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Research article

Three-dimensional black blood contrast enhanced magnetic resonance imaging in patients with acute ischemic stroke and negative susceptibility vessel sign

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ABSTRACT

Purpose: The purpose of this study was to evaluate the enhancement patterns of three-dimensional (3D) black blood (BB) contrast enhanced magnetic resonance (MR) imaging in acute stroke patients with negative susceptibility vessel sign (SVS).

Materials and methods: From January 2014 to August 2016 we retrospectively reviewed MR imaging and MR angiography findings of patients who presented with acute stroke symptoms of less than 24 h duration. For the 394 patients enrolled, we assessed the frequency of patients who exhibited negative SVS on susceptibility weighted MR imaging (SWI) and positive enhancement in 3D BB contrast enhanced MR imaging. We subdivided the enrolled group according to whether the MR angiography findings suggested stenosis (stenosis group) or occlusion (occlusion group). Enhancement patterns on BB contrast enhanced MR imaging were compared between the two groups according to several qualitative parameters: intensity (weak or strong), morphology (linear/eccentric or round/concentric), length (focal or segmental) and multiplicity (single or multiple).

Results: Sixty-two of 394 patients (15.7%) showed positive findings on BB contrast-enhanced MR imaging with negative SVS. Forty-two patients were classified into the stenosis group, and 20 patients were assigned to the occlusion group. Enhancement patterns of the stenosis group showed weak intensity, linear or eccentric morphology and focal lesion length on BB contrast enhanced MR imaging, compared to the occlusion group ($P < 0.001$). In contrast, enhancement patterns of the occlusion group showed strong intensity, round or concentric morphology and longer segmental lesion length, compared to the stenosis group ($P < 0.001$).

Conclusion: Three-dimensional BB contrast enhanced MR imaging in acute stroke patients with stenotic lesions and negative SVS shows enhancement patterns of linear or eccentric morphology and shorter, more focal lesions.

1. Introduction

In acute ischemic stroke successful recanalization is crucial, because a failure of recanalization is closely associated with poor outcomes [1]. Recanalization by intravenous thrombolysis (IVT) can be influenced by the burden, composition, and location of a thrombus [2–7]. Recanalization by mechanical thrombectomy procedures can be affected by underlying intracranial atherosclerotic stenosis (ICAS), which can be a hidden cause of refractory occlusion [8]. Thus identification of intra-arterial thrombus and underlying ICAS would be useful for planning recanalization therapy in patients with acute ischemic stroke.

T2*-weighted gradient echo imaging (GRE) and susceptibility weighted imaging (SWI) have both been used to identify a thrombus within occluded arteries, in the form of a hypointense signal, which is termed a “susceptibility vessel sign” (SVS) [6,9,10]. In contrast to the presence of an SVS, its absence, termed “negative SVS,” is generally associated with fibrin-rich thrombus or an in situ steno-occlusive lesion [9,11].

Black-blood (BB) magnetic resonance (MR) imaging, by selectively suppressing signals from flowing arterial blood, has been used to visualize and quantify the size of the arterial lumen and the outer wall boundaries of large arteries [12–15]. We added three-dimensional (3D) BB contrast enhanced MR imaging to our protocol for acute stroke patients in order to evaluate any differences in enhancement patterns between patients with positive SVS and those with negative SVS. To our knowledge, no previous reports have described the BB enhancement

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features related to intracranial steno-occlusive lesions with negative SVS. For this reason, we investigated the frequency and patterns of BB contrast enhancement in steno-occlusive lesions with negative SVS on MRI in patients with acute ischemic stroke. We also evaluated the usefulness of BB contrast enhanced MR imaging for detection of intra-arterial thrombus and underlying ICAS in acute ischemic stroke patients with negative SVS.

2. Materials and methods

2.1. Patients

Our institutional review board approved this retrospective study, and the requirement for patient informed consent was waived for review of patient records and images. From January 2014 to August 2016, 394 consecutive patients with acute ischemic stroke, with onset within 24 h, were enrolled our study. All patients underwent MR imaging according to our protocol for acute ischemic stroke. We retrospectively analyzed clinical data and radiologic findings for these 394 patients. Exclusion criteria consisted of the following: (a) extracranial cervical artery stenosis of more than 50% ipsilateral to the stroke; (b) evidence of intracranial vascular disease such as dissection, vasculitis and Moya–Moya disease; (c) evidence of hemorrhagic transformation; and (d) any patient who did not undergo SWI or BB sequence imaging, or had MR images which were of insufficient quality for reliable evaluation.

2.2. MR examination

All MR examinations were performed with an Achieva 3.0 T MRI Scanner (Philips Healthcare, Best, Netherlands) with a 16-channel head coil. All evaluated patients had symptoms of stroke on neurologic examination. According to our protocol, MR imaging for stroke was performed immediately after an emergency CT scan, which was done to rule out intracranial hemorrhage. This plan included the following sequences relevant to our study: (a) diffusion weighted imaging (DWI); (b) 3D time-of-flight (TOF) MRA of the intracranial arteries; (c) susceptibility weighted imaging (SWI); and (d) 3D BB contrast-enhanced MR imaging.

