Use of 3-Dimensional, Black-Blood, Contrast-Enhanced, T1-Weighted Magnetic Resonance Imaging to Identify Vascular Occlusion in the Posterior Circulation After Acute Ischemic Stroke

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Background: Three-dimensional, black-blood, contrast-enhanced, T1-weighted magnetic resonance imaging (3D-BB-ceT1-MRI) could play a role in detection of thrombi and symptomatic intracranial atherosclerotic stenosis. We investigated the role of 3D-BB-ceT1-MRI in patients with acute ischemic stroke in the posterior circulation, and compared our findings with those from susceptibility-weighted imaging (SWI). *Materials and Methods:* We retrospectively reviewed 3D-BB-ceT1-MRI for patients between January 2017 and August 2018 with acute ischemic symptoms in the posterior circulation. During this period, 199 patients with acute infarction in the posterior circulation were enrolled. Time-of-flight-magnetic resonance angiography or cerebral angiography was used as the reference standard. *Results:* Of these 199 patients, 47 had vessel occlusion associated with acute infarction. The sensitivity of 3D-BB-ceT1-MRI for detection of vessel occlusion was significantly higher than that of SWI (95.7% versus 53.2%, $P < .001$). Twenty-one lesions with strong enhancement on 3D-BB-ceT1-MRI showed a negative susceptibility vessel sign (SVS) on SWI. *Conclusions:* 3D-BB-ceT1-MRI showed strong enhancement (due to contrast stagnation) in the intra-arterial thrombi of patients with acute infarction in the posterior circulation. 3D-BB-ceT1-MRI had higher sensitivity than that of an SVS on SWI for detection of intra-arterial thrombi.

Key Words: Stroke—thrombus—magnetic resonance imaging—contrast media

Introduction

Recanalization by intravenous or endovascular treatment in patients after acute stroke can be influenced by the clot composition and location of the thrombus.[1–4] In general, a hypointense signal (also termed a "susceptibility vessel sign" [SVS]) on susceptibility weighted imaging (SWI) can be used to detect a thrombus within occluded intracranial arteries.[4–7] Its absence (termed "negative SVS") is, in general, associated with an in situ steno-occlusive lesion or fibrin-rich thrombus.[5,8–10] SWI can be employed to identify the thrombus location, reveal multiple thrombi, and demonstrate the thrombus burden in acute cardioembolic stroke.[7]

Recently, strong enhancement of a thrombus within occluded intracranial arteries on 3-dimensional, black-blood, contrast-enhanced T1 magnetic resonance imaging (3D-BB-ceT1-MRI) was shown to have superior performance compared with that elicited by an SVS on SWI.[8,11] Baik et al showed that 3D-BB-ceT1-MRI in patients with acute intracranial occlusion and a negative SVS had strong enhancement due to stagnation of contrast.[8] Jang et al demonstrated that 3D-BB-ceT1-MRI aided detection of intraluminal thrombi compared with that shown by SWI in patients with acute arterial occlusion.[11]

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Accurate diagnosis of the presence and location of the thrombus in the posterior circulation is important for choosing optimal therapy in stroke patients. The "hyperdense middle cerebral artery (MCA) sign" refers to the focal-increased density of the middle cerebral artery in computed tomography (CT). Similarly, the hyperdense sign in the posterior circulation on noncontrast CT has been shown to be a reliable marker for arterial occlusion.[12] Also, an SWS in the posterior circulation on SWI has been shown to be significantly superior to noncontrast CT for thrombus detection in acute infarction of the posterior cerebral artery (PCA).[7,13] However, studies comparing 3D-BB-ce-T1-MRI with SWI for detection of intra-arterial thrombi in the posterior circulation are lacking.

Here, we retrospectively evaluated the diagnostic performance of strong enhancement on 3D-BB-ce-T1-MRI and compared it with that of an SVS on SWI in patients with acute infarction in the posterior circulation.

Materials and Methods

Ethical Approval of the Study Protocol

Our institutional review board approved the retrospective study protocol. The requirement for informed consent was waived for review of patient medical records and images.

