

Review Article

High-resolution MR Imaging of Carotid Atherosclerotic Plaques

Wonseon Shin, Sung Mok Kim, Yeon Hyeon Choe

Department of Radiology, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Korea

High-resolution carotid MRI allows visualization of carotid atherosclerotic plaque characteristics. MRI serves as a noninvasive option for the detection of active plaque inflammation and intraplaque hemorrhage. Significant gains in signal-to-noise ratio and contrast-to-noise ratio can be obtained for carotid atheroma imaging at 3T compared with 1.5T. Normalized wall index or wall area on MRI has shown its efficacy in monitoring the response after medical therapy. T(2)* quantification in carotid plaques before and after the administration of ultrasmall superparamagnetic iron oxide particles shows difference in response to treatment according to drug doses. In conclusion, high-resolution MRI is useful in the diagnosis and monitoring of carotid atherosclerotic plaques prone to transient ischemic attack and stroke.

Index words : Atherosclerosis · Carotid artery · Magnetic resonance imaging (MRI)

INTRODUCTION

Carotid artery is a major source of cerebral embolism. The detection of unstable carotid plaques is important to prevent future cerebrovascular events, because vulnerable plaques may rupture and cause sudden arterial occlusion or distal embolization. Carotid MRI is considered as a tool for individualized management of carotid atherosclerotic disease to prevent stroke (1).

MRI capabilities in plaque characterization

MRI has been shown to accurately identify the fibrous cap, lipid-rich necrotic core, intraplaque hemorrhage, neovasculature and vascular wall inflammation (Figs. 1–3). MRI is a histologically validated technique for prospective testing of the vulnerable plaque hypothesis (2). High signal intensity (SI) in the

plaque may suggest a focal area of fresh hemorrhage on time-of-flight (TOF) images (3). New contrast agents and targeted molecular imaging open a window for MRI detection of thrombus and assessment of atherosclerotic activity and plaque vulnerability.

MRI techniques

Significant gains in signal-to-noise ratio (SNR) can be obtained for carotid atheroma imaging at 3T compared with 1.5T. There was also a trend towards increased contrast-to-noise ratio (CNR) (4). Excellent agreement was seen between contrast-enhanced MR angiography and T2-weighted SPACE sequence (dark blood-MRI using a 3-dimensional turbo spin echo with variable flip angles sequence) and between observers for assessment of lumen diameter, lumen area, vessel wall area, and degree of North American Symptomatic Carotid Endarterectomy Trial (NASCET) stenosis ($r > 0.80$, $p < 0.001$) (5).

Carotid intima-media thickness (IMT) is not adequately reproducible when tracking the progression of carotid atherosclerosis. The variability of ultrasound measurements of carotid IMT are likely to be reduced by further development of automatic calculation of this index by magnetic resonance imaging (6). Vessel

• Received; July 30, 2012 • Accepted; August 20, 2012

Corresponding author : Yeon Hyeon Choe, M.D., Department of Radiology, Samsung Medical Center, Sungkyunkwan University School of Medicine, 50 Ilwon-dong, Gangnam-gu, Seoul 135-710, Korea.

Tel. 82-2-3410-2509, Fax. 82-2-3410-2559

E-mail : yhchoe@skku.edu

wall imaging could quantify atherosclerotic plaque measurements more reliably with an improved blood suppression technique (7). Accurate co-registration between ultrasonography and other modalities is feasible with a global positioning system (GPS)-like technology, which has significant clinical and research applicability (8). The advantage of MRI over ultrasound is that the measurement variability is smaller, enabling smaller sample sizes and potentially shorter study duration in cardiovascular prevention trials (9).

Horie et al. (10) investigated whether a difference in dynamic enhancement pattern in plaque components could be useful to assess plaque stability with multidetector CT angiography. With MRI, a higher Δ HU was negatively correlated with signal intensity on T1-weighted imaging ($r = -0.56$, $p < 0.0001$). Histology confirmed that Δ HU was positively correlated with fibrous tissue ($r = 0.67$, $p = 0.001$) and negatively correlated with a lipid-rich necrotic core with hemorrhage ($r = -0.70$, $p < 0.001$). Moreover, less neovascularization and inflammation was found in plaques with a higher Δ HU. Delayed-phase images of dynamic CT provide information regarding the dynamic change in contrast media from the early arterial phase. An increase in attenuation (HU) from the early phase on multidetector CT angiography

indicates plaque stability with more fibrous tissue and a less lipid-rich necrotic core, intraplaque hemorrhage, and neovascularization. According to Tartari et al. (11), ongoing contrast-enhanced (CE)-MR angiography with a neurovascular coil for the simultaneous detection of unstable plaques is feasible. Plaque assessment was performed starting with a diffusion-weighted sequence and followed by a fat-suppressed T1-weighted sequence; after contrast-enhanced MR angiography (CE-MRA), all patients were evaluated with a T1-weighted 3-dimensional high-resolution sequence.

