Anatomy of Intracranial Veins

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KEYWORDS

• Veins • Cerebral • Dural sinuses • Deep venous system • Emissary veins

KEY POINTS

- The cranial venous system is complex and extensive.
- Familiarity with cerebral embryology helps understand cerebral venous anatomy.
- Significant redundancy exists regarding cerebral venous pathways.
- Several pathophysiological processes may result from alterations in cerebral venous integrity.

INTRODUCTION

The intracranial venous system drains the cerebrum, brainstem, eyes, meninges, and part of the face. In addition, the cerebrospinal fluid (CSF), which is reabsorbed in part by the arachnoid granulations, is returned to the bloodstream via the cerebral dural sinuses that drain extracranially into the internal jugular veins primarily.[1,2] Therefore, the integrity of the cerebral venous system plays a crucial role in brain homeostasis by eliminating metabolic waste and deoxygenated blood, and contributes directly to the healthy perfusion of cerebral tissue.

Unlike dural sinuses that are contained by the 2 dural layers (periosteal and meningeal), cerebral veins are valveless and have thin walls that do not contain muscular tissue. While cortical veins are mostly located within the subarachnoid space, deep medullary and transmedullary veins lie within the cerebral white matter and its contained CSF spaces.[3] Intracranial veins are primarily categorized as superficial or deep. Superficial venous structures mainly include the superior sagittal sinus and the cortical veins, with major superficial interconnecting anastomosing veins, that is, the veins of Trolard and Labbé. The deep venous system drains primarily into the paired internal cerebral veins and the basal veins of Rosenthal, which join into the midline vein of Galen and drain into the straight sinus, then the transverse and sigmoid sinuses, and eventually into the internal jugular veins. Although considered separately in some textbooks, the veins of the posterior fossa are intimately related to the remainder of the cerebral venous system, and are also generally categorized as superficial and deep veins of the cerebellum and the brainstem. The general arrangement of the cerebral venous system is overall established and predictable; however, numerous variations exist, some of which can lead to clinical consequences.

Embryology of the Cerebral Venous System

Most of the current understanding of human brain embryology may be derived from the works of George Linius Streeter and Dorcas Hager Padget

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who studied large numbers of human embryos ranging in size between 4 mm and 80 mm at the Carnegie Institution of Washington, in Washington, DC and in Baltimore, MD (at the Johns Hopkins Carnegie department of Embryology). Between 1917 and 1940, Streeter, a physician, and anatomist, directed the department of Embryology at the Carnegie Institution of Washington. Later, Padget, who started her career as a medical illustrator in Walter Dandy's Neurosurgery department at Johns Hopkins University, Baltimore, became a scientific researcher at the Carnegie Institution whereby she made remarkable contributions.[4] The enormous work of those 2 pioneers laid the ground for modern embryologic concepts of cerebral vasculature (and many cerebrovascular anomalies).

The first identifiable cerebral venous structure is the primary head vein (Fig. 1), identified in the early embryo (5–8 mm) as a cephalad continuation of the cardinal vein (the anterior portion of which will become the internal jugular vein), which consists of a single layer of endothelial cells.[5] The head vein (the combination of the vena capitis medialis, the vena capitis lateralis and the posttrigeminal vein) gives rise to a continuous primitive meningeal venous plexus that drains the brain through three stems (anterior, middle and posterior).[6] The ventral pharyngeal vein (the sole ventral projection of the head vein) later gives rise to the primitive maxillary vein, which lies medial to the primitive trigeminal ganglion and later contributes to the cavernous sinus (Fig. 2).

Around the 11 to 14 mm stage, lateral dural sinuses develop, which drain the brain through primitive pia-arachnoid vessels as the mesenchyme around the brain gives off the lateral and basal dural coverings and the chondrocranium at the skull base (see Fig. 2). The anterior and middle venous plexi merge to form the embryonic "tentorial plexus" while the posterior plexus becomes the occipital plexus. The choroid plexus then develops fast—faster than the cortical mantle—and drains first into the inferior choroidal vein, then into the superior choroidal vein after the primitive internal cerebral vein develops in relation to small midline thalamus. Later, the thalami become paired, as do both internal cerebral veins, which then fuse posteriorly to form the vein of Galen and the straight sinus.

