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Diffusion and Perfusion MRI Findings of the Signal-Intensity Abnormalities of Brain Associated with Developmental Venous Anomaly

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ABSTRACT

BACKGROUND AND PURPOSE: Developmental venous anomalies are the most common intracranial vascular malformation. Increased signal-intensity on T2-FLAIR images in the areas drained by developmental venous anomalies are encountered occasionally on brain imaging studies. We evaluated diffusion and perfusion MR imaging findings of the abnormally high signal intensity associated with developmental venous anomalies to describe their pathophysiologic nature.

MATERIALS AND METHODS: We retrospectively reviewed imaging findings of 34 subjects with signal-intensity abnormalities associated with developmental venous anomalies. All subjects underwent brain MR imaging with contrast and diffusion and perfusion MR imaging. Regions of interest were placed covering abnormally high signal intensity around developmental venous anomalies on fluid-attenuated inversion recovery imaging, and the same ROIs were drawn on the corresponding sections of the diffusion and perfusion MR imaging. We measured the apparent diffusion coefficient, relative cerebral blood volume, relative mean transit time, and time-to-peak of the signal-intensity abnormalities around developmental venous anomalies and compared them with the contralateral normal white matter. The Mann-Whitney *U* test was used for statistical analysis.

RESULTS: The means of ADC, relative cerebral blood volume, relative mean transit time, and TTP of signal-intensity abnormalities around developmental venous anomalies were calculated as follows: $0.98 \pm 0.13 \times 10^{-3} \text{mm}^2/\text{s}$, $195.67 \pm 102.18 \text{ mL}/100 \text{ g}$, $16.74 \pm 7.38 \text{ seconds}$, and $11.65 \pm 7.49 \text{ seconds}$, respectively. The values of normal WM were as follows: $0.74 \pm 0.08 \times 10^{-3} \text{mm}^2/\text{s}$ for ADC, $48.53 \pm 22.85 \text{ mL}/100 \text{ g}$ for relative cerebral blood volume, $12.12 \pm 4.27 \text{ seconds}$ for relative mean transit time, and $8.35 \pm 3.89 \text{ seconds}$ for TTP. All values of ADC, relative cerebral blood volume, relative mean transit time, and TTP in the signal-intensity abnormalities around developmental venous anomalies were statistically higher than those of normal WM (All $P < .001$, respectively).

CONCLUSIONS: The diffusion and perfusion MR imaging findings of the signal-intensity abnormalities associated with developmental venous anomaly suggest that the nature of the lesion is vasogenic edema with congestion and delayed perfusion.

ABBREVIATIONS: DVA = developmental venous anomaly; rCBV = relative cerebral blood volume; rMTT = relative mean transit time; SI = signal intensity

Developmental venous anomalies (DVAs) are encountered frequently on brain imaging studies. DVAs are identified in up to 2% of the general population, and they are the most common intracranial vascular malformation (63% and 50% of all malformations in postmortem examinations and MR imaging series, respectively).^{1,2} They are composed of dilated medullary veins that drain centripetally and radially into enlarged transcortical or subependymal collector veins.³⁻⁵ DVAs serve

as normal drainage routes of the brain tissue because the normal venous drainage pattern is underdeveloped in the area adjacent to the DVA. These venous channels have no malformed or neoplastic elements and are generally described as having normal intervening parenchyma.^{6,7} However, increased signal intensity (SI) on T2 FLAIR images in the areas drained by DVAs have been reported in 7.8%–54.1% of MR imaging investigations.⁸⁻¹⁰ Such abnormal SI related to DVAs has been explained as edema, ischemia, demyelination, gliosis, leukoaraiosis, or a combination of these conditions.^{11,12} Several studies have been undertaken to understand the mechanism of SI change.¹³⁻¹⁵ However, there has been no report of the diffusion and perfusion changes of abnormal SI in the area of DVAs by using diffusion- and perfusion-weighted MR imaging, to our knowledge. Therefore, the aim of this study was

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to characterize these SIs by using DWI and PWI. DWI would discriminate between vasogenic edema and gliosis, and PWI would demonstrate signs of outflow obstruction and venous congestion.

MATERIALS AND METHODS

Patients

We searched the reports of brain MR imaging with contrast, diffusion, and perfusion studies for the terms “developmental venous anomaly” or “venous angioma” through the databank of our hospital from January 2005 to January 2013. Two hundred fifty-six consecutive patients with DVAs were found. Sixty-eight of 256 (26.6%) subjects showed SI abnormalities in the DVA drainage area. No patient had suspected or known multiple sclerosis. Within these subjects, 34 were omitted from the study group due to the following exclusion criteria: 1) area of SI abnormality <5 mm² ($n = 23$), 2) the lesion not distinguishable from ischemic lesions or infarction of underlying small-vessel disease ($n = 7$), and 3) DVAs accompanied by cavernous malformations ($n = 4$). Finally, 34 subjects (13.3%, 34/256) formed the study group. Our institutional review board approved this study, and informed consent was waived in this retrospective study.

