Original Article

Improvement of Shunt Detection with Arterial Spin-Labeling MR Imaging in Follow-Up of a Treated Cerebral Arteriovenous Malformation

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Objective: To identify and evaluate the pitfalls of using arterial spin labeling (ASL) to diagnose cerebral arteriovenous malformation (AVM) and improve its accuracy in clinical practice.

Materials and Methods: A retrospective study of 54 patients with cerebral AVM was performed. Each patient underwent magnetic resonance imaging (MRI) studies, including pseudo-continuous ASL (pCASL) and conventional cerebral angiography with a digital subtraction angiography (DSA) during a 3-year period. The consensus of the results of the imaging studies was used to evaluate the diagnostic performance of the MRI technique, with DSA used as the gold standard.

Results: Diagnostic accuracy was 94.4% when a positive arteriovenous shunt (AVS) was defined as a high ASL signal in the venous structure or nidus, compared to magnetic resonance angiography (MRA). The misinterpretations of the ASL images of cerebral AVM were due to an arterial transit artifact (ATA) associated with a residual AVS. The other pitfalls were micro-AVMs and very slow-flow AVSs.

Conclusion: To improve the accuracy of ASL in evaluating an AVS in cerebral AVM, it is mandatory to detect high ASL signals in venous structures by comparing with MRA.

Keywords: Arterial spin labeling; Arteriovenous malformation; Arteriovenous shunt; Magnetic resonance angiography

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Digital subtraction angiography (DSA) is accepted as the gold standard for the diagnosis of cerebral arteriovenous malformation (AVM). Treatments for cerebral AVM are glue embolization, surgery, radiosurgery, or a combination of these approaches[1,2]. However, cerebral AVMs are not immediately cured after treatment, especially when radiosurgery is used. Moreover, the response to treatment is delayed, ranging from 12 to 96 months[3-9]. An appropriate imaging study for long-term follow-up, especially in pediatric cases, would be non-invasive and present minimal radiation exposure. Magnetic resonance imaging (MRI) has been introduced to evaluate treatment results and detect a recurrent arteriovenous shunt (AVS). However, dilated arterial feeder or draining veins and enhancement on conventional MRI and magnetic resonance angiography (MRA) are not specific for differentiating between the treatment responses and residual or recurrent AVS.

Arterial spin labeling (ASL) is an MRI technique for perfusion studies, and no contrast is needed. It has been found to have acceptable sensitivity and specificity for detecting AVS[10-13]. In clinical practice, familiarity with the underlying technique and careful interpretation are needed. The present study aimed 1) to identify and evaluate the pitfalls of using ASL to diagnose cerebral AVM, and 2) to improve the

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Table 1. Details of treatments

	n (%)
Treatment	
Conservative	17 (31.5)
Embolization	16 (29.6)
Surgical resection	5 (9.3)
Radiotherapy	6 (11.1)
Embolization + radiotherapy	6 (11.1)
Embolization + surgery	4 (7.4)
Duration from treatment to MRI study	
0 to 6 months	7 (13.0)
>6 months to 1 year	11 (20.4)
>1 year to 2 years	21 (38.9)
>2 to 3 years	8 (14.8)
>3 to 4 years	2 (3.7)
>4 to 5 years	2 (3.7)
>5 years	3 (5.5)
Duration from MRI study to DSA	
0 to 1 year	31 (57.4)
>1 to 2 years	15 (27.8)
>2 to 3 years	8 (14.8)

MRI=magnetic resonance imaging; DSA=digital subtraction angiography

accuracy of ASL in clinical practice.

Materials and Methods

Study designs and subjects

The present study was a retrospective review study conducted at a tertiary hospital. The study was approved by the Institutional Review Board (approval number Si 445/2018), with waived of informed consent. The inclusion criteria were patients with cerebral AVM that underwent MRI and MRA with an ASL sequence and had DSA within three years of the MRI study (Table 1). Treatments for the patients such as conservative treatment, endovascular embolization, surgery, or radiotherapy, are detailed in Table 1. Cases with no available data or low image quality were excluded.

