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MR Evaluation of Developmental Venous Anomalies: Medullary Venous Anatomy of Venous Angiomas

Charles Lee, Michael A. Pennington, and Charles M. Kenney III

PURPOSE: To present characteristic MR findings of developmental venous anomalies (DVAs) in terms of location of caput and draining veins, to correlate these findings with normal medullary venous anatomy, and to suggest an approach to the evaluation of DVAs by means of MR imaging. **METHODS:** We reviewed the contrast-enhanced MR examinations of 61 patients with DVA, which were selected from 4624 consecutive cranial MR examinations. Site of the DVA and size and direction of draining veins were recorded. **RESULTS:** Seventy-two DVAs with 78 draining veins were located: 18 were juxtacortical, 13 were subcortical, and 41 were periventricular or deep. Twenty-six of the DVA caputs were frontal, 16 were parietal, 13 were in the brachium pontis/dentate, seven were in the temporal lobe, three were in the cerebellar hemisphere, three were in the occipital lobe, three were in the basal ganglia, and one was in the pons. The draining veins were superficial in 29 cases and deep in 49. Of the 36 supratentorial deep draining veins, 16 were in the trigone/occipital horn, 11 were in the mid-body of the lateral ventricle, seven were in the frontal horn, and two were in the temporal horn. Among the 14 infratentorial deep draining veins, five were in the lateral recess of the fourth ventricle, four were anterior transpontine veins, three were lateral transpontine veins, and two were precentral cerebellar veins. **CONCLUSION:** The DVA caputs and their draining veins occurred in typical locations that could be predicted from the normal medullary venous anatomy, with the frontal, parietal, and brachium pontis/dentate being the most common locations. Drainage can occur in superficial cortical veins or sinuses or in deep ventricular veins or in both, no matter where the caput is located. Whether drainage was superficial or deep could not be predicted on the basis of the site of the DVA caput. Contrast-enhanced T1-weighted MR images showed the DVAs best, but diagnosis could be made from T2-weighted MR images.

Index terms: Angioma; Brain, anatomy; Brain, magnetic resonance; Veins, abnormalities and anomalies

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Developmental venous anomalies (DVAs), also known as venous angiomas, are becoming the most commonly encountered intracranial vascular lesion in central nervous system imaging (1). Most DVAs are asymptomatic or uncomplicated, and surgery is no longer considered necessary. Although cerebral angiography is the definitive study of choice, it, too, is no longer judged necessary with uncomplicated DVAs (1). Contrast-enhanced computed tomography (CT), which is no doubt responsible for the recent increase in the number of reported cases of DVA, is yielding to the far superior imaging ability of magnetic resonance (MR) as it becomes routinely available. MR imaging is thus becoming the primary study of choice and the means by which diagnosis of DVA is verified.

Although the exact pathogenesis of DVA is unknown, there appears to be a congenital basis (2–4). DVAs can be found in children in whom absence of normal draining veins are seen in the region of the DVA verified by autopsy, surgery, or angiography. The DVA and its draining vein become a compensatory venous drainage system (5). Because no angioma or malformation is present with DVA, Lasjau-

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nias et al proposed the name be changed from *venous angioma* to *developmental venous anomalies* (6). These authors believed that DVA represented nonpathologic variations of venous drainage.

Currently, DVA is thought to represent a primary dysplasia of capillaries and small transcerebral veins (7) or a compensatory mechanism caused by an intrauterine accident resulting in thrombosis of normal venous pathways (8). Because dilated medullary veins can be found with glioblastomas, Huang et al proposed that these vessels may arise from reactivation of embryonic or fetal vascular remnants in response to an increase in vascularity supplying the tumor or in response to hypoplasia or aplasia of the normal venous structures caused by a thrombotic intrauterine event (3).

The purpose of this article is to present our findings with MR imaging of DVA and to compare our experience with that of others. We discuss the normal medullary venous anatomy of the cerebrum and cerebellum as it relates to DVA and present the characteristic locations of the caput medusae and draining veins. Because most DVAs are uncomplicated and MR is usually the imaging technique of choice, we also suggest a diagnostic approach using MR imaging.

Materials and Methods

We reviewed and recorded the MR findings in 61 patients with DVA culled from 4624 consecutive contrast-enhanced cerebral MR examinations performed on a 1.5-T MR unit. Either 0.1 mmol/kg gadopentetate dimeglumine or 0.1 mmol/kg or 0.3 mmol/kg gadoteridol was given to each patient. Standard T1- and T2-weighted spin-echo pulse sequences were used. First-order-motion compensation or gradient-moment nulling was routinely used for all MR images. Of the 61 patients, 28 had coronal images in addition to the usual transaxial images. Another 14 patients had two-dimensional time-of-flight MR angiography done for reasons other than verifying the DVA. Contrast-enhanced CT scans were obtained in 18 of the 61 patients and cerebral angiograms were obtained in six patients for reasons other than verifying the presence of DVA.

All cases of DVA were identified retrospectively from dictated reports. A second review was conducted to eliminate questionable DVA and other anomalies that did not fit the diagnostic criteria for DVA. Therefore, a true prevalence figure may not be valid, because some of the DVAs may not have been reported initially and thus may have been missed in the retrospective review. Because the majority of the DVAs were incidental findings, additional views beyond the standard, routine cerebral study were not obtained.