By the 17 to 20 mm stage, posterior (sigmoid, tentorial, and marginal) sinuses are formed (Fig. 3), while the 2 anterior components of the primitive venous plexus start to involute and form the pro-otic sinus (a stem of the middle dural plexus that connects to the posterior plexus via the sigmoid sinus).[5,7,8]

At the 40 mm stage, the cavernous sinuses form as medial extensions of the pro-otic sinus, which is continuous with the inferior petrosal sinus;

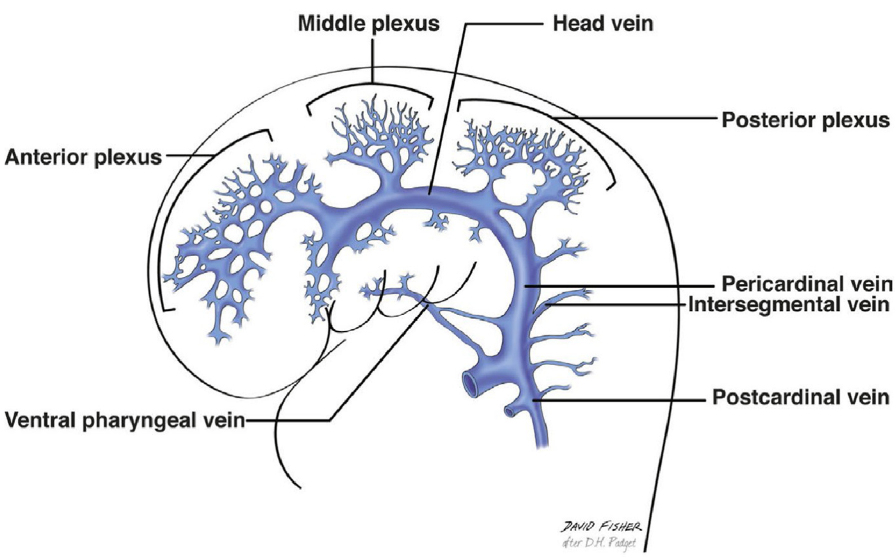

Fig. 1. Dural venous sinus development at day 28, approximately 4–6 mm. The head vein, the cephalad continuation of the cardinal vein, gives rise to a continuous venous plexus of the meninges, which drains all portions of the head. The anterior plexus relates to the diencephalon and mesencephalon, the middle plexus is related to the cerebellum and the posterior plexus is related to the occipital and upper neck regions. (*From* McBain L, Goren O, Tubbs RS. The Embryology of the Dural Venous Sinus: An Overview (Chapter 1), Anatomy, Imaging and Surgery of the Intracranial Dural Venous Sinuses. 2020, Pages 1-7.)

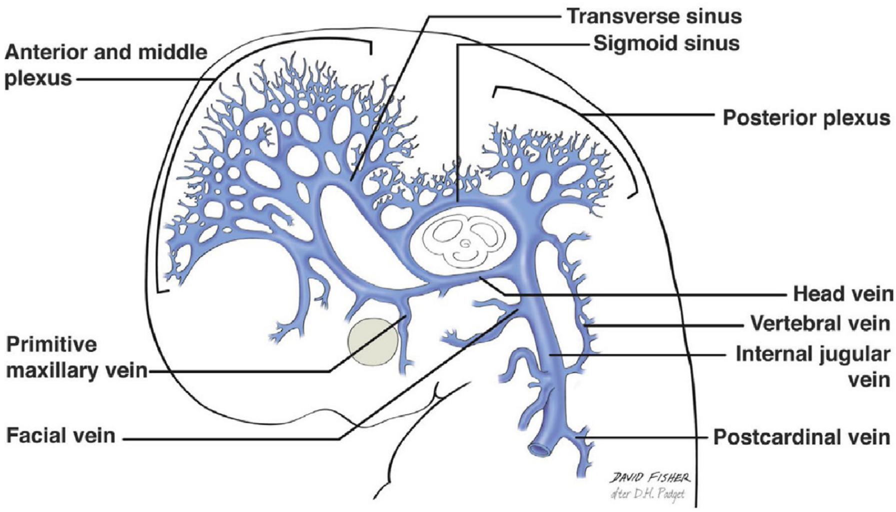

Fig. 2. In the 18 mm embryo, the middle and posterior plexi merge, resulting in forming the sigmoid sinuses posteriorly. The cerebellum and posterior midbrain drain into the posterior plexus. The cavernous sinuses and the pro-otic sinus start forming from the middle plexus. The drainage of the cavernous sinus is through a stalk of the middle plexus, which will give rise to the superior petrosal sinus. (*From* McBain L, Goren O, Tubbs RS. The Embryology of the Dural Venous Sinus: An Overview (Chapter 1), Anatomy, Imaging and Surgery of the Intracranial Dural Venous Sinuses. 2020, Pages 1-7.)