MRI techniques

The images were acquired on a 3.0-Tesla MRI (Philips Ingenia, Philips Healthcare, Best, the Netherlands). The 32-channel head coils were used for reception of the signal.

Post-labeling delays (PLDs) of 1,650 and 2,000 milliseconds were used to obtain 2D pseudo-continuous ASL (pCASL) images (TR/TE, 4,550/16). The distance from the labeling plane to the image plane was 90 mm. The field of view of the image plane was 240×240 mm, with an in-plane spatial resolution of 2.75 mm, this yielded 16 slices per scan. The scan mode was multislices, fast field echo, single-shot EPI, and SENSE factor 2.3. The scan time was 4 minutes 42 seconds per PLD.

In accordance with our routine MRI protocol for AVM, the conventional MRI used was T1-weighted imaging, T2-weighted imaging, fluid-attenuated inversion recovery, susceptibility-weighted imaging, 3D T1-weighted/gadolinium (THRIVE), proton-density-weighted imaging, and time-of-flight MRA.

Operational definition of positive ASL

A pilot study for the operational definition of a positive ASL signal for AVS was conducted with 10 cases of known results. Two neuroradiologists, each with more than 10 years of experience, separately compared the ASL and MRA images to evaluate residual AVS. Consensus was reached by concluding all MRI findings as ASL, MRA, and THRIVE using DSA as the reference standard. A positive AVS on MRI was labeled when a high-signal ASL was found at the location of the venous structure or nidus when compared to MRA (Figure 1).

Image interpretations

MRIs were separately interpreted by two neuroradiologists, who were blinded to the DSA results. Two neurointerventionists, each with over 10 years' experience, interpreted the DSA separately. Each of the final MR results and the final DSA results were reached by consensus.

Statistical analysis

Analyses were performed using PASW Statistics for Windows, version 18.0 (SPSS Inc., Chicago, IL, USA). Kappa statistics were used to evaluate the agreement between the two readers. Sensitivities, specificities, positive predictive values, negative predictive values, and accuracies with their corresponding 95% confidence intervals were reported.

Results

Between July 2016 and July 2018, 71 cases of cerebral AVM were diagnosed by DSA. Only 54 patients met the inclusion criteria and had both ASL and DSA available (Table 2). Eleven cases had curative AVM and 43 had residual AVM (Table 3). For the 54 cases, the sensitivity was 97.6% (95% CI 87.7 to 99.9), specificity was 81.8% (95% CI 48.2 to 97.7), positive predictive value was 95.4% (95% CI 85.6 to

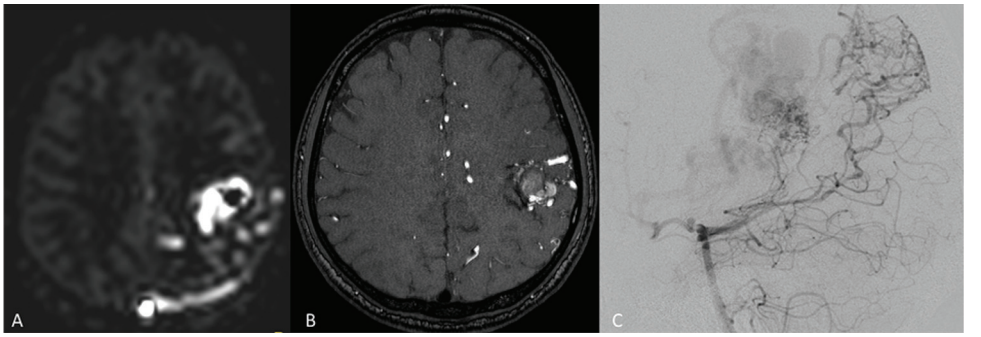

Figure 1. A case of a 34-year-old male with a history of AVM at the left frontoparietal region. (A) pCASL with PLD of 1650 ms shows a high ASL signal intensities at the nidus in the left frontoparietal region and in the draining vein (the cortical veins) and the superior sagittal sinus. (B) Corresponding TOF-MRA source image shows iso-signal of AVM nidus at left frontoparietal region and no flow signal at the draining vein when compared with ASL. (C) DSA shows AVM nidus fed by branches of the left MCA and left PCA. The nidus drained into the posterior parietal cortical vein and then the superior sagittal sinus.