Exclusion Criteria

Exclusion criteria were as follows: (1) evidence of intracranial vascular disease (e.g., dissection, vasculitis, and Moyamoya disease); (2) evidence of hemorrhagic transformation; (3) any patient who did not undergo SWI or BB sequence imaging, or had MR images of insufficient quality for reliable evaluation; and (4) complete or severe stenosis of the proximal vertebral artery (VA) (V1-V3 segments).

Patients

Patients with acute (onset <24 hours) ischemic stroke of the posterior circulation between January 2017 and August 2018 were enrolled. Patients underwent MRI according to the protocol for acute ischemic stroke set by our hospital.

MRI Procedure

MRI was done using an Achieva 3.0-T MRI scanner (Philips Healthcare, Best, the Netherlands) with a 16-channel head coil. All evaluated patients had symptoms of stroke upon neurologic examination. MRI for stroke was undertaken immediately after an emergency CT scan, which was done to rule out intracranial hemorrhage. This protocol included the following sequences relevant to our study: (1) diffusion-weighted imaging; (2) 3-dimensional time-of-flight magnetic resonance angiography (3D-ToF-MRA) of intracranial arteries; (3) SWI; and (4) 3D-BB-ce-T1-MRI.

The protocol has been described previously.[8,11] 3D-BB-ceT1-MRI was undertaken using volumetric isotropic turbo spin-echo acquisition (VISTA; Philips Healthcare) in the coronal plane (slab thickness = 40 mm) for flow suppression. We used the improved motion-sensitized driven-equilibrium (iMSDE) method, which suppresses enhanced signals in blood vessels.[14,15] Acquisition parameters for iMSDE−VISTA images were as follows: repetition time/echo time = 450.0/22.4 ms, flip angle = 90°, echo train = 26, sensitivity encoding = 2, field of view = 256 × 256 mm, matrix = 256 × 256, 1-mm slice thickness and no gap, and scan time = 35-38 seconds. Gadodiamide (.1 mmol/kg body weight; Dotarem; Guerbet, Aulnay-sous-Bois, France) was injected as a bolus intravenously in all patients. 3D-BB-ce-T1-MRI was carried out ~5 minutes after contrast injection. After image acquisition in the sagittal plane, we undertook reconstruction of axial and coronal planes. The mean duration of 3D-BB-ce-T1-MRI from entrance to exit from the MR Suite was 20 (range, 17-23) min.

MRI Data

All MR images were reviewed retrospectively by 2 neuroradiologists (with 20 years and 11 years of experience, respectively) blinded to the clinical information of each patient. They assessed image quality by consensus using a 4-scale scoring system (1, poor; 2, adequate; 3, good; and 4, excellent). Images with a score of 1 were excluded from the final analysis. Disagreements regarding image quality were resolved by consensus.

Enrolled patients were classified as "positive SVS" or "negative SVS" according to the presence or absence of an SVS, respectively. An SVS on SWI was defined as low signal intensity within the affected intracranial artery, in which the diameter of the low-intensity signal within the vessel exceeded the normal diameter of the vessel. Patients were classified as "positive" or "negative" for 3D-BB-ceT1-MRI depending on the presence or absence of intra-arterial enhancement, respectively (Fig 1).

We used only maximum intensity projection images of ToF-MRA for occlusion of the posterior circulation, VA, basilar artery (BA), and PCA segment 1 (P1) or P2. We excluded patients with distal occlusion of the PCA (P3 or P4). Images were evaluated on a picture archiving and communication system by a reviewer with greater than 10 years of experience in MRA interpretation.

Statistical Analyses

We documented the prevalence of a positive SVS or positive contrast enhancement in the posterior circulation. Then, the sensitivity for detection of an intraluminal thrombus was calculated. The sensitivity between 2 imaging sequences was compared using McNemar's test; P less than .05 (2-tailed) was considered significant. We also calculated 95% confidence intervals.