Kwee et al. (12) sought to compare ^{18}F -fluoro-2-deoxyglucose positron emission tomography (^{18}F -FDG PET), CT, and MRI of carotid plaque assessment. Overall, correlations between ^{18}F -FDG PET and CT/MRI findings are weak. Correlations between CT and MRI measurements are moderate to strong, but there is considerable variation in absolute differences. Patterson et al. (13) investigated T(2)* quantification in carotid plaques before and after the administration of ultrasmall superparamagnetic iron oxide particles (USPIOs) in a cohort of patients receiving statin therapy. In the patient study, there was a highly significant difference in post-USPIO T(2)* measurements in plaques between the low- and high-dose statin groups (10 mg and 80 mg of atorvastatin). Quantitative T(2)*

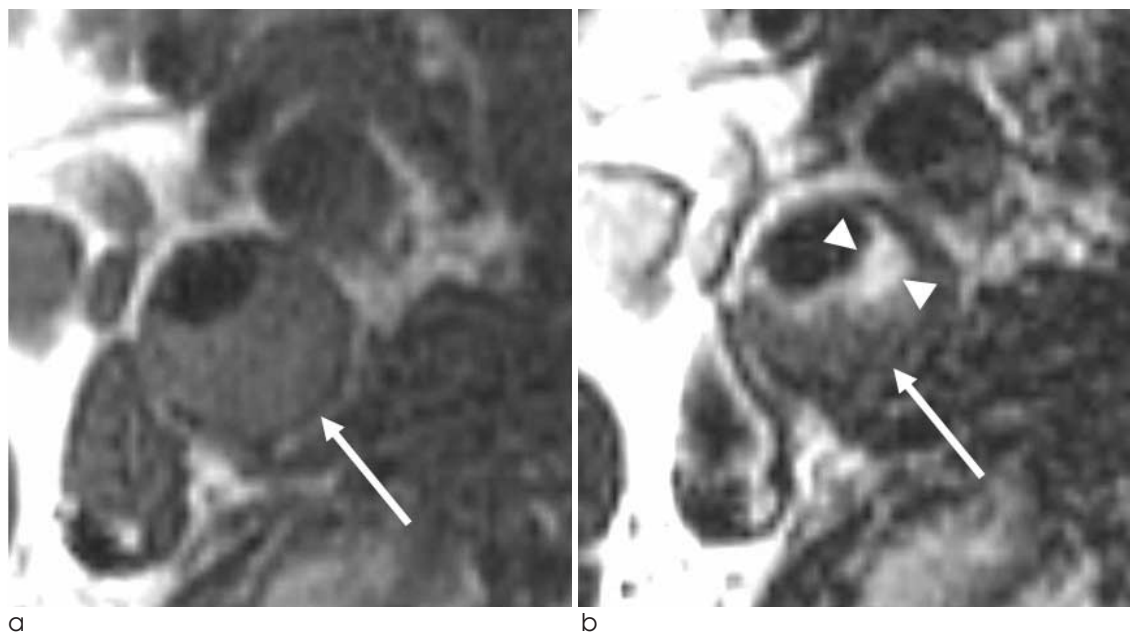


Fig. 1. Lipid-rich plaque. T1-weighted image (a) shows slightly increased signal intensity in the plaque (arrow). T2-weighted image shows a portion of bright signal intensity (arrowheads in the plaque which suggests the presence of fibrosis). The darker signal intensity in the plaque (arrow) implicates lipid-rich components.

($qT(2)^*$) measurements provide an alternative method of quantifying USPIO uptake. These results also demonstrate that changes in USPIO uptake can be measured using post-USPIO imaging only.

Clinical evidences

According to Virani et al. (14), extent of carotid atherosclerosis was associated with atherogenic cholesterol and lipoproteins in 1670 participants of Atherosclerosis Risk in Communities study. Atherogenic/anti-atherogenic cholesterol or particle ratios were associated with presence of a detectable lipid-rich core.