Table 2. Demographic data of all 54 patients who underwent MRI AVM protocol with ASL

Factor	n (%)
Age	
10 to 20 years	5 (9.3)
21 to 30 years	18 (33.3)
31 to 40 years	13 (24.1)
41 to 50 years	5 (9.3)
51 to 60 years	8 (14.8)
61 to 70 years	4 (7.4)
>70 years	1 (1.8)
Sex	
Male	27 (50.0)
Female	27 (50.0)
Size	
Cured	11 (20.4)
<1 cm	4 (7.4)
1 to <3 cm	23 (42.6)
3 to 6 cm	14 (25.9)
>6 cm	2 (3.7)
Location	
Left frontal	12 (22.2)
Right frontal	6 (11.1)
Left parietal	3 (5.5)
Right parietal	4 (7.4)
Left temporal	6 (11.1)
Right temporal	0 (0.0)
Left occipital	1 (1.9)
Right occipital	1 (1.9)
Left basal ganglia	2 (3.7)
Right basal ganglia	2 (3.7)
Left thalamus + left basal ganglia	1 (1.9)
Right thalamus	0 (0.0)
Left insula + basal ganglia	1 (1.9)
Right insula	2 (3.7)
Left cerebellum	3 (5.5)
Right cerebellum	1 (1.9)
Left midbrain	0 (0.0)
Right midbrain	1 (1.9)
Corpus callosum	4 (7.4)
Left CPA	1 (1.9)
Cerebellar vermis	1 (1.9)
Left parieto-occipital	2 (3.7)

CPA=cerebellopontine angle

Table 3. Results of angiogram and MRI by consensus

	MRI	Angiogram		
		Positive shunt	Negative shunt	Total
Curative AVM (n=11)	Positive shunt	0	2	2
	Negative shunt	0	9	9
	Total	0	11	11
Residual AVM (n=43)	Positive shunt	42	0	42
	Negative shunt	1	0	1
	Total	43	0	43

MRI=magnetic resonance imaging; AVM=arteriovenous malformation

98.6), negative predictive value was 90.0% (95% CI 55.9 to 98.4), and accuracy was 94.4% (95% CI 84.6 to 98.8). When compared to the DSA results, only three patients had inconsistent ASL interpretations. For two of these patients, the MRI interpretations were positive for residual shunt, whereas the corresponding cerebral angiogram studies were negative. As for the third patient, the MRI interpretation was false-negative, but the cerebral angiogram study revealed micro-AVM. The interobserver agreement for the interpretation of the MRIs was 0.683.