laterally, the pro-otic sinus anastomoses with a primitive temporal emissary vein to form the petrosquamous sinus. By the 60 to 80 mm embryonic stage, the superior and inferior sagittal sinuses are formed, while posterior (sigmoid, transverse, tentorial) sinuses move backward to their permanent configuration (**Fig. 4**). The otic capsule promotes the development of the superior petrosal sinus, while the pro-otic sinus remains continuous with the petrosquamous sinus.[7,8] Laterally, the petrosquamous sinus and pro-otic sinus remnants are later destined to involute as diploic veins that drain

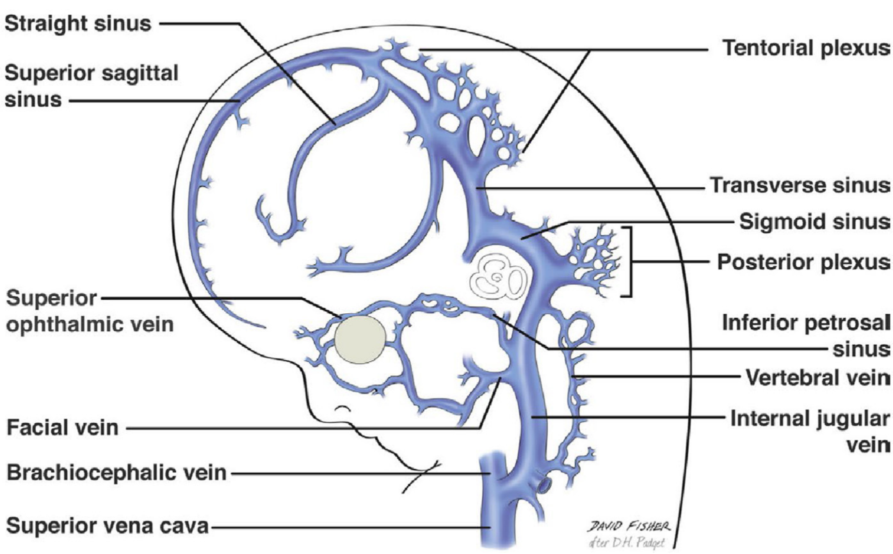

Fig. 3. In the 50 mm embryo, major supratentorial dural sinuses are formed. The growth of the cerebellum promotes the readjustment of the tentorial plexus and the neighboring superior petrosal sinus and posterior fossa veins. The dura mater becomes separated into 2 layers with intervening areolar tissue from which meningeal vessels form. *(From* McBain L, Goren O, Tubbs RS. The Embryology of the Dural Venous Sinus: An Overview (Chapter 1), Anatomy, Imaging and Surgery of the Intracranial Dural Venous Sinuses. 2020, Pages 1-7.)