In a study of patients with atherosclerotic disease with 4 years of follow-up, only severe or bilateral carotid stenosis, and not moderate carotid stenosis and increased carotid intima-media thickness, were associated with progression of brain atrophy (15). According to Ota et al. (16), hemorrhage and larger %lipid-rich/necrotic core were independently associated with a thin or ruptured fibrous cap status at an early to advanced stage of carotid atherosclerosis. For the 798 MRI slices included, multivariate ordinal regression analysis demonstrated larger %lipid-rich/necrotic core (odds ratio for 10% increase, 1.49; $p = 0.02$) and presence of hemorrhage (odds ratio, 5.91; $p < 0.001$)

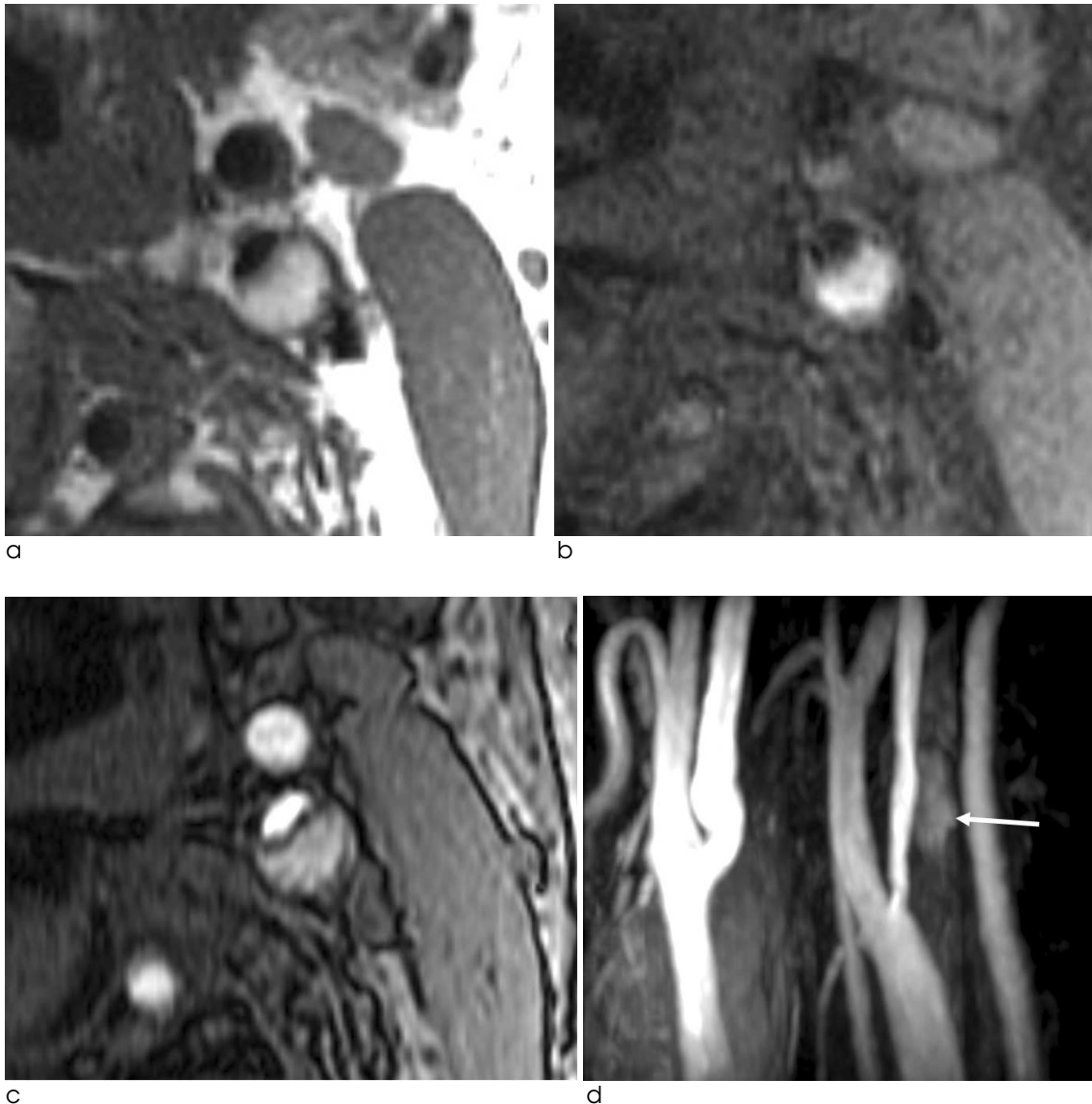


Fig. 2. Hemorrhagic plaque in a 64-year-old male with vascular dementia. The plaque signal intensity is bright on a T1-weighted image (a), T1-weighted image with fat-saturation (b), and source image of time-of-flight MR angiography (c). On a maximum intensity projection image (d), there is a halo sign (arrow) due to intraplaque hemorrhage.