DVAs were defined as vascular lesions with multiple enlarged vessels converging on a single (sometimes multiple) dilated parenchymal vessel. Without cerebral angiography it was difficult to determine whether the enlarged vessel was arterial or venous; however, the location of the vessels and their proximity to and junction with known venous structures suggested that they were indeed venous structures, and probably medullary veins. The classical fan-shaped caput medusae was not always apparent in each case, with the multiple vessels appearing as linear, curvilinear, or dotlike structures, depending on the orientation of the vessel with respect to the plane of imaging.

The DVAs were also classified by location as juxtacortical, subcortical, and deep, according to Valavanis et al (2). *Juxtacortical* (or superficial) was defined as within the gray matter or at the gray-white junction. *Subcortical* was defined as below the juxtacortical region but not adjacent to the ventricular wall. *Deep* (or periventricular) was defined as adjacent to the lateral, third, or fourth ventricle or within the center of the structure, such as the pons. Supratentorial deep DVAs were defined as being adjacent to the frontal horn, the mid-body of the lateral ventricle, the temporal horn, the trigone, or the occipital horn. Infratentorial deep DVAs were those adjacent to the fourth ventricle within the brachium pontis or dentate nucleus.

The terminal or draining vein to which the caput medusae joins was classified as either a deep or superficial draining vein. In the supratentorial compartment, *superficial* draining veins were identified as those that joined either a cortical vein or the sagittal sinus. *Deep* draining veins were identified as those that joined the subependymal veins of the lateral ventricles and ultimately the vein of Galen. In the infratentorial compartment, *superficial* draining veins were identified as those that joined the cerebellar hemispheric veins, superior and inferior vermian veins, transverse or sigmoid sinus, and torcula. *Deep* draining veins were those that joined the subependymal veins of the fourth ventricle and thus either the anterior or lateral transpontine veins, or laterally and inferiorly to the veins of the lateral recess of the fourth ventricle, or superiorly to the precentral cerebellar vein.

Results

Sixty-one patients had a total of 72 DVAs and 78 draining veins. Twenty-nine patients were male and 32 were female; ages ranged from 4 months to 71 years (mean age, 37 years). Seven were children younger than 10 years old and six were teenagers. Fifty-one patients had single DVAs, nine patients had two DVAs, and one patient had three DVAs. Fifty-four DVAs were supratentorial and 18 were infratentorial. Thirty-five were on the right side, 31 on the left side, and three were bilateral.

There were 18 juxtacortical, 13 subcortical, and 41 periventricular or deep DVAs, located in the frontal (n = 26), parietal (n = 16), brachium pontis/dentate (n = 13), temporal (n = 7), cerebellar hemisphere (n = 3), occipital (n = 3), basal ganglia (n = 3), and pontine (n = 1) regions. Of the 18 juxtacortical DVAs, seven joined superficial veins and 11 joined deep veins. Of the 13 subcortical DVAs, six joined superficial veins and 10 joined deep veins. Of the 41 periventricular/deep DVAs, 16 joined superficial veins and 28 joined in deep veins. There were 29 superficial draining veins and 49 deep draining veins. There were also six DVAs with dual draining veins, of which five joined both superficial and deep veins (Fig 1) and one in which both veins joined deep veins (Fig 2).

In the supratentorial compartment, 20 terminal veins of the DVA joined superficial veins (Figs 3 and 4). Of the 36 DVAs joining to deep veins in the supratentorial compartment, the site of junction was with the subependymal veins of the trigone/occipital horn in 16, with the mid-body of the lateral ventricle (longitudinal caudate vein of Schlesinger) in 11, with the frontal horn in seven, and with the temporal horn in two (Figs 1 and 5). In the infratentorial compartment, the nine superficial draining veins were in the sigmoid or transverse sinus (n = 4), in the vermis (n = 3), and in the cerebellar hemisphere (n = 2). The 14 deep infratentorial veins included the vein of the lateral recess of the fourth ventricle (n = 5), the anterior transpontine (n = 4) and lateral transpontine veins (n = 3), and the precentral cerebellar veins (n = 2) (Figs 2 and 6).

Discussion

In 1951 Russell and Rubinstein (9) classified cerebral vascular malformations into telangiectasias, arteriovenous malformations (AVMs), venous angiomas, and cavernous angiomas. Courville (5) gave descriptions of small vascular malformations in 1963, which he characterized as being composed solely of venous structures. He identified a single dilated vein or clusters of venules located in the subcortical or deep white matter region in the cerebrum and cerebellum; he noted that these venules cluster in the shape of a tree, with the draining vein representing the trunk (Fig 4). This central vein traverses through the cortex either to the surface or deep into the subependymal veins in the walls of the ventricles.

In 1968 Constans et al (10) provided radiologic description of two cases of DVA. Since then, numerous radiographic studies of DVA have been reported (1, 2, 6–8, 10–15). Huang et al (3) defined these DVAs as malformations of venous structures without any abnormality of the capillary or arterial structures. DVA is characterized by a caput medusae or an umbrellalike convergence of multiple venules on a single, or occasionally multiple, enlarged parenchymal or medullary vein, like the trunk of a tree or the shank of an umbrella. This dilated terminal vein penetrates the cortex to drain either (*a*) superficially to cortical veins or sinuses, (*b*) deeply to subependymal veins of the lateral ventricle and then into the galenic system, (*c*) to the fourth ventricle and then to the pontomesencephalic vein, or (*d*) to the precentral cerebellar vein and into the galenic system. In DVAs, normal cerebral tissue intervenes between the dilated veins, whereas in cavernous angiomas there is no tissue separating the sinusoidal vascular spaces. Huang et al (3) suggested that the term *angioma* be dropped and that *medullary venous malformation* be used instead. Later, Lasjaunias et al (6) renamed these malformations *developmental venous anomalies*.