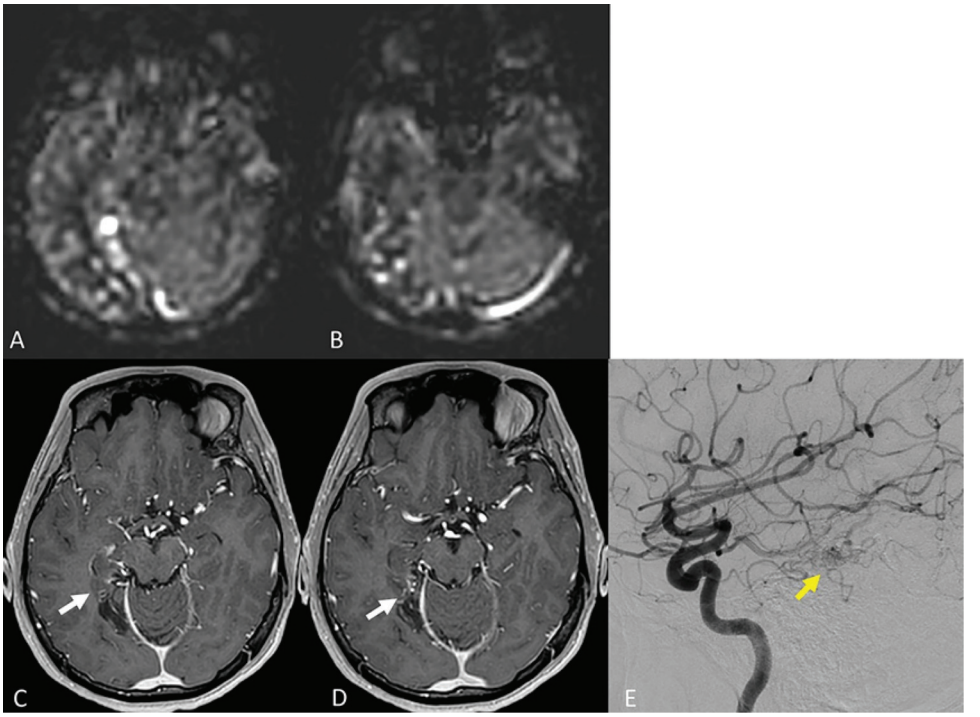

Figure 2. A case of a 27-year-old male with AVM at right hippocampus post glue embolization. (A, B) pCASL with PLD of 1650 ms shows a high ASL signal at the right basal vein of Rosenthal and the left transverse sinus. (C, D) Post-contrast T1-THRIVE shows faint enhancement at the right medial temporal region (arrow). (E) DSA shows a small AVM nidus (arrow).

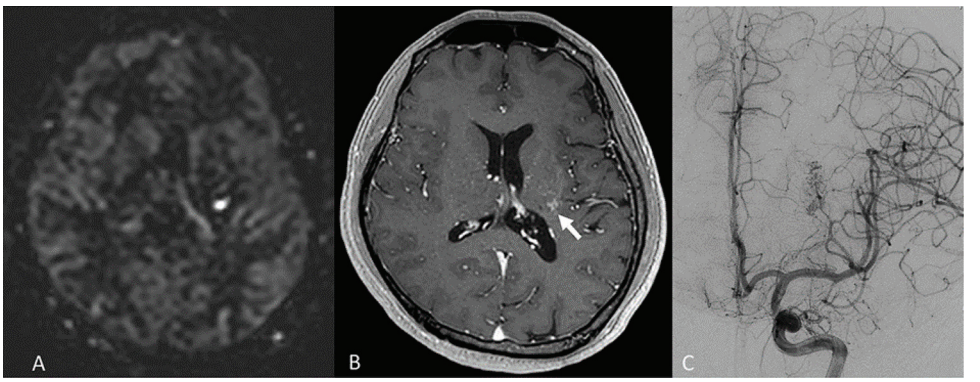

Figure 3. A case of a 40-year-old male with a small AVM at the posterior left basal ganglia. (A) pCASL with PLD of 1650 ms shows a high signal intensity at the posterior left basal ganglia corresponding with a small enhancement of the nidus (arrow on post contrast T1-THRIVE [B]). (C) DSA shows nidus which has an arterial feeder from the lenticulostriate arteries and anterior choroidal artery. The nidus drained into the left thalamostriate vein and then the basal vein of Rosenthal.

Discussion

The authors designed the present study to evaluate the role of the ASL sequence in patients with cerebral AVMs and observed a high accuracy in evaluating residual shunts. Conventional MRI often gives equivocal results, especially for posttreatment AVMs. Patchy enhancement of the lesion in such cases makes it difficult to differentiate between granulation tissue and a small residual AVS (Figure 2). In slow-flow AVMs, the high signal intensity of ASL may be visualized in the nidus (Figure 3).