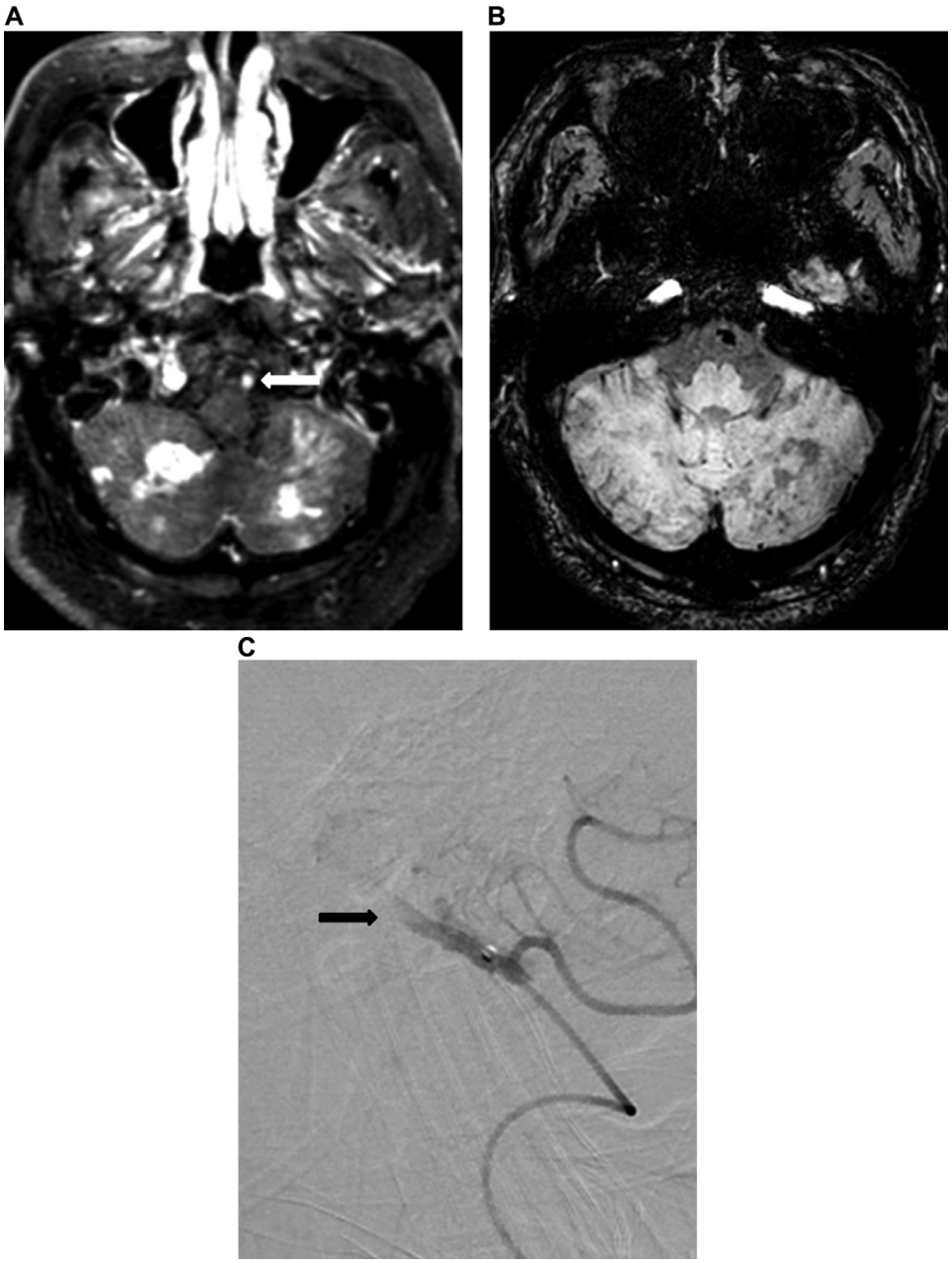

Figure 1. *A 75-year-old man with unilateral vertebral artery (VA) and basilar artery (BA) occlusion. A. 3D-BB-ceT1-MRI shows strong enhancement due to contrast stagnation in the left VA (arrow). B. SWI shows a positive SVS in the left VA (arrow). C. Lateral vertebral angiography shows complete occlusion and a thrombus with underlying atherosclerosis (arrow).*

Statistical analyses were carried out using SPSS v22.0 (IBM, Armonk, NY, USA).