DVAs were once considered to be the rarest of vascular malformations (16). However, with the advent of CT and, more recently, MR imaging, DVAs are now known to be the most common of the cerebral vascular malformations (1). In one large series of 4069 consecutive brain autopsies, 105 DVAs were found, a frequency of 2.5%. In this same series, only 24 AVMs and 16 cavernous angiomas were found. Thus, DVAs were more than four times as common as AVMs, and represented 63% of all vascular malformations found in this series (7). Garner et al (4), in a review of 8200 craniospinal MR studies, found that DVA represented 50% of all vascular malformations.

In a review of all 62 cases of DVA found in the literature up to 1980 plus 36 cases of their own, Huang et al (3) found that DVAs occur slightly more often in male subjects, between the second and fifth decades, and are found most frequently in the frontal and parietal lobe (40%) and cerebellum (27%), and less often in the parietal and parietooccipital lobe (15%), basal ganglia and thalamus (11%), temporal lobe (3%), brain stem (2%), and intraventricular lo-

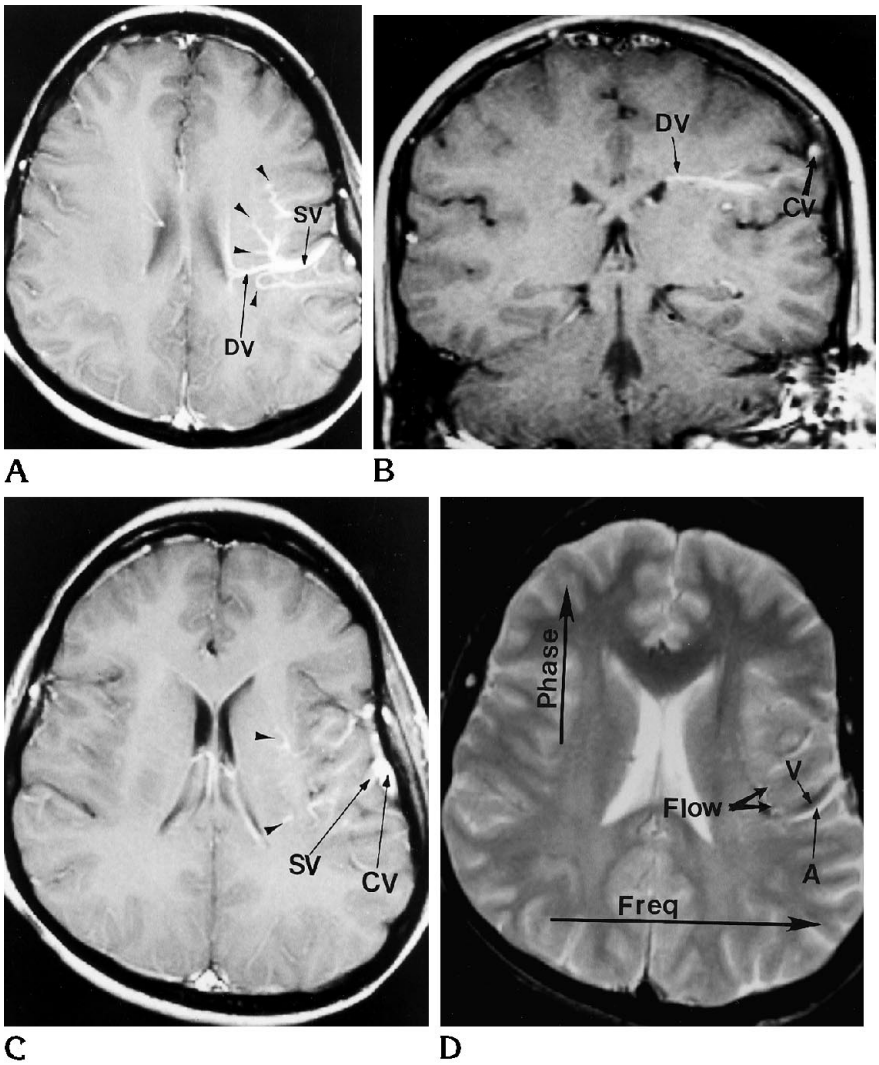

Fig 1. Subcortical DVA with both deep and superficial draining veins. 25-year-old woman with a left parietal subcortical DVA with dual drainage to both deep and superficial veins.

A, T1-weighted contrast-enhanced axial MR image shows the subcortical caput (*arrowheads*) with a larger superficial vein (*SV*) and a smaller deep vein (*DV*) to the trigone/occipital horn region.

B, T1-weighted contrast-enhanced coronal MR image shows the deep draining vein (*DV*) to the trigone/occipital horn region and an enlarged cortical vein (*CV*).

C, Lower T1-weighted contrast-enhanced axial MR image shows the inferior portions of the caput as dotlike structures (*arrowheads*) and the cortical vein (*CV*) to which the collector vein (*SV*) joins.

D, T2-weighted axial image at same level as *C*. The caput is not seen as well as in *C*. Flow phase-shift artifact related to the collector vein of the DVA that joins a superficial cortical vein is seen well. In this image, the phase- and frequency-encoding axes were swapped. The bright signal artifact (*A*) is shifted upstream (or in an outer direction) from the dark flow void of the vein (*V*) along the axis of the frequency-encoding gradient. Therefore, flow is directed outward from the center of the cranium, and the flow in the collector vein is outward or superficially toward the cortex.

cations (2%). The series of Garner et al (4) of 100 patients with DVA is the largest in which frontal (42%), parietal (24%), cerebellar (14%), basal or ventricular (11%), occipital (4%), brain stem (3%), and temporal (2%) locations were identified. Unlike the series by Huang et al (3), which was based mainly on surgical cases and angiographic data, Garner's study was based on 4340 cerebral angiograms, 25 600 CT scans, and 8200 MR images.