The present study results corresponded with those of the previous research, in which most false-positive ASL findings were due to arterial transit artifacts (ATAs)[14,15]. The tagged blood water protons were still in the arteries, showing a high signal intensity in

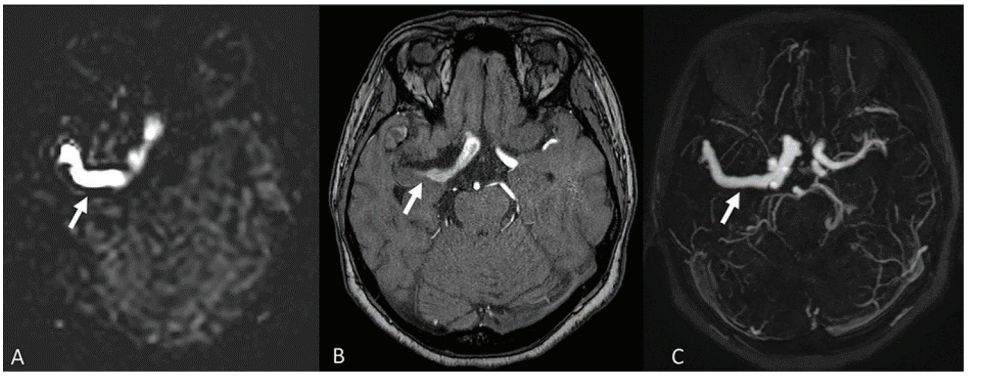

Figure 4. Arterial transit artifact (ATA). (A) High signal intensity on pCASL with PLD of 1650 ms (arrow) corresponded with slow flow in the M1 segment of the right MCA, which shows positive remodeling from atherosclerotic/post treatment change on MRA-TOF image (B) and enhancement on contrast-enhanced MRA (C).

the ASL images. This can be found in pathological or slow-flow arteries, such as when there is vasculopathy of the AVM itself, atherosclerosis (Figure 4), and poor cardiac output. A post-labeling delay time which was too short was another factor for ATA.

In clinical practice, the authors found that the accuracy of ASL in evaluating cerebral AVMs was improved when ASL and MRA images were compared. When the ASL signal corresponded to the arterial signal in MRA, it was ATA. The authors' pilot study revealed that this method increased accuracy from 85.2% to 94.4%.

The false-negative ASL findings occurred when small lesions, such as micro-AVM, and skull base locations were involved, with the findings resulting from artifacts at the air-tissue interface[14]. The authors found that using the original or gray scale ASL image improved the contrast in cases in which subtle findings on the color mapping of the ASL risked being missed.

There are technical limitations of ASL. For example, the field of view of the ASL does not cover the entire brain. It is also sensitive to susceptibility artifacts, such as surgical material, calcification, or dental hardware[14]. In addition, the post-labeling delay time needs to be appropriated. In the present study, the proper time was approximately 1,650 milliseconds in most cases.

Studies have reported a good correlation of ASL with DSA[11-13]. A study of ASL in 26 patients with dural arteriovenous fistulas or small cerebral AVM compared to DSA reported a sensitivity of 78%, a specificity of 85%, a positive predictive value of 88%, and a negative predictive value of 74%[13]. The accuracy was lower with small lesions, as the present study cases.

The main limitation of the present study was its retrospective nature. In addition, the present study used 2D-pCASL with an echo-planar imaging readout. With the newer technique of 3D-pCASL with a fast spin-echo readout, the image quality may be different.

Conclusion

ASL was helpful in evaluating cerebral AVMs. To correct the major pitfall of ASL in interpreting cerebral AVMs, differentiation between high ASL signals in venous structures and ATAs by comparing ASL imaging with MRA is mandatory. Proper timing of post-labeling delay will reduce ATA artifacts.

What is already known on this topic?

The gold standard for the diagnosis of cerebral AVM and AVS is a cerebral angiogram, which is an invasive procedure. Conventional MRI and MRA are non-invasive techniques for evaluating this condition, but it is difficult to differentiate between posttreatment changes and residual or recurrent AVS.

What this study adds?

ASL is a non-invasive MRI technique for evaluating cerebral AVMs. The detection of a high ASL signal in the venous structure by comparing with MRA is mandatory to improve the accuracy of ASL in evaluating AVS in cerebral AVMs.

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Conflicts of interest

The authors declare that there are no conflicts of interest related to any aspect of the present study.

