Comparison of Three-Dimensional T1-Weighted Magnetic Resonance and Contrast-Enhanced Ultrasound Plaque Images for Severe Stenosis of the Cervical Carotid Artery

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Background and Purpose: Magnetic resonance (MR) and contrast-enhanced ultrasound assess characteristics and neovascularization, respectively, of the carotid plaque. The purpose of the present study was to clarify how findings of contrast-enhanced ultrasound plaque imaging are related to those of 3-dimensional (3D) fast spin echo (FSE) T1-weighted MR plaque imaging (WI) in severe stenosis (≥70%) of the cervical carotid artery. *Methods:* Fifty-three patients underwent 3D FSE T1-WI and contrast-enhanced ultrasound. For each patient, the averaged contrast ratio on MR (CR_{MR}) was calculated by dividing the averaged internal carotid artery plaque signal intensity by the sternocleidomastoid muscle signal intensity; maximally enhanced intensities on the intraplaque and lumen time-intensity curves were obtained from contrast-enhanced ultrasound data, and the ratio of the maximal intensity of the intraplaque curve to that of the lumen curve was calculated and defined as contrast effect (CE_{US}). *Results:* A linear correlation ($r = .702$; $P < .0001$) was observed between CR_{MR} and CE_{US}. Receiver operating characteristic curve analyses to evaluate the ability of the CE_{US} to differentiate each category of CR_{MR} from the other 2 categories showed that the sensitivity was significantly lower for category II ($1.30 \le CR_{MR} \le 1.60$) than for category I ($CR_{MR} < 1.30$) or III ($1.60 < CR_{MR}$). The CE_{US} was lower in plaques with higher CR_{MR} than in those with lower CR_{MR} in a subgroup of category III ($P = .0196$). *Conclusion:* Findings of contrast-enhanced ultrasound plaque imaging are related to those of 3D FSE T1-WI MR

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Received April 6, 2017; revision received June 12, 2017; accepted June 21, 2017.

Grant support: This work was partly supported by a Grant-in-Aid for Strategic Medical Science Research from the Ministry of Education, Culture, Sports, Science and Technology of Japan (S1491001) and the Scientific Research from Japan Society for the Promotion of Science (JP15K10313).

Conflict of interest statement: K.O. declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Consigned research funds from Nihon Medi-Physics Co., Ltd. and Bristol-Myers Squibb.

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1052-3057/$ - see front matter

http://dx.doi.org/10.1016/j.jstrokecerebrovasdis.2017.06.029

plaque imaging according to the life history of arterial plaque and its neovascularization. **Key Words:** Carotid plaque—magnetic resonance imaging—T1-weighted image—contrast-enhanced ultrasound.

Introduction

In cervical carotid stenosis, plaque characteristics can be assessed by magnetic resonance (MR) plaque imaging. Compared with the other T1-weighted sequences for MR plaque imaging, the spin echo T1-weighted MR plaque imaging (WI) technique and the source image of 3-dimensional (3D) time-of-flight MR angiography with appropriate scanning parameters have been shown to be more accurate in quantifying intraplaque components of the carotid artery.[1] Several investigators have also demonstrated that preoperative carotid MR plaque imaging using such preferred sequences predicts the development of artery-to-artery emboli during the exposure of the carotid arteries in endarterectomy[2] or during carotid artery stenting[3]; preoperative high intensity in the carotid plaque on T1-WI was significantly associated with this development of emboli. Furthermore, a 3D fast spin echo (FSE) T1-WI technique capable of minimizing partial volume effects and motion artifacts and enhancing black-blood effects while maintaining T1-WI contrast has recently been adopted.[4,5] A comparison of diagnostic accuracy between previous T1-WI sequences and 3D FSE T1-WI for carotid plaque characterization using pathological specimens excised during carotid endarterectomy showed that, because it provides improved contrast of lipid-rich plaques, 3D FSE T1-WI could characterize carotid plaque composition (e.g., hemorrhage, lipid-rich or necrotic core and fibrosis) more accurately than previous T1-WI sequences.[4]

Contrast-enhanced ultrasound can generate real-time images of microbubbles as intravascular tracers that penetrate the carotid plaque from the vessel lumen or adventitial side through neovessels.[6-8] Recent studies have demonstrated that visual or quantitative evaluation of the contrast effect (CE_{US}) using contrast-enhanced ultrasound enabled the histopathological assessment of neovascularization of the carotid plaque, suggesting that the high CE_{US} in plaque may reliably predict the presence of rich neovessels.[6,9-12] Several investigators have also shown that a preoperative high CE_{US} in the carotid plaque on ultrasound was significantly associated with the development of artery-to-artery emboli during the exposure of the carotid arteries in endarterectomy[13] or during carotid artery stenting.[14,15]

The above findings suggested that both high intensity on T1-WI and the high CE_{US} on ultrasound in the carotid artery indicate the presence of unstable and vulnerable plaque, and investigating whether these two imaging modalities display the same pathological conditions of the carotid plaque is of interest. The purpose of the present study was thus to clarify how findings of contrast-enhanced ultrasound plaque imaging are related to those of 3D FSE T1-WI MR plaque imaging in severe stenosis of the cervical carotid artery.

Methods

Study Design

The present study was designed as a prospective, cross-sectional study. This protocol was reviewed and approved by the institutional ethics committee, and written, informed consent was obtained from patients or their next of kin prior to participation.

Patients

Patients with the following conditions were included in the present study: (1) internal carotid artery (ICA) stenosis of 70% or higher as per the North American Symptomatic Carotid Endarterectomy Trial[16] on angiography/arterial catheterization; (2) useful preoperative residual function (modified Rankin Scale score, 0-2); and (3) no ipsilateral carotid territory ischemic symptoms or ipsilateral carotid territory ischemic symptoms more than 6 months before presentation (defined as asymptomatic)[17] or ipsilateral carotid territory ischemic symptoms between 2 weeks and 6 months before presentation (defined as symptomatic).[17] Patients with previous allergic reactions to eggs[10] and those who did not undergo MR plaque imaging were excluded.

MR Plaque Imaging and Data Processing

Preoperative 3D FSE T1-WI of the affected carotid bifurcation was performed using a 1.5-T MR imaging scanner (Signa HDxt; GE Healthcare, Milwaukee, WI) and an 8-channel neurovascular coil under a previously described imaging protocol.[4,5] In patients with stenosis of 70% or higher in bilateral internal carotid arteries, the symptomatic side for symptomatic patients and the side with the greater degree of stenosis for asymptomatic patients underwent data processing.

An investigator (blinded to other data) processed the 3D FSE T1-WI data using a free software package (OsiriX; Pixmeo, Geneva, Switzerland) as follows (Fig 1)[5]: The curved planar reformation image was generated parallel to the long axis of the common carotid artery and the ICA by manually setting and automatically connecting reference points in the center of the vessel lumen on each axial source image. On the curved planar reformation image