Our series shows relatively more cerebellar lesions with an equal occurrence of parietal and cerebellar sites: frontal (36%), cerebellar (22%), parietal (22%), temporal (10%), occipital and basal ganglia (4%), and pons (2%). Wilms et al (14), on the other hand, found an equal occur-

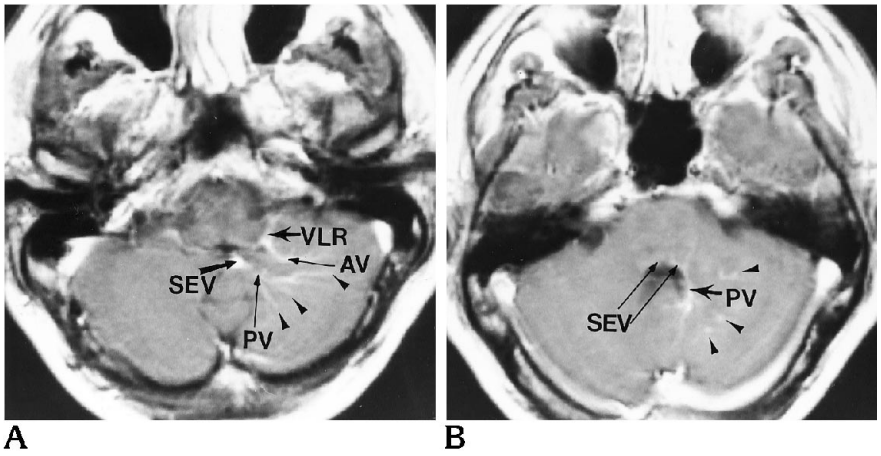

Fig 2. Dual DVA with single, deep draining vein. 31-year-old man with two deep DVAs on the same side in the brachium pontis/dentate region, but with single drainage to an enlarged left vein of the lateral recess of the fourth ventricle.

A, Lower T1-weighted contrast-enhanced axial MR image shows that the posterior DVA collector vein (*PV*) drains into enlarged subependymal veins (*SEV*) of the fourth ventricle and then into the vein of the lateral recess of the fourth ventricle (*VLR*). The more anterior DVA collector vein (*AV*) also drains into the VLR. *Arrowheads* indicate caputs.

B, Higher T1-weighted contrast-enhanced axial MR image shows enlarged subependymal veins (*SEV*) joining the posterior DVA collector vein (*PV*).

rence of frontal and cerebellar lesions in their series of 28 patients with 29 DVAs: frontal (38%), cerebellar (38%), parietal (10%), occipital (10%), and temporal (7%).

DVAs can be located both superficially, juxtacortical or subcortical (Figs 1, 3, 5), and deep, or periventricular (Figs 2, 4, 6), a categorization first suggested by Valavanis et al (2). This classification has some relevance, because, according to these authors, the juxtacortical DVAs drain superficially to cortical veins or sinuses; periventricular DVAs drain deep to the subependymal, ventricular veins and ultimately into the vein of Galen; and subcortical DVAs may drain either way.

In a review of seven cases, Valavanis et al (2) found the most common sites of the DVA caput to be subcortical (n = 4) and then juxtacortical (n = 2) and periventricular (n = 1). The only other study to review DVAs in this fashion was reported by Ostertun et al (7), who found 21 DVAs in 20 patients. These investigators found the subcortical location (n = 13) to be the most common and the periventricular location (n = 8) the next most common.

Our findings depart greatly from theirs in that in our series the deep or periventricular location was the most common site (n = 41), with the juxtacortical (n = 18) and the subcortical (n = 13) locations far less common. This may in part be attributable to the higher number of infratentorial DVAs we found that were located predominantly deep or periventricularly in the brachium pontis/dentate region (Figs 2, 6) or in the pons and that drained deeply. With the supratentorially located DVAs, we found roughly an equal mixture in the juxtacortical and periventricular/deep location, and fewer in the subcortical location.

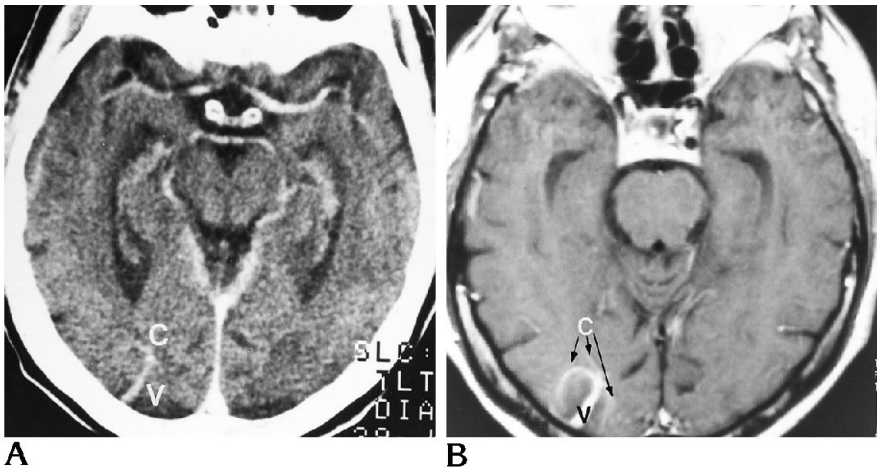

Fig 3. Subcortical DVA with superficial draining vein. 63-year-old man with a subcortically located DVA in the right occipital region that drains superficially to the cortex.