Results

Patients

During the study period, 199 patients with acute infarction in the posterior circulation were enrolled. Fifty-four patients had vessel occlusion in the posterior circulation and territorial infarction according to ToF-MRA. Of these patients, 5 were excluded from this study due to the poor quality of 3D-BB-ceT1-MR images and 2 because of suspected dissection-related occlusion. Forty-seven patients (28 men and 19 women; median age, 71.5 [range, 37-92] years) had vessel occlusion associated with acute territorial infarction on ToF-MRA. The demographic data of the patients are described in Table 1.

Thrombus Detection

The location of the occlusion on ToF-MRA and positive findings of thrombus detection on SWI and 3D-BB-ceT1-MRI are described in Table 2. Sixteen patients (BA

Table 1. *The demographic data of the patients*

	All (n = 47)
Median age (y)	71.5
Age range (y)	37-92
Sex, male (%)	28 (59.6)
Diabetes mellitus (%)	12 (25.5)
Hypertension (%)	24 (51.1)
Current smoking (%)	16 (34.0)
Hyperlipidemia (%)	15 (31.9)
Previous heart disease (%)	11 (23.4)
Previous stroke history (%)	17 (36.2)

occlusion = 5; P1 occlusion = 11) underwent cerebral angiography for thrombectomy and showed complete recanalization of the occluded artery after manual aspiration thrombectomy. Thirteen patients with acute unilateral occlusion of the VA had a territorial embolic or lobar infarction (posterior inferior cerebellar artery [PICA] lobar infarction = 4 cases; other cerebellar embolic infarction = 5; occipital lobe embolic infarction = 2; thalamic infarction = 1; pons infarction = 1).

The sensitivity of 3D-BB-ceT1-MRI for detection of vessel occlusion in the posterior circulation was significantly higher than that of SWI (95.7% versus 53.2%, $P < .001$). All BA occlusions were detected on SWI and 3D-BB-ceT1-MRI. The sensitivity for detection of acute occlusion of the PCA and VA on SWI was relatively low (PCA = 57.9%; VA = 23.1%). Thirteen patients with unilateral occlusion on ToF-MRA and territorial infarction had strong enhancement of the VA on 3D-BB-ceT1-MRI (Fig 2). In 1 lesion in P2 and 1 lesion in the PICA with a positive SVS on SWI, the thrombus could not be detected using 3D-BB-ceT1-MRI (Fig 3). Twenty-one lesions with strong enhancement 3D-BB-ceT1-MRI showed a negative SVS on SWI. Of these 21 lesions, 15 had acute occlusion with an atherosclerotic severe stenosis in the territorial artery related to infarction (VA = 10; P1 = 4; P2 = 1).

Table 2. *Location of vessel occlusion on Time-of-Flight MR angiography/cerebral angiography and number of positive findings of thrombus detection*

	Total (n = 47)	3D BB-enhanced T1 MR imaging (%)	SWI (%)
PCA 1	11	11 (100)	6 (54.5)
PCA 2	8	7 (87.5)	5 (62.5)
PICA	9	8 (88.9)	6 (66.7)
BA	5	5 (100)	5 (100)
VA	13	13 (100)	3 (23/1)
SCA	1	1 (100)	0 (0)

Abbreviations: BA, basilar artery; 3D BB-enhanced T1 MR imaging, 3-dimensional black-blood T1 MR imaging; PCA, posterior cerebral artery; PICA, posterior inferior cerebellar artery; SWI, susceptibility-weighted imaging; VA, vertebral artery; SCA, superior cerebellar artery.