were independently associated with a worse (intact thin or ruptured) stage of fibrous cap status.

Patients with carotid artery lesions and intraplaque hemorrhage tend to be at higher risk of a subsequent ipsilateral ischemic event. Risk evaluation of carotid artery disease should include plaque characteristics (17). Intraplaque hemorrhage evaluated by MRI identified neurologically unstable patients with increased levels of high-sensitivity C-reactive protein regardless of the degree of carotid stenosis (18).

Virani et al. (19) assessed the relationship between regulated on activation, normal T-cell expressed and secreted (RANTES) and carotid atherosclerotic plaque burden and plaque characteristics. Among 1769 inclusive participants, multivariable regression analysis revealed that total wall volume [$\beta = 0.09, p = 0.008$], maximum wall thickness ($\beta = 0.08, p = 0.01$), vessel wall area ($\beta = 0.07, p = 0.02$), mean minimum fibrous cap thickness ($\beta = 0.11, p = 0.03$), and high-sensitivity C-reactive protein ($\beta = 0.09, p =$

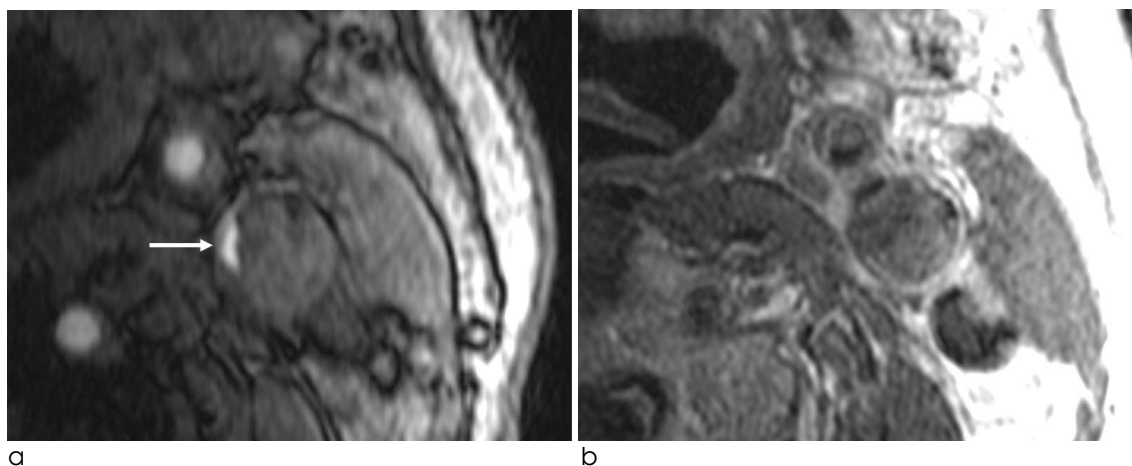


Fig. 3. Necrotic plaque in a 73-year-old male with stroke.
 a. A source image of time-of-flight MR angiography shows severe luminal narrowing (arrow) of the left internal carotid artery.
 b. contrast-enhanced T1-weighted MR image shows no significant enhancement in the plaque except the outer layers.

