spin echo T1 weight imaging (SE-T1WI) reflects properties of the carotid plaque. However, the resolution of the slice direction is low. Recently, 3 dimensional fast SE (3D-FSE) has also been used for carotid plaque, but there is no report to date that compares the contrast of SE-T1WI with 3D-FSE. The purpose of this study is to compare the contrast of RADial Acquisition Regime SE (RADAR-SE) using radial scan and variable refocusing flip angle 3D-FSE (VRFA-FSE). In the evaluation of Gd-DTPA phantom, the contrast of VRFA-FSE was higher than RADAR-SE. In the low concentration phantom, the signal intensity ratio (SIR) was equivalent between the two methods, but the SIR of VRFA-FSE was higher for the high-concentration phantom. Based on these findings, it is thought that VRFA-FSE is useful for the evaluation of the distribution of carotid plaque.

Key Words: Magnetic Resonance Imaging, Plaque Imaging, T1-weighted Image, Signal Intensity Ratio

1. Introduction

Carotid plaques not only cause internal carotid stenosis or occlusion but fragile carotid plaques are also a serious risk factor of cerebral infaction.[1)] Black blood (BB) method suppressing carotid blood flow signals is widely used for the evaluation of carotid plaque fragility in MRI.[2)] However, methods of carotid artery plaque imaging include (1) double Inversion Recovery method using electrocardiogram synchronization, (2) radial scan method, and (3) 3 dimensional (3D) fast spin echo (VRFA-FSE) method using variable refocusing flip angle;[3)] the issue is that plaque contrast vary from different imaging methods. To the contrary, it is said that plaque signals with spin echo (SE) method have favorable correlation with properties of carotid plaque.[4)] At our hospital, we perform carotid artery plaque imaging using the two methods, RADial Acquisition Regime (RADAR)-SE method, a spin echo radial scan method, and isoFSE, a VRFA-FSE method.
RADAR-SE collects one echo per TR and can obtain favorable contrast equivalent to that by the SE method of carteician method[5)] however, the disadvantage is low resolution in slice direction due to 2 dimensional (2D) imaging. Meanwhile, isoFSE, a VRFA-FSE method, performs 3D-isotropic imaging thus can produce multi planar reconstruction (MPR) (Figure 1) and may be able to compensate the low resolution in slice direction, the disadvantage of RADAR-SE. However, contrast has not been compared to date.

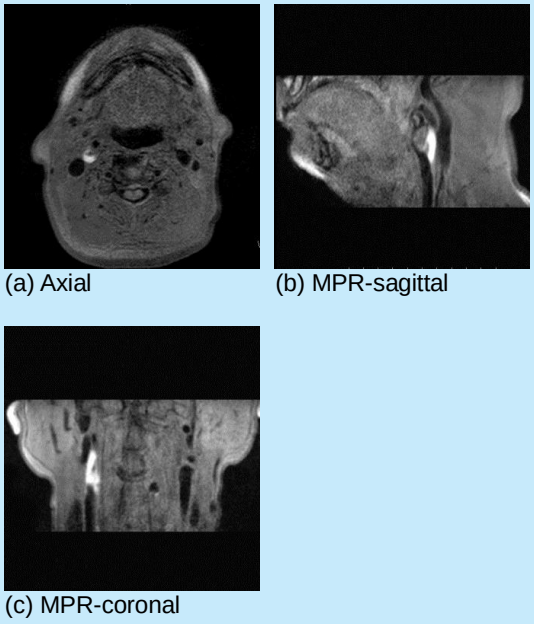


Figure 1: isoFSE image
The creation of MPR images will make it possible to observe the distribution of plaque in a 3 dimensional manner.

2. Objectives

The objective is to compare the contrast in RADAR-SE, carotid plaque imaging method used at our hospital and in T1 weighted image (T1WI) of

isoFSE. We also validate the effect of the application of signal intensity ratio (SIR) Map (Figure 2) normally used in RADAR-SE, which displays the properties of carotid plaques in color, to isoFSE.

3. Equipment and Method

All imaging was performed using ECHELON*.
Imaging parameters for RADAR-SE were as follows: Horizontal section, repetition time (TR) 500 ms, echo time (TE) 15 ms, field of view (FOV) 18 cm, slice thickness 4 mm, matrix 256 × 404, number of slices 9, and imaging time 6 min. 45 sec. Imaging parameters for isoFSE as follows: Horizontal section, TR 500 ms, TE 12 ms, FOV 20 cm, slice thickness 1 mm, matrix 192 × 192, number of slices 180, and imaging time 5 min. 41 sec.
In both imaging methods, pre-saturation pulse was applied in upward and downward directions of slices to suppress blood flow signals, and moreover, flow reduction pulse applied with an inclined magnetic microfield was used.

3.1 phantom study

Phantoms are solutions at different concentrations (5, 4, 3, 2, 1, 0.75, 0.5, 0.25, 0.1, 0.075, 0.05, and 0.025 mmol/l) prepared by diluting Gd-DTPA (meglumine gadopentetate, Bayer, Osaka, Japan) and saline filled in syringes. QD head coil was used for imaging. Imaging was repeated 5 times and statistically significant differences were tested by Wilcoxon signed rank test.