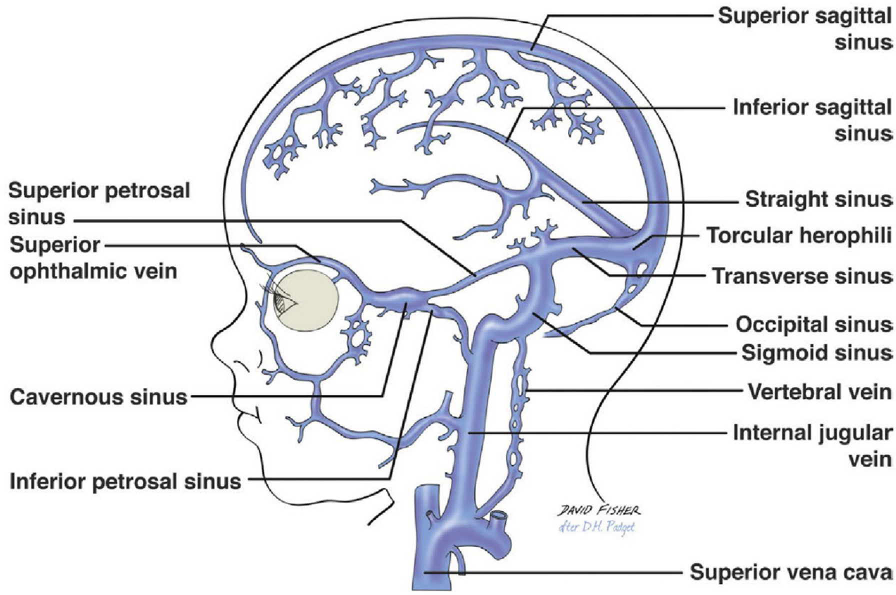

Fig. 4. In the 80 mm embryo (16th–20th weeks), the dural sinuses are formed. The torcular Herophili forms from a remnant of the embryonic tentorial plexus to connect the medial extensions of both transverse sinuses to the superior sagittal sinus. The deep venous (Galenic) system develops to increasingly drain the diencephalons instead of the primitive tentorial sinus. The cortical vein network is gradually formed. Of note, the superior and inferior anastomotic veins (veins of Trolard and Labbe) form beyond 3 months, as they are not primary venous structures. (*From* McBain L, Goren O, Tubbs RS. The Embryology of the Dural Venous Sinus: An Overview (Chapter 1), Anatomy, Imaging and Surgery of the Intracranial Dural Venous Sinuses. 2020, Pages 1-7.)

meningeal structures via the foramen ovale. Medially, the primitive tentorial sinus also involutes after the superior petrosal sinus has formed and is connected to the cavernous sinus.[5,7,8] Variations may occur in the form of emissary channels as a result of incomplete involution of those venous structures, lateral and medial.

Cerebral Venous System Classifications

A number of existing classifications of cerebral veins exist, each with their own individual merit, whether focused on anatomic dissections,[9] embryologic development,[7] scientific terminology,[10] neuroradiology,[11] neuroangiography,[12–14] neurosurgery,[15–19] or 3D modeling.[20] MR imaging mapping of intracranial veins using quantitative susceptibility mapping (QSM) to estimate venous oxygen concentration has also been described as a way to render 3-dimensional venograms along with physiologic information on oxygen extraction fraction (OEF).[21]

Those classifications have in common the general categorization into superficial (cortical) veins and dural sinuses, deep veins, and posterior fossa veins. The emissary veins and the diploic venous system, not commonly mentioned in most classifications, also have clinical and physiologic significance.

Considerable variations in cerebral venous anatomy exist between individuals, and between cerebral hemispheres within the same individuals. In addition, anatomic descriptions vary between textbooks. Similar to the concept of "angiosome," that is, the territory subserved by a specific feeding artery, the concept of "venosome" was developed to refer to anatomic territories that are drained by specific veins.[22]

Superficial Venous System

A sufficiently detailed description of cerebral veins follows, although a completely thorough description of the intracranial venous system falls beyond the scope of this review.

Dural sinuses

The dural sinuses may be paired or unpaired. Major paired sinuses include the transverse, sigmoid, superior petrosal, inferior petrosal, cavernous and sphenoparietal sinuses; the basilar venous plexus may be added to that list (Figs. 5 and 6). Major unpaired dural sinuses are the superior sagittal sinus (SSS), the inferior sagittal sinus (ISS), the straight sinus, the occipital sinus, and the intercavernous sinus (Fig. 7). The dural sinuses are also discussed elsewhere in this issue (see Morris, et al), and Joseph and colleagues have provided a detailed

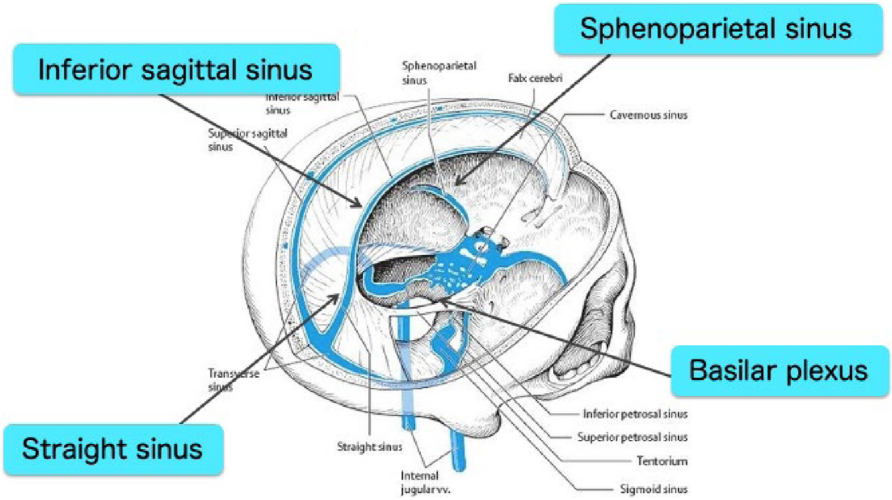

Fig. 5. Major dural sinuses. The superior and inferior sagittal sinuses run at the upper and lower edges of the falx cerebri. The cavernous sinuses are connected in the midline via intercavernous channels and connect laterally to the sphenoparietal sinuses. Note the basilar plexus lies on top of the clivus and connects posteriorly to the superior petrosal sinuses.