MR Imaging Protocol and Postprocessing

MR imaging was performed at 3T (Achieva; Philips Healthcare, Best, the Netherlands) with an 8-channel sensitivity-encoding head coil. For all patients, we obtained the following images: axial contrast-enhanced spin-echo T1-weighted images after intravenous injection of contrast material (gadoterate meglumine, Dotarem; Guerbet, Aulnay-sous-Bois, France; 0.1 mmol/kg body weight by power injector) (TR/TE = 500/10 ms, section thickness = 5 mm, acquisition matrix = 256 × 226); axial T2-weighted fluid-attenuated inversion recovery images (TR/TE = 11000/125 ms, section thickness = 5 mm, acquisition matrix = 368 × 265); spin-echo EPI DWI (TR/TE = 3000/76 ms, section thickness = 5 mm, acquisition matrix = 128 × 128, b-value = 0, 1000 s/mm²); and dynamic susceptibility contrast MR PWI (TR/TE = 1720/35 ms, flip angle = 40°, section thickness = 5 mm, acquisition matrix = 128 × 128, 50 volumes, acquisition time = 1 minute 30 seconds). All MR images were acquired with the same FOV (240 × 240 mm).

We processed the dynamic susceptibility-weighted contrast-enhanced perfusion MR imaging by using a dedicated software package (nordicICE; NordicNeuroLab, Bergen, Norway). Perfusion maps of relative cerebral blood volume (rCBV), relative mean transit time (rMTT), and time-to-peak were made by using an acknowledged tracer kinetic model applied to first-pass data.^{16,17} We used γ -variate fit to diminish the recirculation effect. We performed deconvolution of the measured signal-time curves by using singular-value decomposition with the arterial input function of approximately 5 pixels retrieved from the middle cerebral artery branches. TTP was obtained by computing the arrival time of contrast material to maximum concentration.

MR Imaging Data Analysis and Statistics

Two neuroradiologists (S.T.K., H.N.J.) analyzed the MR images retrospectively. One had 22 years' experience with brain imaging,

The ADC, rCBV, rMTT, and TTP values of signal-intensity abnormalities associated with developmental venous anomalies and contralateral normal white matter

	DVAs	Normal WM	P Values ^a
ADC ^b	0.98 ± 0.13	0.74 ± 0.08	<.001
rCBV ^c	195.67 ± 102.18	48.53 ± 22.85	<.001
rMTT ^d	16.74 ± 7.38	12.12 ± 4.27	<.001
TTP ^e	11.65 ± 7.49	8.35 ± 3.89	<.001

^a Mann-Whitney *U* test.

^b Apparent diffusion coefficient is expressed as 10⁻³mm²/s.

^c Relative cerebral blood volume is expressed as mL/100 g.

^d Relative mean transit time is expressed as seconds.

^e Time-to-peak is expressed as seconds.

and the other had 5 years' experience with brain imaging. DVAs were identified on contrast-enhanced T1WI. We defined the drainage territory as brain parenchyma directly adjacent to the visualized medullary and collector vein of the DVA. When increased SI was seen within the drainage territory of a DVA on a T2 FLAIR image, it was defined as an SI abnormality associated with a DVA.

Regions of interest were placed covering the abnormally high SI around DVAs on T2 FLAIR imaging, not including the collecting vein because these can confound perfusion measurements. All ROIs were copied to corresponding sections of the apparent diffusion coefficient and perfusion maps. ROIs were manually drawn on the T2 FLAIR images for normal-appearing contralateral white matter, and ROIs on the ADC and perfusion maps were obtained in the same way. We measured the values of ADC, rCBV, rMTT, and TTP, respectively, and analyzed differences in values of ADC, rCBV, rMTT, and TTP between the SI abnormalities associated with the DVA and contralateral normal WM. The Mann-Whitney *U* test was used for statistical analysis. Null hypotheses of no difference were rejected if *P* values were <.05. A commercially available software program (PASW, Version 18.0; IBM, Armonk, New York) was used for all statistical analyses.

RESULTS

The mean age of the 34 patients was 63.7 years (range, 38–81 years), and 52.9% ($n = 18$) were men. The mean area of the region of interest of SI abnormalities associated with DVAs was 64.5 mm² (range, 8.8–260.2 mm²).