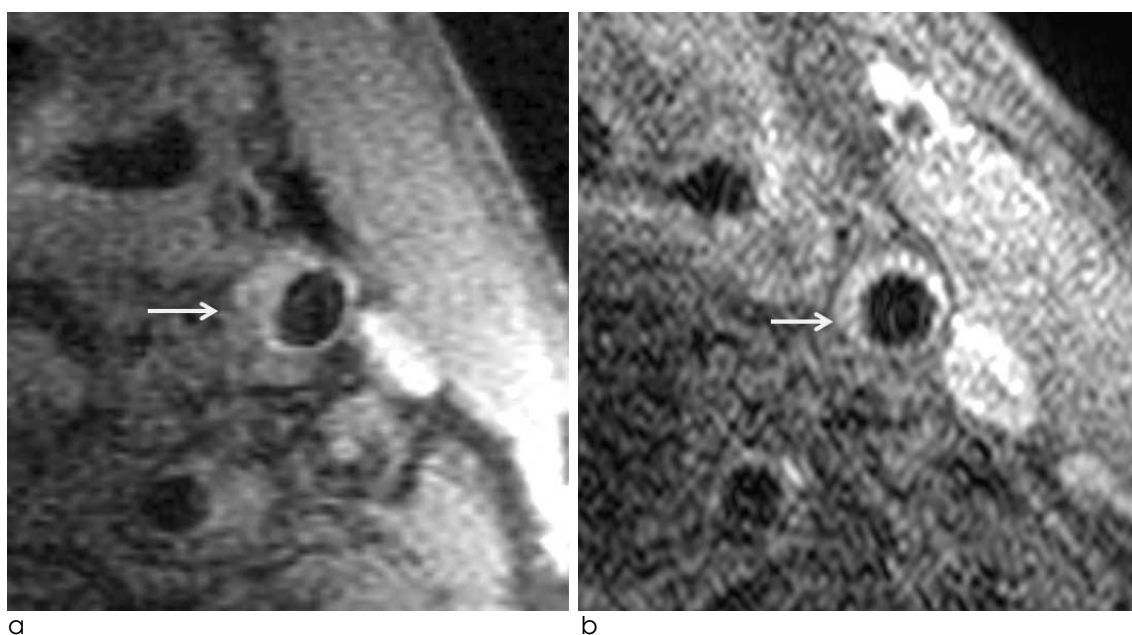


Fig. 4. Plaque regression after statin treatment in a 73-year-old male.
 a. T1-weighted image with fat-saturation at 1.5T shows an eccentric plaque in the left internal carotid artery.
 b. T1-weighted image with fat-saturation at 3T shows significant improvement in plaque thickness after 3-year low dose statin treatment.

0.01) were positively associated with RANTES.

Therapy monitoring

Carotid MRI helps improve risk stratification for stroke in patients and monitor the response to medical therapies; assessing efficacy of medical treatment at individual and population levels. Using ultrasound, computed tomography or MRI, plaques may be measured to monitor regression and progression of plaque volumes or plaque components (Fig. 4). Contrast-enhanced ultrasound, dynamic contrast-enhanced MRI, and FDG-PET are being explored to target plaque inflammation and neovascularization. Noninvasive imaging and other advances in risk stratification aim to improve and individualize the management of patients with carotid atherosclerosis (20). Saam et al. (21) found that increased normalized wall index on MRI and the use of statin therapy are associated with reduced rates of plaque progression amongst individuals with advanced, asymptomatic carotid atherosclerosis. According to Lee et al., nicotinic acid (high dose, 2 g) significantly reduced carotid wall area on MRI compared with placebo (adjusted treatment difference: -1.64 mm^2 [95% confidence interval: -3.12 to -0.16]; $p = 0.03$) (22).

In conclusion, high-resolution MRI enables visualization of carotid atherosclerotic plaque characteristics prone to transient ischemic attack and stroke. Carotid MRI allows quantification of plaque volumes and plaque components and thereby monitoring of response to therapy.

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경동맥 경화관의 고해상도 자기공명영상

성균관대학교 의과대학 삼성서울병원 영상의학과

신 원 선 · 김 성 목 · 최 연 현

고해상도 경동맥 자기공명영상(MRI)을 이용하여 경화관 특성을 파악할 수 있다. MRI는 경화관의 활동성 염증이나 경화관내 출혈을 비침습적으로 진단할 수 있는 능력이 있다. 3T MRI는 1.5T MRI에 비해 신호 대 잡음비와 대조도 대 잡음비가 높다. 동맥벽의 면적이나 표준화된 동맥벽 면적을 MRI로 측정하면 약물 치료 후 반응을 평가할 수 있다. 결론적으로 고해상도 MRI는 일과성 허혈이나 뇌졸중을 발생하기 쉬운 경화관의 진단과 치료 후 평가에 유용하다.

통신저자 : 최연현, (135-710) 서울시 강남구 일원동 50, 삼성서울병원 영상의학과
Tel. (02) 3410-2509 Fax. (02) 3410-2559 E-mail: yhchoe@skku.edu