(1) Contrast evaluation
In order to evaluate contrast in RADAR-SE and isoFSE, phantom imaging was performed and contrast was calculated using the following formula:

$$\text{Contrast} = (SIa - SIb)/(SIa + SIb)$$

SIa: Signal value of phantom of Gd-DTPA diluted solution
SIb: Signal value of saline

(2) Signal intensity ratio evaluation
Signal intensity rate was calculated using the phantom at the concentration of 0.1 mmol/l (T1 value: 1,039 ms)[6] as a reference value, which is close to the T1 value of muscle.

$$\text{Signal intensity ratio} = SI_{Gd}/SI_{0.1}$$

SI_{Gd}: Signal values of phantoms of Gd-DTPA diluted solution at each concentration
$SI_{0.1}$: Signal value of the phantom of Gd-DTPA diluted solution at the concentration of 0.1 mmol/l

3.2 Clinical study

In patients who underwent carotid plaque imaging, RADAR-SE and isoFSE were used for imaging and compared after creating SIR Map.
RAPID NV coil was used for imaging, and the same imaging parameters as the phantom study were used.

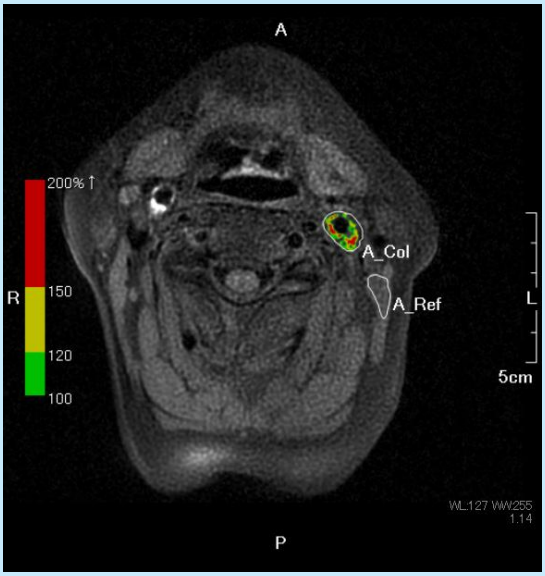


Figure 2: SIR Map
Plaques with signal intensity 1.0 to 1.2 times stronger than that of sternocleidomastoid muscle are shown in green, plaques with signal intensity 1.2 to 1.5 times stronger are shown in yellow, and plaques with signal intensity of 1.5 times stronger or more are shown in red.
Plaques in green mainly consist of fibers, those in yellow are mainly lipids and necrosis, and those in red are mainly bleeding.

4. Results and Discussion

4.1 Phantom study

Contrast in RADAR-SE and isoFSE was calculated (Figure 3). In the evaluation using phantoms, the contrast of isoFSE was higher than RADAR-SE ($p<0.05$).

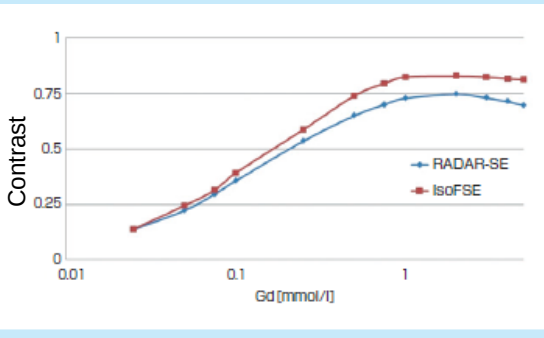


Figure 3: Contrast in RADAR-SE and isoFSE
Contrast in isoFSE is higher as compared with RADAR-SE.

The SIR was calculated by using the concentration of 0.1 mmol/l as a reference value (Figure 4). In the low concentration phantom, no significant difference was observed between VRFA-FSE and RADAR-SE ($p>0.05$), but the SIR of VRFA-FSE was higher in the high-concentration phantom ($p<0.05$). Therefore, isoFSE is considered useful in the detection of fragile plaques, as plaques mainly consisting of bleeding, tissue with a short T1 value, show higher signal intensity. In the SIR Map analysis, the SIRs were equivalent in the area mainly consisting of fibers shown in green (SIR: 1.0 to 1.2) and the area mainly consisting of lipids and necrosis shown in yellow (SIR: 1.2 to 1.5), not affecting the color map analysis. The SIR of isoFSE was high in the area mainly consisting of bleeding shown in red (SIR: 1.5 or more), however, the results of SIR analysis were shown in red for both. Accordingly, it was considered that color map analysis without change in SIR threshold value will have a little effect on the results.