A, Contrast-enhanced CT scan shows the collector or draining vein (*V*) and part of the caput medusa (*C*).

B, T1-weighted contrast-enhanced axial MR image shows the caput (*C*) and the collector vein (*V*) better than the CT scan does.

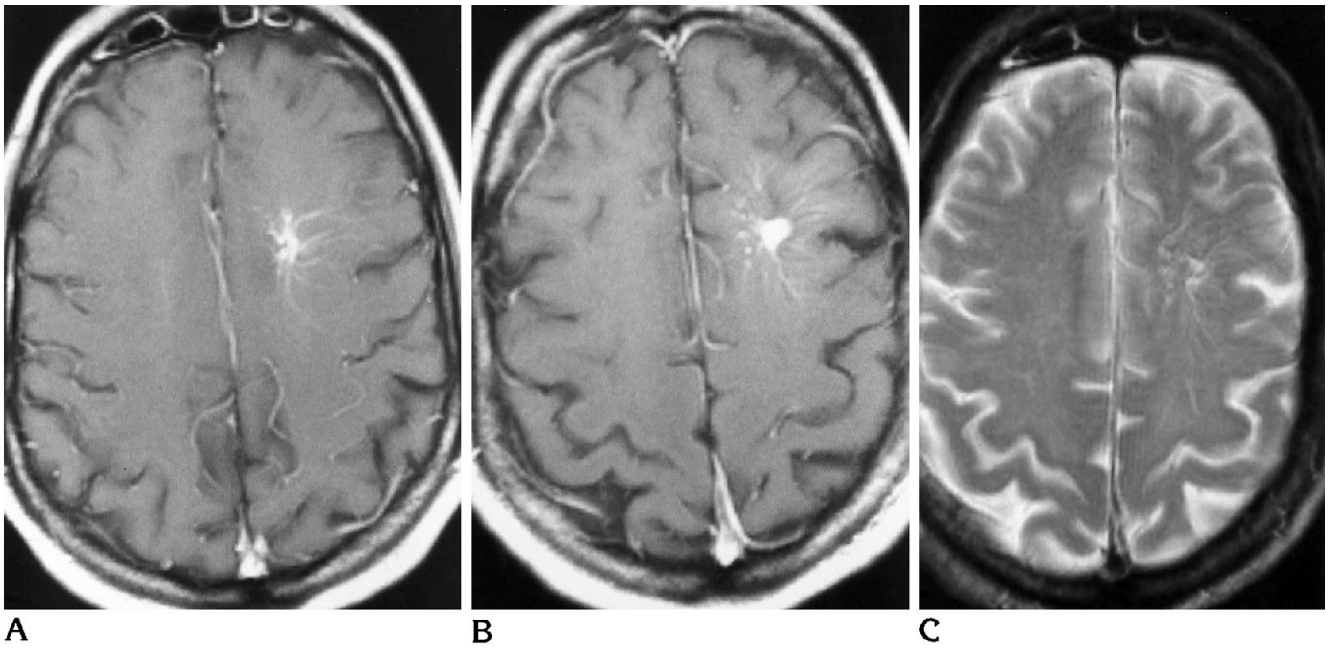

Fig 4. Deep DVA with superficial draining vein. 46-year-old man with a periventricular or deep DVA in the left posterior frontal region that drains superficially to the cortical veins.

A, Lower T1-weighted contrast-enhanced axial MR image shows the typical radial array of the caput medusae portion of the DVA located just above the lateral ventricle.

B, Higher T1-weighted contrast-enhanced axial MR image shows convergence of the caput on a dilated draining vein.

C, T2-weighted axial image at same level as *B*. The caput is seen well, but the vein is not seen as well as in *B*.

In the series by Valvanis et al (2), the DVAs drained both superficially and deeply in three cases, superficially in two, and deeply in two. DVAs drained superficially in 15 cases and deeply in six in the series by Ostertun and Solymosi (7). Again, our findings departed from these in that we found more deeply draining veins (n = 26) than superficially draining veins (n = 18). We also found that DVAs of superficial draining medullary veins did not necessarily join superficial cortical veins or sinuses, or that deep DVAs did not necessarily join deep ventricular veins. In fact, with juxtacortical, subcortical, and even periventricular sites, the DVA

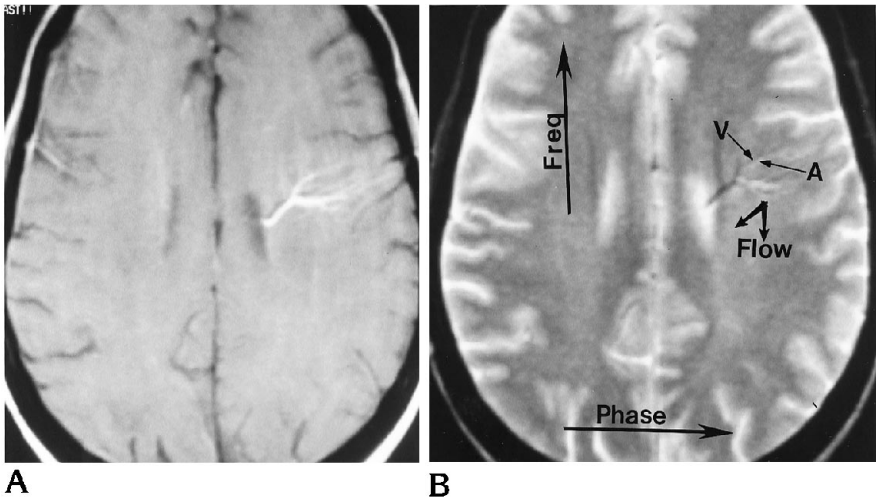

Fig 5. Subcortical DVA with deep draining vein. 30-year-old woman with a left frontal subcortical DVA that joins with the subependymal veins at the mid-body of the left lateral ventricle.