The values of ADC, rCBV, rMTT, and TTP of abnormal SI associated with DVAs and normal WM are summarized in the Table. The mean values of SI around DVAs were 0.98 ± 0.13 10⁻³mm²/s for ADC, 195.67 ± 102.18 mL/100 g for rCBV, 16.74 ± 7.38 seconds for rMTT, and 11.65 ± 7.49 seconds for TTP, respectively. The mean ADC, rCBV, rMTT, and TTP values of normal WM were as follows: 0.74 ± 0.08 10⁻³mm²/s, 48.53 ± 22.85 mL/100 g, 12.12 ± 4.27 seconds, and 8.35 ± 3.89 seconds. There was a significant difference between the SI abnormalities associated with DVAs and normal WM in all terms of ADC, rCBV, rMTT, and TTP (all *P* < .001, respectively) (Fig 1).

DISCUSSION

In the present study, SI abnormalities associated with DVAs were seen in 13.3% of DVAs (34/256), and this value is in the range of prevalence of 7.8%–54.1% that is reported in previous studies.^{8–10} Abnormal SI associated with DVAs is not a rare finding in an imaging study, and some possibilities have been proposed as the

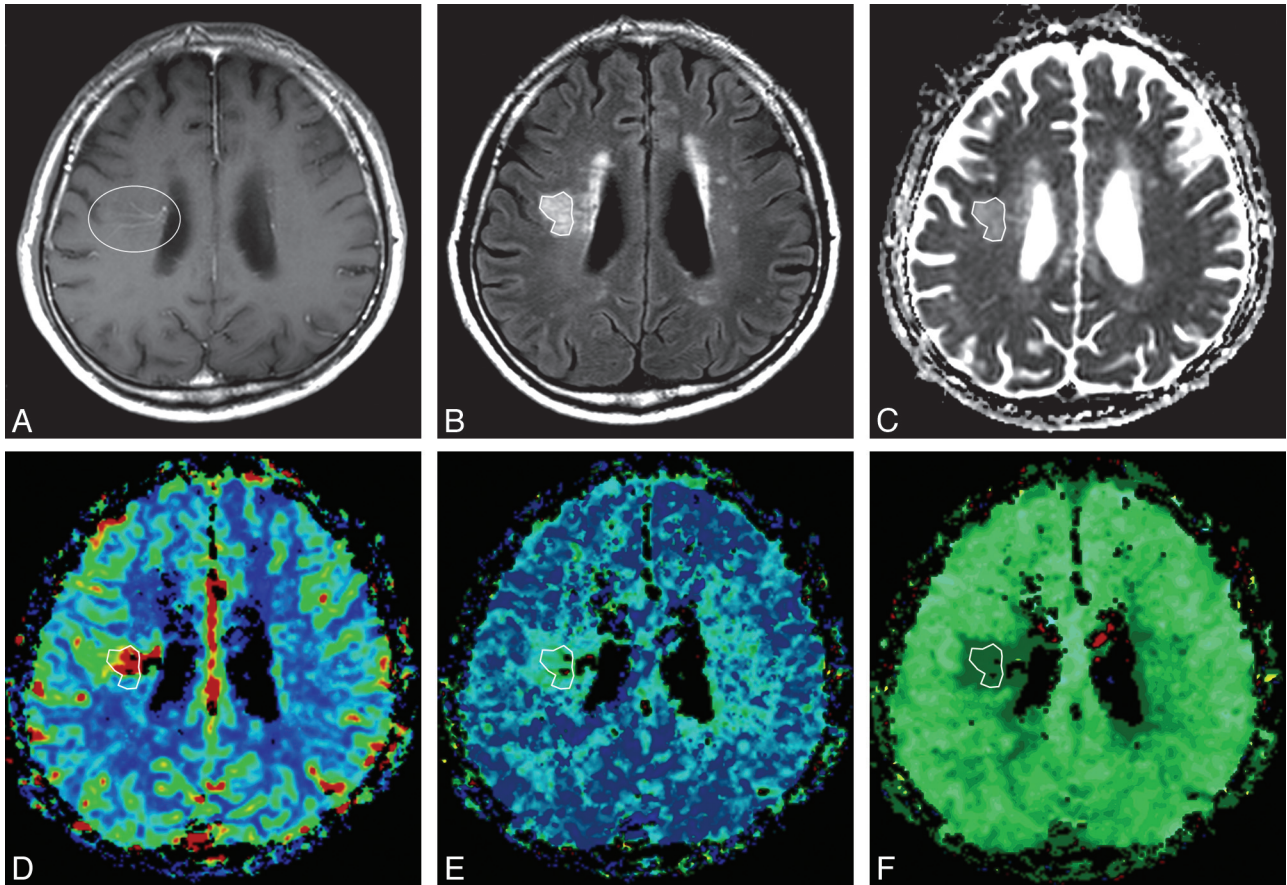


FIG 1. A 60-year-old man with blurred vision and headache. *A*, Postcontrast T1-weighted axial image shows a dilated medullary vein draining into the subependymal collecting vein in the right corona radiata (*circle*), representing a developmental venous anomaly. *B*, Abnormal signal intensity is seen in the area of the DVA (*polygon*) on the axial T2 fluid-attenuated inversion recovery imaging. *C*, Apparent diffusion coefficient. *D*, Relative cerebral blood volume. *E*, Relative mean transit time. *F*, Time-to-peak map demonstrates increased values of the corresponding area compared with contralateral normal white matter. These findings suggest that the nature of the SI abnormalities around DVAs is vasogenic edema with congestion and delayed perfusion.