DWI was performed using the following parameters: TR/TE = 2972.2/78.3 ms, FA = 90°, FOV = 220 × 220 mm, matrix = 128 × 130, slice thickness/gap = 5 mm/23%, and echo train length (ETL) = 1. 3D. TOF-MRA from the petrous portion of the internal carotid artery (ICA) was generated with the following parameters: TR/TE = 23/3.5 ms, FA = 20°, FOV = 200 × 200 mm, matrix = 364 × 222, sensitivity encoding factor = 2.5, slice thickness = 1.2 mm, echo train length (ETL) = 1, and number of average = 1. TOF-MRA scan time was 4.11 min. Susceptibility weighted imaging (SWI) was performed with the following parameters: TR/TE = 29.6/0 ms, FA = 17°, FOV = 210 × 210 mm, matrix = 232 × 232, slice thickness/gap 3.0 mm/100%, and echo train length (ETL) = 4. Dynamic susceptibility contrast PWI was performed with the following parameters: TR/TE = 1790.5/35 ms, FA = 40°, FOV = 220 × 220 mm, matrix = 128 × 126, slice thickness/gap = 5 mm/23%, echo train length (ETL) = 63, and scan time = 1.35 min.

The 3D BB contrast enhanced MR imaging sequence was then performed using volumetric isotropic turbo spin-echo acquisition (VISTA; Philips Healthcare, Best, the Netherlands) in the coronal plane (40 mm-thick slab) for flow suppression. We used the improved motion-sensitized driven-equilibrium (iMSDE) technique that suppresses enhanced blood vessel signals [16]. Acquisition parameters for iMSDE-VISTA images were as follows: repetition time (RT)/echo time (ET) = 450.0/22.4 ms, flip angle (FA) = 90°, echo train = 26, sensitivity encoding = 2, field of view (FOV) = 256 × 256 mm, matrix = 256 × 256, 1 mm slice thickness and no gap, and scan time = 35–38 s. Gadodiamide 0.1 mmol/kg (Dotarem; Guerbet, Aulnay-sous-Bois, France) was injected as a bolus intravenously in all patients. Three-dimensional BB contrast MR imaging was obtained approximately 5 min after contrast injection. Mean MR examination time, from entrance to exit from the MR suite, was 20 min (range, 17–23 min).

2.3. MR imaging analysis

All MR images were reviewed retrospectively by two neuroradiologists with 10–11 years of experience. Cases in which readers disagreed were reviewed together and resolved by consensus. Initially, the 394 enrolled patients were classified as being positive or negative for SVS according to the presence or absence of the SVS sign. A susceptibility vessel sign on SWI was defined as the presence of low signal intensity within the affected intracranial artery, in which the diameter of the low-intensity signal within the vessel exceeded the normal vessel diameter. Patients were also classified as either positive or negative for BB enhancement, depending on the presence or absence of intra-arterial enhancement, compared to the normal portion of the vessel on BB contrast enhanced MR imaging. Our criteria for defining positive BB enhancement did not include thin enhancement of both vessel walls with normal MR angiography. Those patients with lesions having positive BB enhancement on MR angiography and negative SVS were divided into a stenosis group and an occlusion group.

Qualitative assessment of BB enhancement pattern characteristics, including intensity, morphology, length of intravascular lesion, and multiplicity was performed by 2 neuroradiologists who were blinded to patient data, including both clinical information and cerebrovascular MR imaging findings. Intensity of enhancement was graded as follows: weak enhancement was less than the pituitary infundibulum or choroid plexus but greater than adjacent brain white matter; strong enhancement was similar to or greater than the pituitary infundibulum or choroid plexus. Morphologic characteristics of the enhancement pattern were defined as either eccentric or concentric. An eccentric morphology showed less than 50% vessel diameter involvement, either transversely in the coronal plane, or linearly, along the vessel wall in the axial plane. A concentric morphology showed greater than 50% diameter involvement, either transversely or along both sides of the vessel wall in the axial plane (round pattern). The length of the enhancement pattern was graded as either focal, referring to a short lesion less than 5 mm long, or segmental, which denoted a lesion longer than 5 mm but within the same segment of the artery. Enhancing lesions were also noted to be either single or multiple (Fig. 1).

A stenosis of 50% or more was considered substantial. The percentage of stenosis was estimated on TOF-MRA using the formula of [(a − b)/a] x 100% (a = narrowed vessel diameter, b = proximal normal vessel diameter). Because of the small diameters of intracranial vessels, we focused on stenoses involving the larger more proximal intracranial arteries, including the M1 and M2 segments of the middle cerebral artery, the A2 segment of the anterior cerebral artery, the P1 and P2 segments of the posterior cerebral artery, the basilar artery and the V4 segments of the vertebral arteries.

2.4. Statistical analysis

We noted the incidence of negative SVS and positive BB enhancement in our acute stroke patient population, and then looked for differences between the stenosis group and the occlusion group. Patient characteristics and enhancement features were compared between the two groups using the Mann-Whitney *U* test for continuous variables and the χ^2test or Fisher's exact test for categorical variables. Finally, diagnostic performance parameters, including sensitivity, specificity, positive predictive value and negative predictive value of the BB enhancement patterns for detection of thrombus and ICAS, were calculated. All statistical analyses were performed with SPSS software