A, T1-weighted contrast-enhanced axial MR image shows caput converging on a dilated deep draining vein.

B, T2-weighted axial MR image shows flow phase-shift artifact (*A*) caused by the obliquely oriented vein (*V*) of the caput. The artifact is not seen well with the collector or draining vein itself. Phase- and frequency-encoding is labeled to show that the bright line artifact (*A*) is displaced posterior to the flow void of the vein (*V*) in the direction of frequency encoding, indicating that the direction of flow (*arrows*) in the DVA is posteriorly directed along the direction of frequency encoding, and thus directed in a deep direction.

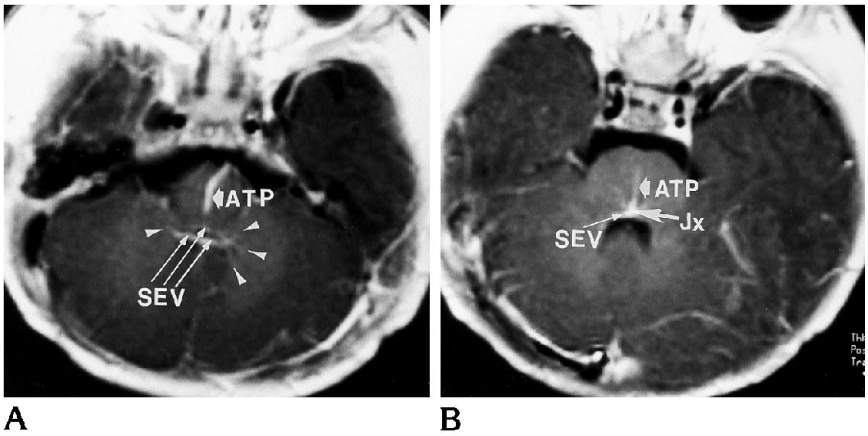

Fig 6. Deep DVA with deep draining vein. 4-month-old boy with bilateral, periventricular or deep DVAs located in the brachium pontis/dentate region with deep drainage to the subependymal veins of the fourth ventricle and then to the anterior transpontine vein.

A, T1-weighted contrast-enhanced axial MR image shows the bilateral caputs (*arrowheads*), enlarged subependymal veins (*SEV*), and enlarged anterior transpontine vein (*ATP*).

B, Higher T1-weighted contrast-enhanced axial MR image shows the junction (*Jx*) of the subependymal veins (*SEV*) with the anterior transpontine vein (*ATP*).

caput in each site joined either superficial or deep veins, with the majority joining deep veins at all three sites (Fig 1).

A review of the normal medullary venous anatomy can illustrate the characteristic sites of DVAs and their draining veins. Supratentorial, normal medullary veins are divided into two groups: superficial medullary veins, which are short venous channels in the white matter about 1 to 2 cm below the gray matter and drain to the cortical surface, and deep medullary veins, which are longer venous channels in the white matter just below the superficial group and drain toward the lateral ventricle. There is also a third group, which completely traverse the cortex to the ventricular veins, called *intracerebral anastamotic* or *transcerebral* veins (16). These transcerebral veins allow a superficially located DVA to drain deep to the ependymal veins, and allow a periventricular DVA to drain to the cortical veins (Fig 7). The supratentorial, superficial draining veins join with cortical or hemispheric veins and eventually drain to the superior sagittal sinus.