Discussion

The present study focused on 3D-BB-ceT1-MRI findings in patients with infarction in the posterior circulation compared with findings obtained using SWI. We demonstrated that strong enhancement on 3D-BB-ceT1-MRI in patients with acute ischemic stroke of the posterior circulation strongly suggests an acute occlusion in the artery of territorial infarction. The diagnostic value of 3D-BB-ceT1-MRI for detection of occluded arteries in the posterior circulation was significantly higher than that for an SVS on SWI.

A positive SVS on SWI is, in general, a specific marker for detection of intra-arterial thrombi. However, a negative SVS can be associated with several findings: a small thrombus, a fibrin-rich thrombus, or a stenosis related to the occlusion.[5,9,16] Also, a clot length greater than 6 mm can denote a positive SVS on SWI.[17]

Studies focusing on an SVS on SWI have been undertaken mainly in patients with acute infarction in the anterior circulation. Some scholars have reported the role of SWI for detection of thrombi in patients with infarction in the posterior circulation.[7,13] Park et al[7] described an SVS for intra-arterial thrombi in 25 patients with acute infarction of the PCA compared with a hyperdense PCA sign on noncontrast CT. An SVS was found in 92% of cases, and 78% of patients without occlusion on MRA showed an SVS. In particular, a positive SVS without occlusion on MRA was detected in patients with occlusion of P3/P4 segments. Wang et al[13] reported an SVS on SWI in 81 patients with large-artery occlusion in the posterior circulation. Only 27.2% (22 of 81) of patients showed a positive SVS. The lower frequency of a positive SVS may be partially caused by common calcification of the VA or BA, prevalence of in situ steno-occlusive lesions, or artifacts from the paranasal sinuses and base of the skull. Also, differences in study design, such as imaging modalities or patients' inclusion criteria for detection of a positive SVS, may play a role.

Our study revealed the occlusion site within the posterior circulation from the VA to distal PCA. Overall, a positive SVS on SWI was found in 53.2% (26 of 47) of cases. All BA occlusions had a positive SVS. However, the prevalence of a positive SVS of the PCA and VA on SWI was relatively low (PCA = 57.9%; VA = 23.1%) because of a higher prevalence of in situ steno-occlusive lesions in this area. Also, our results and data from other studies have shown variable detection of an SVS on SWI.[7,13] Taken together, these findings suggest that an SVS on SWI is influenced by the volume, length, and composition of a thrombus, or underlying atherosclerotic lesions.

We employed 3D-BB-ceT1-MRI in patients suspected of having infarction in the posterior circulation. In this way, we detected intracranial arterial thrombi and evaluated any mismatch in diffusion/perfusion to aid endovascular treatment. We used the iMSDE method because it compensates for the limitations of the standard MSDE

