Carotid Plaque Evaluation Using Gemstone Spectral Imaging: Comparison with Magnetic Resonance Angiography

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Background: The present study compared the applicability of computed tomography carotid plaque imaging using effective *Z* maps with gemstone spectral imaging (GSI) to that of magnetic resonance plaque imaging using 3-dimensional time-of-flight magnetic resonance angiography. *Methods:* Stenosis was assessed in 18 carotid arteries of 14 patients, and the effective *Z* values of noncalcified carotid plaques were compared with the signal intensities of magnetic resonance angiography. *Results:* It was found that the effective *Z* value of noncalcified carotid plaques was significantly lower for a group with high signal intensity than for a group with low signal intensity on magnetic resonance angiography ($P < .001$). The area under the receiver operating characteristic curve of effective *Z* values was .975, and the presumed cutoff effective *Z* value required to discriminate low and high intensity plaques on magnetic resonance angiography was 7.83. *Conclusions:* The effective *Z* value generated by GSI is a useful parameter to detect vulnerable carotid plaque materials. **Key Words:** Stroke—atherosclerosis—lipid—computed tomography—magnetic resonance angiography.

Introduction

Carotid artery stenosis is one of the critical factors of ischemic stroke,[1,2] and neuroradiological evaluation plays an important role for the diagnosis.[2,3] Especially, plaque composition and luminal patency of the carotid artery must be assessed to determine suitable therapeutic strategies including medication and surgery.[4,5]

Atherosclerotic carotid plaque contains lipid-rich necrotic core (LRNC), intraplaque hemorrhage (IPH), calcification, and fibrous components, and vulnerable carotid plaque tends to consist of LRNC and IPH, rather than calcification and fibrous components.[6,7] The vulnerability of carotid plaque can be evaluated using magnetic resonance imaging (MRI). MRI shows LRNC as regions of iso to high signal intensity, LRNC with recent IPH as areas of high signal intensity compared with neighboring muscle on T1-weighted images and 3-dimensional time-of-flight magnetic resonance angiography (MRA), and calcification appears as low-intensity areas on all imaging sequences.[8-16]

Computed tomography angiography (CTA) for carotid artery can demonstrate the degree of stenosis and calcification.[8,17,18] The ability of computed tomography (CT) to visualize and evaluate vulnerable plaque remains controversial, although several articles have suggested that vulnerable plaque can be classified as LRNC, IPH, and fibrous components by CT numbers (Hounsfield units).[19,20]

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Rapid kilovoltage (kV)-switching dual-energy CT with a gemstone detector (gemstone spectral imaging [GSI]) enables generation of virtual monochromatic 40- to 140-keV images and effective atomic numbers (effective Z) maps from a single scan.[21-23] The present study compared CT plaque imaging of carotid artery stenosis using GSI with MRA.

Methods

Patients

This retrospective study analyzed data obtained from all patients with carotid artery stenosis who underwent cervical GSI–CTA using rapid kV-switching dual-energy CT with a gemstone detector (Discovery CT750 HD; GE Healthcare, Milwaukee, WI) at our hospital during the recent 2 years. The inclusion criteria of the present study comprised assessment by MRA and GSI–CTA, intervals between assessments of less than 2 months, and stable neurological manifestations or medications at all assessments. Finally, 18 vessels in 14 patients (12 men and 2 women; mean age, 73 years; age range, 57-86 years) were enrolled. Our institutional review board approved the present study and waived the need for written informed consent because of its retrospective design.

CT Protocols

GSI–CTA of the carotid arteries was performed after an injection of nonionic water-soluble iodinated contrast material (Omnipaque 350; Daiichi-Sankyo, Tokyo, Japan). The flow rates and volume of contrast material were determined based on a fixed duration (12 seconds) of injection and dose tailored to the weight of each patient (252 mgI/kg), followed by a 30 mL saline chaser at the same flow rate. Scan delay was determined using a test bolus.

The parameters of dual-energy CT were as follows: slice thickness, .625 mm; rotation speed, .5 second; tube voltage, rapid kV switching between 80 and 140 kVp; tube current, 630 mA; pitch .984:1; and matrix, 512 × 512. Acquired images were reconstructed with a 50% adaptive statistical iterative reconstruction blend using a standard kernel. Virtual monochromatic 40- to 140-keV images were generated by postprocessing, and effective Z maps were created using dedicated GSI viewer software (Advantage Workstation VolumeShare 5, GE Healthcare). Targeted reconstruction (10 cm) was performed at the carotid bifurcation on each effective Z map. In addition, 70-keV images were also reconstructed as reference using the same workstation because the image contrast of the 70-keV images is considered to be almost equivalent to that of 120-kV polychromatic images according to previous reports.[24,25]

MRI Systems and Protocols

Eighteen vessels in 14 patients were assessed by MRA using a Discovery MR750w 3T (GE Healthcare), a Magnetom Skyra 3T (Siemens, Erlangen, Germany), or an Achieva 1.5T (Philips Medical Systems, Best, the Netherlands) magnetic resonance system. The scan protocols for the MRA were as follows: GE Discovery MR750w: repetition time (TR)/echo time (TE), 20 ms/3.69 ms; flip angle, 16°; slice thickness, 1.8 mm; field of view, 23 × 23 cm; matrix, 256 × 224; Siemens Magnetom Skyra: TR/TE, 20 ms/3.69 ms; flip angle, 15°; slice thickness, 1 mm; field of view, 20 × 20 cm; matrix, 320 × 192; and Philips Achieva: TR/TE, 25 ms/6.71 ms; flip angle, 18°; slice thickness, .7 mm; field of view, 20 × 20 cm; matrix, 288 × 144.

Image Evaluation

GSI plaque imaging was initially quantified by generating effective Z maps and 70-keV images for comparison with MRA. Regions of interest (ROIs) on GSI–CTA source images were defined as areas of hypoattenuated plaque at 3 sequential stenotic levels (.625 mm × 3), excluding areas of massive high attenuation that were considered to be due to calcification. The mean effective Z values of corresponding slices were measured in each patient. ROIs on MRA were defined as areas of plaque at the same level of the corresponding ROIs on GSI–CTA. The relative signal intensity ratio (SIR) of each patient, calculated as the maximal signal intensity of plaque compared to the mean signal intensity of the adjacent sternocleidomastoid muscle, was measured on MRA. The composition of carotid plaque can be estimated from the SIR on MRA.[9-16] We investigated the correlation between SIRs and mean effective Z values of carotid plaque. We also evaluated the correlation between SIRs and 70-keV CT values. Thereafter, the plaque was classified as having high or low SIR (>1.5 and ≤1.5, respectively, on MRA), which was considered to reflect vulnerable and stable plaques, respectively.[9-16] The effective Z values and 70-keV CT values of carotid plaque were then compared between the groups with high and low SIRs.

Statistical Analysis

Correlations between SIRs on MRA and effective Z values or 70-keV CT values were investigated with the Pearson correlation coefficient test. Differences in effective Z values and 70-keV CT values between patients with high and low SIRs were analyzed by the Mann–Whitney U test. Receiver operating curves were also analyzed for quantitative effective Z analysis and 70-keV CT values, and areas under the receiver operating curve were calculated. These statistical evaluations were performed using SPSS software version 23.0 (SPSS Inc., Chicago, IL). Significance was established at a P value less than .05.

Results

Significant correlation was found between SIRs on MRA and mean effective Z values of carotid plaque ($r = -.496$, $P < .05$). Meanwhile, there was no significant correlation