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Evaluation of carotid vessel wall enhancement with image subtraction after gadobenate dimeglumine-enhanced MR angiography

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Abstract

Objectives: This study was aimed at testing the value of image subtraction for evaluating carotid vessel wall enhancement in contrast-enhanced MR angiography (MRA).
Materials and methods: IRB approval was obtained. The scans of 81 consecutive patients who underwent carotid MRA with 0.1 mmol/kg of gadobenate dimeglumine were reviewed. Axial carotid 3D T1-weighted fast low-angle shot sequence before and 3 min after contrast injection were acquired and subtracted (enhanced minus unenhanced). Vessel wall enhancement was assigned a four-point score using native or subtracted images from 0 (no enhancement) to 3 (strong enhancement). Stenosis degree was graded according to NASCET.
Results: With native images, vessel wall enhancement was detected in 20/81 patients (25%) and in 20/161 carotids (12%), and scored 2.0 ± 0.6 (mean ± standard deviation); with subtracted images, in 21/81 (26%) and 22/161 (14%), and scored 2.5 ± 0.6, respectively ($P < 0.001$, Sign test). The overall stenosis degree distribution was: mild, 41/161 (25%); moderate, 77/161 (48%); severe, 43/161 (27%). Carotids with moderate stenosis showed vessel wall enhancement with a frequency (17/77, 22%) significantly higher than that observed in carotids with mild stenosis (1/41, 2%) ($P = 0.005$, Fisher exact test) and higher, even though with borderline significance ($P = 0.078$, Fisher exact test), than that observed in carotids with severe stenosis (4/43, 9%).
Conclusion: Roughly a quarter of patients undergoing carotid MRA showed vessel wall enhancement. Image subtraction improved vessel wall enhancement conspicuity. Vessel wall enhancement seems to be an event relatively independent from the degree of stenosis. Further studies are warranted to define the relation between vessel wall enhancement and histopathology, inflammatory status, and instability.

Keywords: Carotid arteries; MR angiography; Image subtraction; Vessel wall enhancement

1. Introduction

Morphology and content of the atherosclerotic plaque at the carotid bifurcation play a crucial role among the risk factors for ischemic neurological events [1]. Pathologic examinations of specimens obtained from carotid endarterectomy have shown that the majority of ruptured plaques contains a lipid-rich core covered by a thin cap of fibrous tissue and infiltrated by macrophages [2–4]. Moreover, intraplaque neovasculature may contribute to plaque instability [5]. Accordingly, imaging techniques which enable us to reveal vulnerable and inflamed atherosclerotic plaques might considerably improve

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the management of patients at risk of ischemic stroke, the third cause of death and the first cause of morbidity in the western world. Recent literature suggests that contrast-enhanced magnetic resonance (MR) imaging enable us not only to quantify fibrous and lipid plaque components [6] but also to identify plaque enhancement as a marker of plaque inflammation [7].

The visualization of plaque enhancement is not an easy task. Lipids, fibrous tissue, calcium as well as necrosis and hemorrhage can be found in the plaque in different amount. Moreover, the plaque itself is located between extravessel structures with variable signal intensity and the lumen, where contrast is frequently still present when plaque enhancement should be detected. On the other hand, subtraction technique is routinely used for contrast-enhanced MR angiography and has also been proposed to evaluate the increased vessel map associated to breast tumors [8] or to detect the inflammatory status of demyelinating plaques in the brain of patients with multiple sclerosis [9].

Thus, we formed the hypothesis that a pixel-by-pixel electronic subtraction (enhanced minus unenhanced images) can be used as a tool to improve plaque enhancement evaluation. The main purpose of this work was to investigate whether the evaluation of vessel wall enhancement can be more confident using image subtraction after contrast-enhanced MR angiography.

2. Materials and methods

2.1. Study population

Institutional review board approval was received for this retrospective study and informed consent was not required. From February 2004 to June 2005, 81 consecutive patients with unilateral or bilateral carotid stenosis diagnosed with color Doppler ultrasound were referred to our Institution and underwent bilateral carotid MR angiography at our Department of Radiology. They were 51 males and 30 females with mean age of 71.8 years ± 8.4 (mean ± standard deviation) and a median age of 73.0 years. Seventy-four of them were outpatients, while seven came from the Vascular Surgery day-hospital; none of them was in unstable clinical conditions and all of them were well cooperating.

2.2. MR imaging

All MR examinations were conducted with a 1.5-T unit with 40 mT/m gradient power (Magnetom Sonata, Siemens, Enlargen, Germany) with phased array head, neck and cervical spine coils and with the patient in supine position. A three-plane morphologic scout gradient-echo scan and a two-plane vessel scout gradient-echo scan were acquired to define the location for the following three sequences.

(1) A three-dimensional fast low-angle shot T1-weighted sequence [TR/TE (ms) 20/4.8; flip angle 70°; matrix 256 × 256; field of view (FOV) 260 mm × 260 mm; slice thickness 3 mm; 20 axial partitions; two axial presaturation slabs of 100 mm thickness above and below the acquired volume] was acquired centered on the carotid bifurcations. When the two carotid bifurcations were located on different cranio-caudal levels, the axial sequence was centered at the middle point along the vertical axis between the level of the right bifurcation and the level of the left bifurcation.
(2) A three-dimensional fast low angle shot gradient-echo sequence [TR/TE (ms) 3.4/1.29; flip angle 30°; matrix 180 × 385; FOV 300 mm × 188 mm; slice thickness 0.9 mm; 72 coronal partitions] was acquired before and after an automated bolus injection (power injector Spectris, Medrad, Indianola, PA, USA) of 0.1 mmol/kg of gadobenate dimeglumine (Gd-BOPTA, MultiHance, Bracco Imaging, Milan, Italy) at a rate of 2 mL/s and with a mean delay time of 12–15 s, under care-bolus control.
(3) Three minutes after this angiographic sequence, the sequence described at the point (1) was repeated with the same sequence parameters.

2.3. Image analysis

The internal carotid stenosis were evaluated and graded on maximum intensity projections and multiplanar reformatted images obtained from the coronal acquisition according to NASCET criteria: mild (0–29%), moderate (30–69%) or severe (70–99%) stenosis [10].

The angiographic coronal scans (sequence 2) were automatically postprocessed at the end of the acquisition with electronic subtraction and presented on the first consolle (i.e., that used for image acquisition) as three-dimensional maximum intensity projections, as usually happens for MR angiography.

Image analysis was performed on a remote workstation (Leonardo, Siemens, Enlargen, Germany) by two readers in consensus. They were a fourth-year resident in radiodiagnostics and a neuroradiologist with 9 years of clinical experience.

Subtracted images of the axial scans (sequence 3 minus sequence 1) were obtained by electronically subtracting the unenhanced images from the corresponding enhanced ones. The vessel wall enhancement was evaluated in two separated sessions with a time interval of at least 2 weeks. In the first session, for each of the 81 patients, the two readers visually compared the 20 pairs of axial images composed of the unenhanced image and the contrast-enhanced image; in the second session, for each of the 81 patients, the two readers evaluated only the 20 subtracted axial images. During the two sessions, a random order of patients was used. A four-point ordinal score was assigned to the contrast enhancement of the vessel wall of each carotid bifurcation, by consensus: 0, when there was no detectable wall enhancement; (1) when the wall enhancement was judged as uncertain; (2) when the wall enhancement was judged as certain but limited to only a single focus; (3) when the wall enhancement was judged as certain for two or more than two enhancing foci.

2.4. Statistical analysis

To compare the differences between the enhancement score obtained on the basis of native unenhanced and enhanced axial