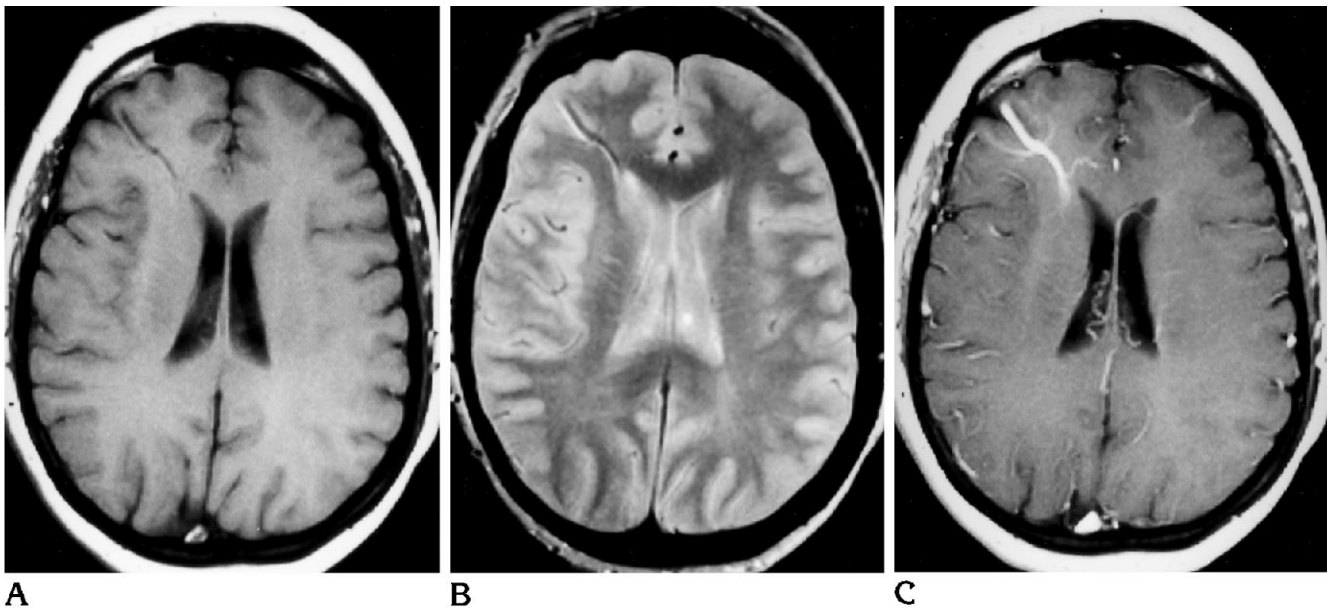

Fig 7. Deep DVA with superficial draining vein. Comparison of unenhanced T1-weighted (*A*) intermediate T2-weighted (*B*), and contrast-enhanced T1-weighted (*C*) MR images of a left frontal deep DVA. Portions of the caput are seen best on the contrast-enhanced T1-weighted image (typical caput is seen better on next higher image, not included). The collector vein is seen well in all images, probably because of its large size. Despite the caput's not being seen on unenhanced T1- and T2-weighted images, DVA is the most likely diagnosis because of the markedly enlarged medullary vein. However, differentiation from an AVM may be difficult without contrast imaging.

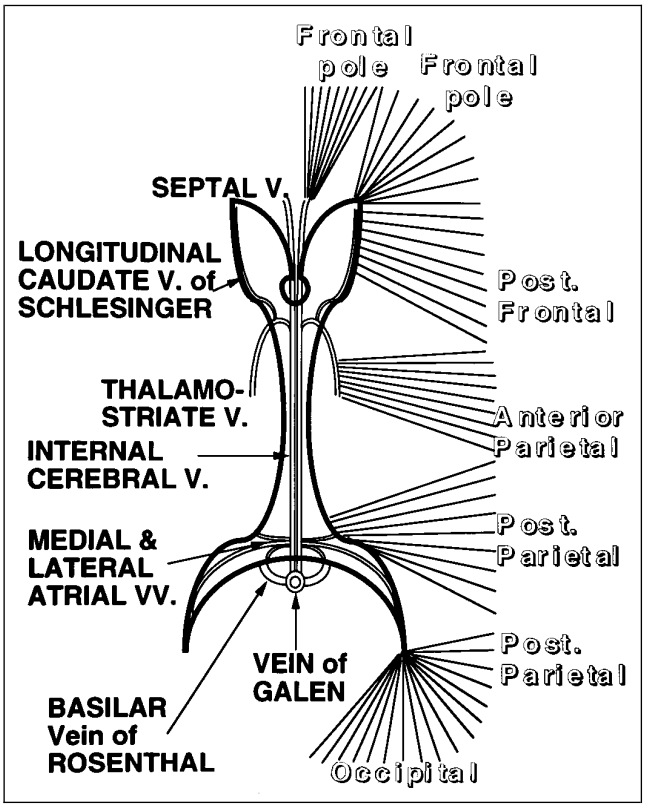

Fig 8. Drawing of the normal supratentorial medullary and subependymal venous anatomy in the axial plane.

The supratentorial deep medullary veins converge on the lateral ventricle in a wedge-shaped or fanlike pattern clustering typically on the anterolateral corner of the frontal horn, the head and body of the caudate nucleus or mid-body of the lateral ventricle (longitudinal caudate vein of Schlesinger), the temporal horn, the trigone, and the occipital horn. The veins converging on the frontal horn then drain to the vein of the septum pellucidum, those of the mid-body drain to the striothalamic vein and lateral subependymal vein, those of the temporal horn drain to the lateral atrial and inferior ventricular subependymal veins, those of the trigone drain to the medial and lateral atrial subependymal veins, and those of the occipital horn drain to the medial and lateral atrial subependymal veins (16). One of the subependymal veins that may be enlarged with DVA is the longitudinal caudate vein of Schlesinger, which parallels the walls of the lateral ventricle. Eventually, all these drain into the internal cerebral vein and thus the vein of Galen (Fig 8). Therefore, one would expect to find enlarged veins at these points of convergence, and for the caputs to be located adjacent to these. Accordingly, we found the supratentorial, deep or periventricular DVA caputs to be located at the frontal horn, the mid-body of the lateral ventricle, the temporal horn, the trigone, and the occipital horn, with their veins draining to the same site.

Infratentorial medullary venous anatomy likewise can be divided into superficial and deep draining groups (3). The anterior superficial draining veins empty into the hemispheric veins of the cerebellar hemisphere and then into the petrosal sinuses. The posterior, superficial draining veins empty into the vermian veins and then into the transverse sinus or torcula (17). The deep medullary veins of the cerebellum converge on the corners of the fourth ventricle on the dentate nucleus and brachium pontis. These veins then drain into the subependymal veins of the fourth ventricle, which then drain either into the vein of the lateral recess of the fourth ventricle (Fig 2) or anteriorly through the transpontine veins, which penetrate the substance of the pons (Fig 6). The principal transpontine vein is a midline vein draining the floor of the fourth ventricle. This vein penetrates the pons anteriorly at the junction of the pons with the medulla and is referred to as the *anterior transpontine vein*. A more laterally located vein is referred to as the *lateral transpontine vein* (3, 18–20). Eventually, the transpontine veins drain into the pontomesencephalic vein, and ultimately into the galenic system. Another pathway for deep drainage runs superiorly to the precentral cerebellar vein and eventually into the vein of Galen. The veins of the lateral recess of the fourth ventricle, on the other hand, drain into the petrosal sinuses. Goulao et al (17), however, include these veins with the group of deep drainers of the fourth ventricle (Fig 2). Another prominent transcerebral deep-draining medullary vein is a longitudinally oriented one within the tegmentum of the pons and midbrain, paralleling the course of the aqueduct. This is referred to as the *longitudinal intrategmental vein*, which may drain AVMs or DVAs of the pons or medulla (3, 19). This vein then drains to lateral pineal veins and eventually into the vein of Galen. We found infratentorial deep DVA caputs and their draining veins to be located in the periventricular, brachium pontis/dentate nucleus regions draining mainly into the deep venous system, with the vein of the lateral recess of the fourth ventricle being the most commonly involved, followed by the anterior