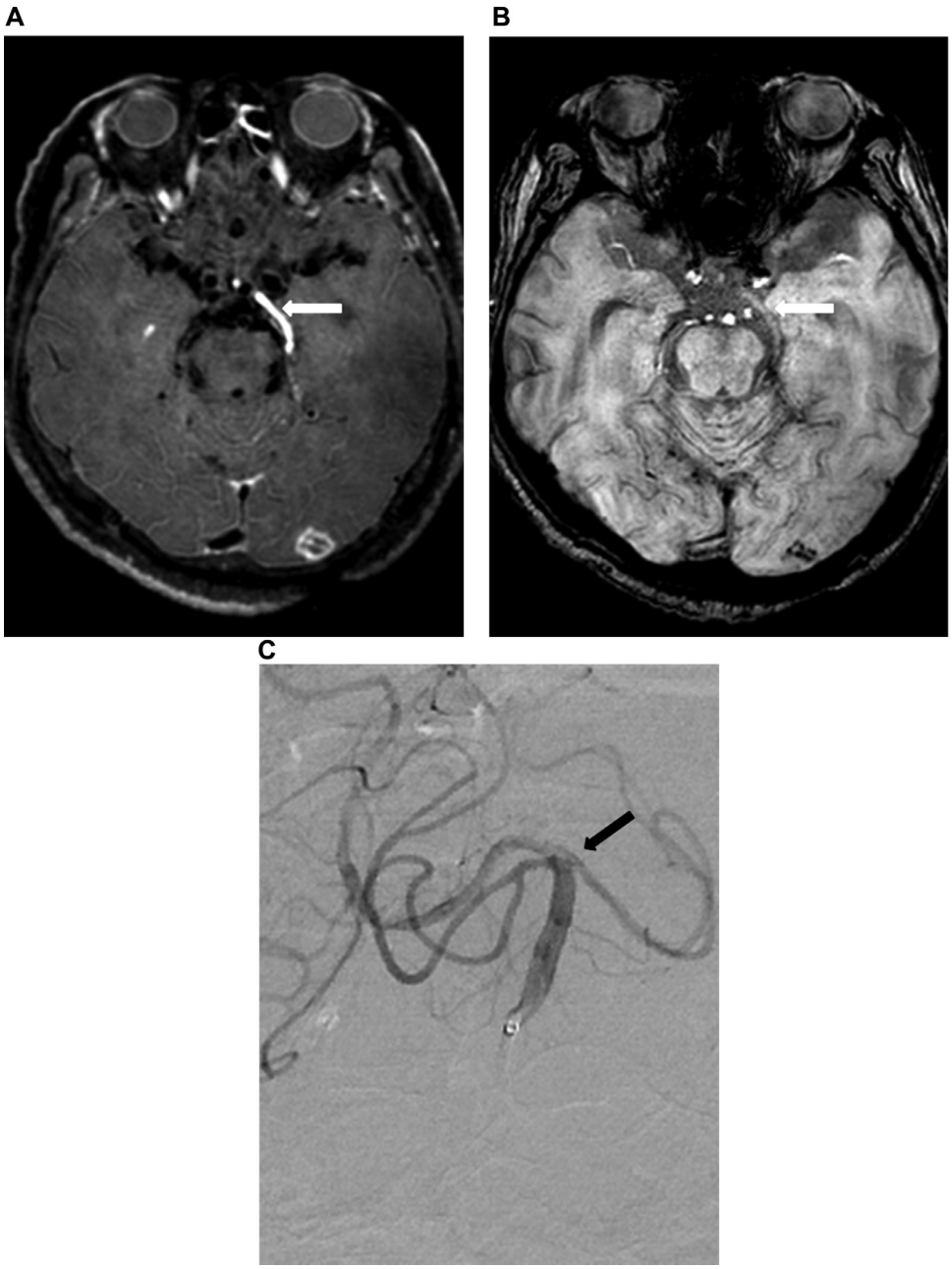

Figure 2. *A 69-year-old man with unilateral posterior cerebral artery (PCA) occlusion. A. 3D-BB-ceT1-MRI shows strong enhancement due to contrast stagnation in the left PCA (arrow). Strong enhancement at the in situ thrombus and distal portion of the thrombus may be attributed to contrast stagnation and a lack of suppression due to slow flow in the distal portion of the thrombus on BB-ceT1-MRI. B. SWI shows a negative SVS in the left PCA (arrow). C. Angiography of the basilar artery shows complete occlusion of the left PCA orifice (arrow).*

method: signal loss, inherent T2 decay, and B_1 inhomogeneity.[18] Use of the iMSDE method for 3D-BB-ceT1-MRI helps to suppress enhanced signals in blood vessels and improves the contrast-to-noise ratio between the blood-vessel lumen and adjacent tissues.[19] Furthermore, with fast 3D VISTA, iMSDE can achieve appropriate suppression of blood signals during imaging. 3D-BB-ceT1-MRI is affected less by the diameter and location of arteries, steno-occlusive lesions, or thrombus components than that of an SVS on SWI. The main finding of 3D-BB-ceT1-MRI is strong enhancement due to contrast stagnation in the front and rear of the thrombus in the intracranial occlusion.[11]

