Utility of 3-Dimensional Ultrasound Imaging to Evaluate Carotid Artery Stenosis: Comparison with Magnetic Resonance Angiography

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Background: We evaluated the utility of 3-dimensional (3-D) ultrasound imaging for assessment of carotid artery stenosis, as compared with similar assessment via magnetic resonance angiography (MRA). *Methods:* Subjects comprised 58 patients with carotid stenosis who underwent both 3-D ultrasound imaging and MRA. We studied whether abnormal findings detected by ultrasound imaging could be diagnosed using MRA. Ultrasound images were generated using Voluson 730 Expert and Voluson E8. *Results:* The degree of stenosis was mild in 17, moderate in 16, and severe in 25 patients, according to ultrasound imaging. Stenosis could not be recognized using MRA in 4 of 17 patients diagnosed with mild stenosis using ultrasound imaging. Ultrasound imaging showed ulceration in 13 patients and mobile plaque in 6 patients. When assessing these patients, MRA showed ulceration in only 2 of 13 patients and did not detect mobile plaque in any of these 6 patients. Static 3-D B mode images demonstrated distributions of plaque, ulceration, and mobile plaque, and static 3-D flow images showed flow configuration as a total structure. Real-time 3-D B mode images demonstrated plaque and vessel movement. Carotid artery stenting was not selected for patients diagnosed with ulceration or mobile plaque. *Conclusions:* Ultrasound imaging was necessary to detect mild stenosis, ulcerated plaque, or mobile plaque in comparison with MRA, and 3-D ultrasound imaging was useful to recognize carotid stenosis and flow pattern as a total structure by static and real-time 3-D demonstration. This information may contribute to surgical planning. **Key Words:** Carotid artery stenosis—3-dimensional ultrasonography—magnetic resonance angiography—ulceration—mobile plaque.

Introduction

The presence of a carotid artery stenosis is a well-established risk factor for ischemic stroke. Several studies of ultrasound imaging, magnetic resonance angiography (MRA), computed tomographic angiography, digital subtraction angiography (DSA), and histology analysis of the carotid artery plaque support the notion that certain surface features and morphology of plaques are also associated with a higher risk of cerebral ischemia.[1,2] For example, plaque ulceration is associated with thrombus formation that can lead to cerebral ischemia. The ischemic episode itself can be the result of intra-arterial

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embolization, distal hemodynamic insufficiency, or the combination of the two.[3] A recent study also concluded that a mobile plaque is an important predictive factor for repeated ischemic stroke.[4,5]

For diagnosis or screening of carotid artery lesions, 2-dimensional ultrasound imaging is generally used. Although abnormal plaque characteristics and carotid stenosis can be detected by conventional 2-D ultrasound, the 3-dimensional (3-D) demonstration of lesions is impossible by the conventional technique. Using 2-D ultrasound, every examiner forms an adequate 3-D mental impression of the carotid artery lesion, although this can be difficult, especially in the context of complex plaque structures. 3-D ultrasound allows visualization of stenosis lesion in all 3 dimensions at the same time, providing an improved overview and a more clearly defined demonstration of adjusted anatomical planes.[4,6-11]

MRA is a useful imaging method to screen for carotid artery stenosis, and magnetic resonance (MR) plaque imaging can be used to characterize the plaque components.[12,13] Because the degree of carotid artery stenosis is an important indication for surgery, neurosurgeons are more familiar with MRA than ultrasound imaging for the diagnosis of carotid artery stenosis. Previous studies comparing MRA with ultrasound imaging for the examination of carotid artery stenosis were performed using 2-D ultrasound imaging and concluded that MRA was superior to ultrasound imaging for precise evaluation.[14,15]

We studied whether the abnormal findings detected by 3-D ultrasound imaging could also be diagnosed using MRA in patients with carotid artery stenosis.

Patients and Methods

Subjects comprised 58 patients with carotid artery stenosis who underwent 4-dimensional ultrasonography and MRA. Mean age was 63 years (range, 48-90 years); 46 patients were male, and 11 patients were symptomatic. When patients had stenosis lesions on both sides, the side of the carotid artery with thicker plaque on ultrasound imaging was included in this study (left side in 30 patients). Carotid endarterectomy was performed in 15 patients, and carotid artery stenting was performed in 3 patients.

The 4-D ultrasound system used for this study was the Voluson 730 Expert (GE Healthcare, Tokyo, Japan) in 56 patients, and this machine and Voluson E8 (GE Healthcare, Tokyo, Japan) were used in 2 patients. This system automatically constructs static and real-time 3-D images with multislice image information. About 5 seconds was usually required for automatic scanning, and 10 seconds was required for 3-D imaging. We used the term "static 3-D imaging" for 3-D imaging without pulsation, and "real-time 3-D imaging" for pulsating 3-D imaging. MR imaging was performed using Signa HDxt 3.0 Tesla (GE Healthcare, Tokyo, Japan), and time-of-flight MRA using maximum intensity projection was evaluated. In some patients in whom plaque was suspected on the basis of ultrasound imaging and/or MRA, black blood (BB)-MR imaging was also performed. Imaging parameters for MRA was as follows: repetition time/echo time (TR/TE) = 26.0/2.7 milliseconds, flip angle 20, scan time 239 seconds, section thickness 1.0 mm, field of view (FOV) 190 × 170, matrix 512 × 224, and voxel volume .39 mm^3. BB-MR imaging fat suppressed T1- and T2-weighted sequences were applied with the following parameters: TR/TE = 923/6.9 milliseconds and scan time 237 seconds for T1-weighted imaging, TR/TE = 1875/83.0 milliseconds and scan time 215 seconds for T2-weighted imaging, and both types of images were obtained with flip angle 90, slice thickness 5.0 mm, FOV 256 × 125, and acquisition timing (frequency; 256, phase 192, NEX 1.0, and phase FOV 1.0).

The ability of MRA to detect abnormal findings (eg, stenosis, ulceration, or mobile plaque) detected by ultrasound imaging was assessed.

Evaluation was performed by 3 neurosurgeons (I.M., M.A., and A.G.). Stenosis rate was evaluated using European Carotid Surgery Trial[16] for ultrasound, and North American Symptomatic Carotid Endarterectomy Trial[17] for MRA.

Results

Among 58 patients, the degree of stenosis was mild (less than 50%) in 17 patients, moderate (50%-69%) in 16 patients, and severe (more than 70%) in 25 patients on ultrasound images. Using ultrasound imaging, plaque with ulceration was detected in 13 patients, and mobile plaque was recognized in 6 patients. Although examiners must form an adequate 3-D mental impression of the carotid artery lesion using 2-D ultrasound system, we could observe 3-D structure constructed automatically using 4-D ultrasound system. As static 3-D B mode ultrasound images showed the total structure of carotid lesions, the distributions of carotid plaque, the localization of ulceration, and mobile plaque were demonstrated from any direction. Static 3-D color Doppler or power Doppler ultrasound images showed a flow image as a total structure from any direction. Real-time 3-D B mode ultrasound images demonstrated pulsating plaque and the carotid wall as a total structure.

Real-time 3-D B mode images obtained using Voluson E8 showed smooth pulsation of the arterial wall, and this imaging was superior to that obtained using 730 Expert for visualization of a pulsating mobile plaque. Real-time 3-D color Doppler or power Doppler imaging was possible using Voluson E8, and this imaging showed pulsating flow pattern as a total structure. Furthermore, this type of imaging was not possible when using Voluson 730 Expert. Visualization of the plaque by static