discussion of anatomic variants of the dural sinuses.[23]

The cavernous sinus receives blood from the superior and inferior ophthalmic veins, the sphenoparietal sinus, and the superficial middle cerebral vein (MCV). Numerous midline intercavernous communications are present normally (see Fig. 7). The cavernous sinus communicates posteriorly with the transverse/sigmoid sinus junction via the superior petrosal sinus, and inferiorly through the inferior petrosal sinus, which drains the auditory canal veins and ends in the internal jugular vein (IJV).

In case of sinus occlusion, numerous anastomotic channels may become functional to facilitate venous drainage (Fig. 8).

Superficial cerebral veins

Cortical veins drain the superficial subterritory of the brain which is supplied by cortical arteries and their perforating distal rami outside of the internal border zone that separates the deep cerebral territory, supplied by perforating lenticulostriate arteries.[24] Large eponymous anastomotic veins (veins of Trolard and Labbé) drain into the superficial middle cerebral vein (MCV), which

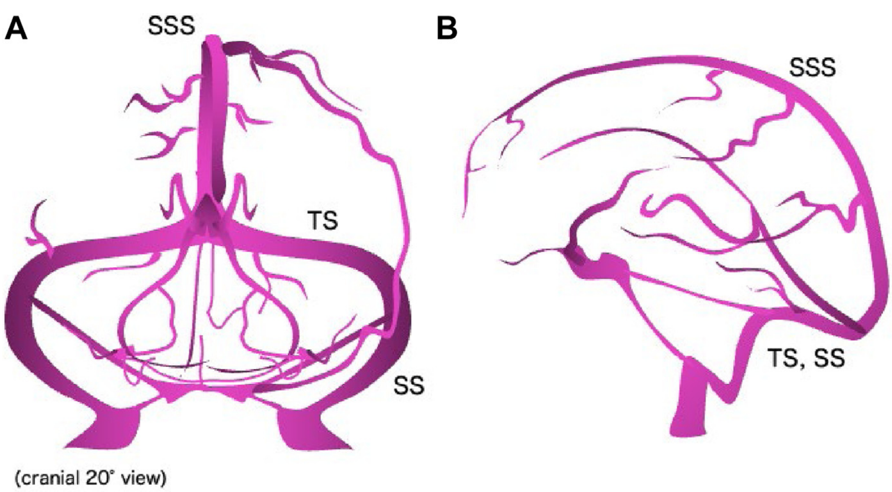

Fig. 6. Major dural sinuses anteroposterior (*A*) and lateral (*B*) views: the superior sagittal sinus (SSS) is midline, unpaired, and drains most of the blood of both hemispheres; the paired transverse (TS) and sigmoid (SS) sinuses drain cerebral venous blood into the paired internal jugular veins.