The diagnostic role of 3D-BB-ceT1-MRI in patients with infarction in the anterior circulation was investigated by Jang et al.[11] They found that the diagnostic accuracy of 3D-BB-ceT1-MRI for an intra-arterial thrombus in patients with acute infarction in the anterior circulation was significantly greater than that using SWI. The sensitivity of 3D-BB-ceT1-MRI was significantly higher than that of an SVS on SWI (97.9% versus 80.9). In the present study, the overall sensitivity of 3D-BB-ceT1-MRI for thrombus detection

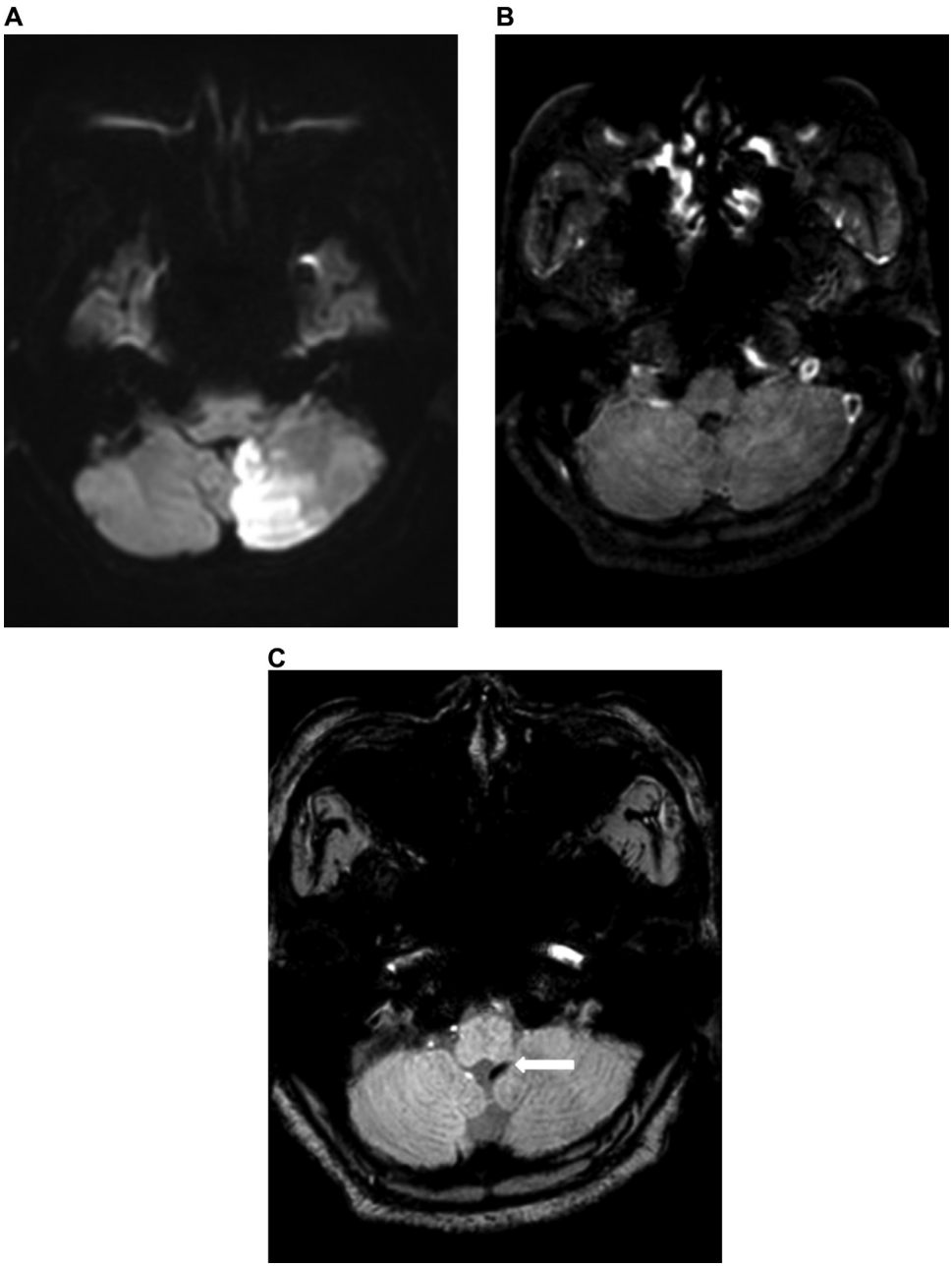

Figure 3. *A 76-year-old woman with acute infarction of left posterior inferior cerebellar artery (PICA). A. Diffusion-weighted imaging shows acute infarction of the left PICA. B. 3D-BB-ceT1-MRI does not show contrast stagnation C. SWI shows a positive SVS in the left PICA (arrow).*

in the posterior circulation was significantly higher than that using SWI (95.7% versus 53.2%, $P < .001$). These data suggest that strong enhancement of an occluded artery due to contrast stagnation on 3D-BB-ceT1-MRI is a useful marker for identification of thrombus location in the anterior circulation and posterior circulation.

False-negative detection of a thrombus on SWI in patients with infarction in the anterior circulation has been documented for relatively small arteries (e.g., anterior cerebral artery) or due to occlusion related to underlying atherosclerosis.[11] Baik et al[8] reported the findings of 3D-BB-ceT1-MRI in 62 patients with acute ischemic stroke and a negative SVS on SWI. Of these patients, 42 (67.8%) had acute infarction related to underlying atherosclerotic lesions. 3D-BB-ceT1-MRI in patients with underlying atherosclerotic lesions and a negative SVS showed linear/eccentric, shorter, and more focal enhancement in the stenotic area. Also, in patients with complete occlusion due to an intra-arterial thrombus, strong intensity of enhancement, a round or concentric morphology of the thrombus, and an enhanced area of long segments were revealed. In the present study, false-negative lesions in patients with infarction in the posterior circulation on SWI were associated mostly with occlusion due to underlying atherosclerosis. All lesions