etiology. Among them, considerable studies have supported venous congestion as the cause of SI change around a DVA.^{3,8,10,18-25} Some studies have shown that DVAs may have thickened and hyalinized vessel walls without a smooth-muscle layer or elastic lamina.^{11,18-20} Dillon²¹ substantiated increased venous pressure within a DVA by measuring a 15-mm Hg pressure gradient across the stenotic collecting vein of a DVA in 1 patient. Truwit³ reported that a focal stenosis of the draining vein may be seen at the point where it penetrates the dura to enter the dural sinus, resulting in delayed filling and emptying of the DVA. Narrowing of the veins can cause lessened compliance, increase resistance to flow, and reduce the capacity of the vessel to adjust to pressure changes.¹⁰ Besides, a single collecting vessel in a DVA drains an abnormally large parenchymal territory, resulting in relative volume overload and chronic cerebral edema or ischemia.^{10,22} Impaired cerebral blood flow attributed to venous congestion has been reported in the drainage vicinity of the DVA.²³⁻²⁵ In recent CT and MR perfusion studies, increased CBV, CBF, and MTT can be observed in the region of the DVA.^{26,27}

Abnormal SI lesions are understood as vascular-induced leukoariosis associated with chronic cerebral ischemia, resulting from venous congestion.¹⁰ In addition, it seems reasonable that the underlying venous hypertension may be a causative factor in

hemorrhage, one of the rare complications of DVAs, as well as ischemia. A recent study revealed a significant relationship between abnormal SI in the drainage territory of DVAs and hypointense foci on phase-sensitive MR imaging, indicating microhemorrhage or cavernous malformation.⁸ Venous hypertension would overload the vessel wall and cause injury, resulting in microhemorrhage from the weakest point and reactive angiogenesis.^{28,29} For the angiogenesis, lack of vasoregulatory capacity of the neovasculature leads to repeated hemorrhage and formation of cavernous malformations, eventually.^{30,31}

The results of the present study correspond well with the aforementioned studies. SI abnormalities in the draining area of DVAs showed higher ADC value, increased rCBV, and perfusion delay, compared with the normal white matter, representing venous congestion. The ADC value would increase in reactive gliosis—disruption of cell membranes, loss of myelin, or any process that may alter the integrity of axons that would reduce the restriction of water motion.³² However, gliosis alone did not cause increased rCBV and perfusion delay. A previous study showed that areas of gliosis demonstrated significantly higher ADC values ($1.76 \pm 0.09 \times 10^{-3} \text{ mm}^2/\text{s}$) than areas of vasogenic edema ($1.35 \pm 0.06 \times 10^{-3} \text{ mm}^2/\text{s}$) without overlap.³² The ADC value for SI abnormalities in the draining area of DVAs was 0.98 ± 0.13

$\times 10^{-3} \text{ mm}^2/\text{s}$, which is lower than that of gliosis. It is difficult to simply compare the ADC value in our study with that in the references because there is an absence of comparable gliosis evaluation and the area range of 34 cases in our study is quite broad. However, the alteration of perfusion parameters in SI abnormalities around DVAs compared with normal white matter could suggest that it has at least a component of vasogenic edema rather than gliosis alone.

Our study has several limitations. First, this was a retrospective study. Second, it had a small sample size. Third, the prevalence of SI abnormalities in the territory of DVAs in our study may not be entirely accurate and may potentially have selection bias because cases with DVAs were detected from reports of brain MR imaging with contrast and diffusion and perfusion studies. Fourth, we did not include the collecting vein in ROIs to avoid confusion of values of the perfusion measurements. However, the tributary veins were included in the ROIs, and this inclusion may have affected the results. Fifth, there was a lack of information about the values of DWI and PWI in the vicinity of the DVA without SI change. Further research is needed from 2 perspectives: Radiologically, diffusion tensor imaging could determine the pathophysiology of abnormally high signal intensity of white matter around DVAs in more detail. The clinical correlations, detailed follow-up, and management in clinical practice would be outside the scope of this imaging-based study.

CONCLUSIONS

The prevalence of abnormal SI associated with DVAs is not low, and vasogenic edema and venous congestion are the primary pathophysiologic characteristics of the SI abnormalities in the draining territory of DVAs.

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