References

1. Hofmeister C, Stapf C, Hartmann A, Sciacca RR, Mansmann U, terBrugge K, et al. Demographic, morphological, and clinical characteristics of 1289 patients with brain arteriovenous malformation. Stroke 2000;31:1307-10.
2. Tranvinh E, Heit JJ, Hacein-Bey L, Provenzale J, Wintermark M. Contemporary imaging of cerebral arteriovenous malformations. AJR Am J Roentgenol 2017;208:1320-30.
3. Blauwblomme T, Naggara O, Brunelle F, Grévent D, Puget S, Di Rocco F, et al. Arterial spin labeling magnetic resonance imaging: toward noninvasive diagnosis and follow-up of pediatric brain arteriovenous malformations. J Neurosurg Pediatr 2015;15:451-8.
4. Choe JG, Im YS, Kim JS, Hong SC, Shin HJ, Lee JI. Retrospective analysis on 76 cases of cerebral arteriovenous malformations treated by gamma knife radiosurgery. J Korean Neurosurg Soc 2008;43:265-9.
5. Pollock JM, Whitlow CT, Simonds J, Stevens EA, Kraft RA, Burdette JH, et al. Response of arteriovenous malformations to gamma knife therapy evaluated with pulsed arterial spin-labeling MRI perfusion. AJR Am J Roentgenol 2011;196:15-22.
6. Yamamoto M, Ide M, Jimbo M, Takakura K, Lindquist C, Steiner L. Neuroimaging studies of postobliteration nidus changes in cerebral arteriovenous malformations treated by gamma knife radiosurgery. Surg Neurol 1996;45:110-9; discussion 9-22.
7. Shimizu K, Kosaka N, Yamamoto T, Shioura H, Kodera T, Kikuta K, et al. Arterial spin labeling perfusion-weighted MRI for long-term follow-up of a cerebral arteriovenous malformation after stereotactic radiosurgery. Acta Radiol Short Rep 2014;3:2047981613510160.
8. Kodera T, Arai Y, Arishima H, Higashino Y, Isozaki M, Tsunetoshi K, et al. Evaluation of obliteration of arteriovenous malformations after stereotactic radiosurgery with arterial spin labeling MR imaging. Br J Neurosurg 2017;31:641-7.
9. Liscák R, Vladyka V, Simonová G, Urgosík D, Novotný J Jr, Janousková L, et al. Arteriovenous malformations after Leksell gamma knife radiosurgery: rate of obliteration and complications. Neurosurgery 2007;60:1005-14; discussion 15-6.
10. Haller S, Zaharchuk G, Thomas DL, Lovblad KO, Barkhof F, Golay X. Arterial spin labeling perfusion of the brain: emerging clinical applications. Radiology 2016;281:337-56.
11. Wolf RL, Wang J, Detre JA, Zager EL, Hurst RW. Arteriovenous shunt visualization in arteriovenous malformations with arterial spin-labeling MR imaging. AJNR Am J Neuroradiol 2008;29:681-7.
12. Yu SL, Wang R, Wang R, Wang S, Yao YQ, Zhang D, et al. Accuracy of vessel-encoded pseudocontinuous arterial spin-labeling in identification of feeding arteries in patients with intracranial arteriovenous malformations. AJNR Am J Neuroradiol 2014;35:65-71.
13. Le TT, Fischbein NJ, André JB, Wijman C, Rosenberg J, Zaharchuk G. Identification of venous signal on arterial spin labeling improves diagnosis of dural arteriovenous fistulas and small arteriovenous malformations. AJNR Am J Neuroradiol 2012;33:61-8.
14. Amukotuwa SA, Yu C, Zaharchuk G. 3D Pseudocontinuous arterial spin labeling in routine clinical practice: A review of clinically significant artifacts. J Magn Reson Imaging 2016;43:11-27.
15. Deibler AR, Pollock JM, Kraft RA, Tan H, Burdette JH, Maldjian JA. Arterial spin-labeling in routine clinical practice, part 1: technique and artifacts. AJNR Am J Neuroradiol 2008;29:1228-34.