with a negative SVS on SWI showed strong enhancement on 3D-BB-ceT1-MRI. Only 2 lesions with a positive SVS on SWI were shown to be negative on 3D-BB-ceT1-MRI.

In our study, occlusion of the VA (n = 13) and PICA (n = 9) was observed. Usually, lesions in these arteries are not deemed to be serious because they elicit mild symptoms. In particular, acute unilateral VA occlusion showed strong enhancement in the present study. With respect to VA occlusion, the relatively low sensitivity of an SVS on SWI has been associated with a high prevalence of underlying stenosis due to calcified plaques.[13] Therefore, strong enhancement on 3D-BB-ceT1-MRI in patients with infarction of VA/PICA territories suggests that the acute event occurs at these sites.

Our study had 3 main limitations. First, a small number of cases were evaluated. A larger number of patients and longitudinal prospective studies are needed to validate our results. Second, we did not carry out cerebral angiography in all patients. A lack of confirmation by cerebral angiography affects our ability to generalize our findings. Third, the scan time in MRI protocols for stroke patients has important implications for the rapidity of treatment. The scan time of 3D-BB-ceT1-MRI in the present study was 4 minutes. However, we believe that the benefits of accurate detection of intra-arterial thrombi in patients with acute infarction in the posterior circulation outweigh the disadvantage of a slightly longer scan time.

Conclusions

3D-BB-ceT1-MRI showed strong enhancement (due to contrast stagnation) in the intra-arterial thrombi of patients with acute infarction in the posterior circulation. 3D-BB-ceT1-MRI had higher sensitivity than that of an SVS on SWI for detection of intra-arterial thrombi. Using the described method, the location of an intra-arterial thrombus could be detected readily with a sensitivity of 95.7%. We believe that 3D-BB-ceT1-MRI is a useful method for identification of thrombus location in patients with acute infarction of the posterior circulation.

Ethical Approval

Our institutional review board approved this retrospective study.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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