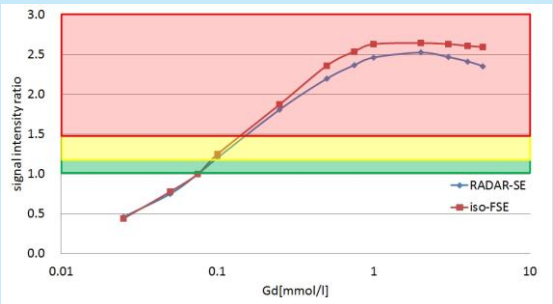
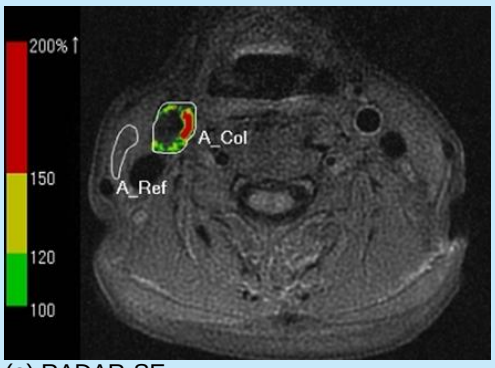


Figure 4: SIRs of RADAR-SE and isoFSE
The background colors correspond to SIRs.
The SIRs were equivalent at 0.25 mmol/l or less. The SIR of isoFSE is higher in the area at higher concentration, but there is a little effect on color map analysis.

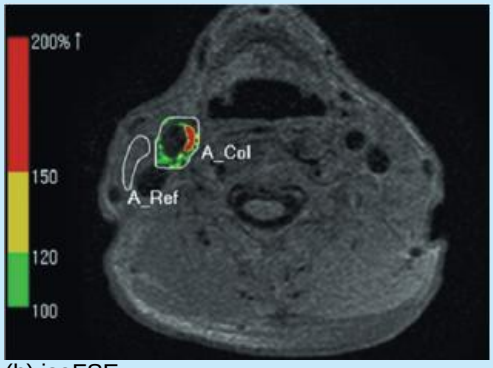
4.2 Clinical study

The examples of the results of SIR color map analysis in clinical cases are presented (Figure 5). Due to different pixel sizes, the values of area in the SIR Map analysis results are different. Therefore, the ratio of area of plaques of each component is also presented (Table 1). The ratios of area in each patient are mostly comparable. It is considered that slightly different values resulted from the effect of partial volume effect due to different slice thickness.

RADAR-SE is a radial scan method; as it does not require the use of ECG synchronization to suppress artifacts of pulsation in the carotid artery, it is possible to fix TR.



(a) RADAR-SE



(b) isoFSE

Figure 5: Right carotid artery stenosis
Both RADAR-SE and isoFSE showed plaques mainly consisting of bleeding in the directions of 1 to 3 o'clock. The distribution of plaques was also comparable.

Table 1: Signal intensity ratio of plaques in the patient in Figure 4

	Area (mm^2)		Ratios of area (%)	
	RADAR-SE	isoFSE	RADAR-SE	isoFSE
200 -	35.1	32.5	35.8	29.2
150 - 200	14.7	18.0	15.0	16.2
120 - 150	23.1	30.1	23.5	27.0
100 - 120	25.2	30.8	25.7	27.6

Therefore, the advantage is that signal intensity of plaques will not be dependent on subject's heart rate. Moreover, as plaque contrast by SE method was compared with pathological tissues and it was reported to show favorable correlation,[4] we have performed imaging by RADAR-SE as a standard method for the purpose of diagnosing the properties of plaques at our hospital. However, as there was an issue of low resolution in slice direction due to 2D imaging with slice thickness of 4 mm, it was unsuitable in grasping the distribution of plaques in the long axis direction.

Meanwhile, as isoFSE is 3D-isotropic imaging with slice thickness of 1 mm, it can easily grasp the presence and distribution of carotid plaques by using MPR. Also, as short T1 values are visualized as higher signal intensity as compared with RADAR-SE, it is considered to be a good method for the detection of

fragile plaques. However, as signal intensity of plaques and pathological tissues were not compared using isoFSE method, we consider that RADAR-SE should be used for the accurate diagnosis of properties of plaques at present. Moreover, as isoFSE uses no method to suppress motion artifacts such as pulsation in the carotid artery, it is prone to cause artifacts as compared with RADAR-SE.
Therefore, it is considered best to use them in a complementary manner, RADAR-SE for the diagnosis of properties of plaques and isoFSE for the diagnosis of presence and distribution of plaques.

5. Conclusion

We compared contrast and SIR between RADAR-SE and isoFSE, carotid artery plaque imaging methods. The isoFSE, a VRFA-FSE method, shows contrast and SIR comparable to RADAR-SE; however, as it shows high intensity signals in tissues with short T1 value, it is prone to show high signal intensity in fragile plaques. Also, it was considered that there will be a little effect when SIR color map analysis of isoFSE is performed using the same threshold value as RADAR-SE.
The isoFSE is an imaging method that complements a disadvantage of RADAR-SE, low resolution in slice direction.

*ECHELON is a registered trademark of Hitachi Medical Corporation.

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