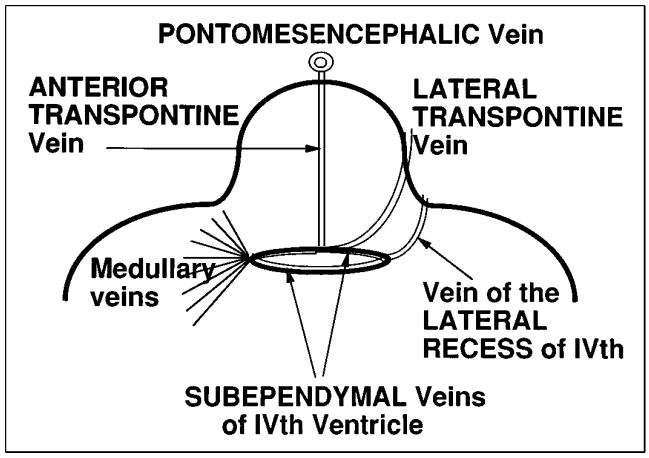

Fig 9. Drawing of the transpontine and lateral recess of the fourth ventricle venous anatomy in the axial plane.

transpontine vein and the lateral transpontine vein (Fig 9). We found only two subcortical, infratentorial DVAs that were adjacent to the brachium pontis/dentate region, and no juxtacortical superficial DVAs in the posterior fossa.

In all our cases, both the caput medusae and the draining vein were seen best on contrast-enhanced T1-weighted images. Most of the DVAs and draining veins could not be appreciated on the unenhanced T1-weighted images unless they were large. Some of the DVAs and draining veins could also be seen on T2-weighted images as flow voids or as flow phase-shift artifacts (Figs 1, 5, 7). Generally, the draining vein was seen more often than the caput on T2-weighted images (Fig 7). Small DVAs were not seen as easily. Some of the draining veins appeared hyperintense on the T2-weighted images, which may be explained by slow flow and even-echo rephasing.

The flow-phase shift artifact occurs because of the finite time delay between the frequency- and phase-encoding gradients, and can be seen well only in vessels oriented obliquely to these gradients (21). By the time the phase-encoding steps have been performed, flowing blood has moved from where it was when frequency-encoding occurred. This produces a shift seen as a bright white line parallel to the flow void of the vessel, which appears as a black line. Thus, there appear to be alternate bands of white and dark. The direction of flow within the vessel can be predicted by the location of the bright artifact that is shifted in the same direction as the flow. This is also termed *upstream spatial misregistration*. The bright artifact is shifted in front of the vessel along the axis of frequency encoding if the flow of the vessel is directed anteriorly, and behind the vessel if the flow is directed posteriorly. If the vessel is oriented perpendicular and oblique to the plane of imaging, then the bright artifact is seen as a dot, but may be missed because it is small. Flow enhancement, even-echo rephasing, and gradient-moment nulling contribute to the production of this bright signal. Because most MR imagers use some form of motion or flow compensation or gradient-moment nulling, this flow-phase shift artifact should be seen in obliquely oriented DVAs. The gradient-moment nulling itself also causes spatial misregistration and thus shift, but is seen better on the first than on the second echo (21).

In DVAs with two draining veins, the direction of flow was difficult to ascertain on routine MR images (Fig 1). In DVAs with veins joining both superficial and deep veins, it was difficult from conventional MR images alone to determine whether drainage occurred in both directions. Direction of flow can be determined more definitively with angiography or phase-contrast MR angiography. None of the DVAs was seen on the two-dimensional time-of-flight MR angiogram, either because they were too small or because they were not included in the field of view, since the MR angiogram was obtained for reasons other than verification of the presence of DVA.

In patients with complicated DVAs in whom hemorrhage or a cavernous angioma is seen on T2-weighted images, contrast-enhanced T1-weighted images should be obtained with thin sections in all planes in order to show the typical caput medusae radiating from the terminal or draining vein. MR venography and conventional angiography should be used if the size of the DVA and its draining vein needs to be known.

In conclusion, MR imaging has shown that DVAs are the most common vascular anomaly in the central nervous system to date. Contrast-enhanced MR images can clearly show the caput medusae and direction of the venous drainage. It is the orientation of the DVA and the imaging plane that determine whether the typical caput medusae appearance will be seen. DVAs and their draining veins occur in characteristic sites that can be predicted if the normal medullary venous anatomy is known. We found that superficial DVAs do not necessarily join with superficial cortical veins or sinuses, and that deep DVAs do not necessarily join with

ventricular subependymal veins. We could not predict from the size of the DVA or its location which veins (superficial or deep) the DVA would join.

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