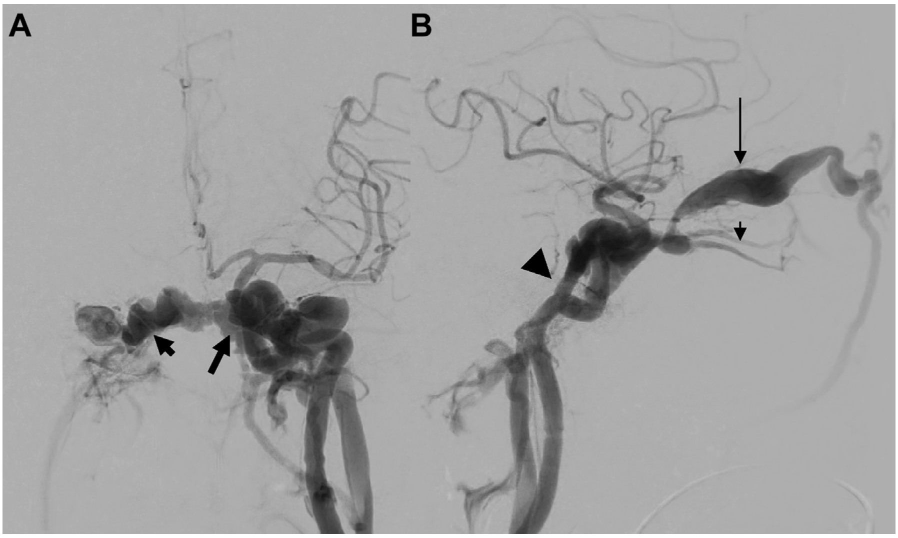

Fig. 7. (*A*, *B*) Early angiographic opacification of both cavernous sinuses in a patient with a carotid-cavernous fistula. Left internal carotid artery angiogram, antero-posterior view (*A*) shows early venous filling of the left cavernous sinus (*A*, *long thick arrow*) with near-immediate filling of the right cavernous sinus (*A*, short *thick arrow*) through midline intercavernous anastomoses. Lateral view of left carotid angiogram, early arterial view shows early filling of a massively dilated superior ophthalmic vein (*B*, *long thin arrow*) and duplicated inferior ophthalmic veins (*B*, *short thin arrow*), and dilated inferior petrosal sinus (*B*, *large arrowhead*).

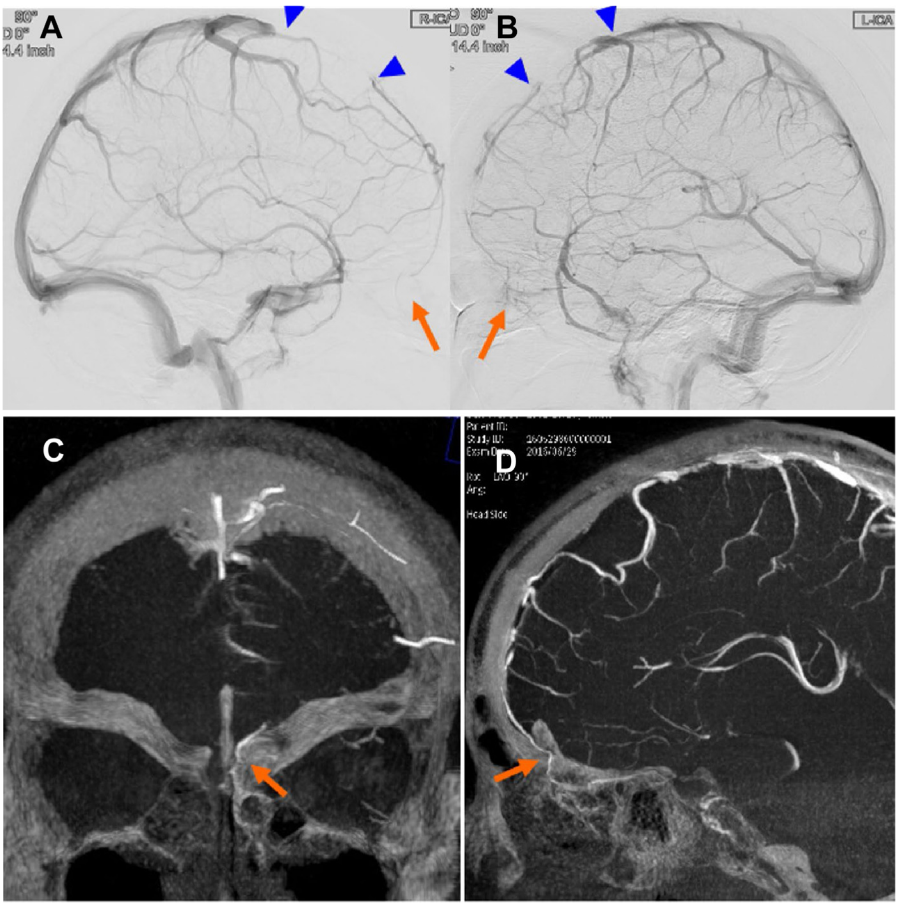

Fig. 8. (*A–D*) Superior sagittal sinus occlusion noted on the venous phase of right (*A*) and left (*B*) internal carotid artery angiograms (*blue arrowheads*); a small anterior skull base vein (*orange arrows*) is noted. CTA, coronal (*C*), and parasagittal (*D*) reconstructed images allow to characterize a bridging vein of the cribriform plate (*orange arrows*).

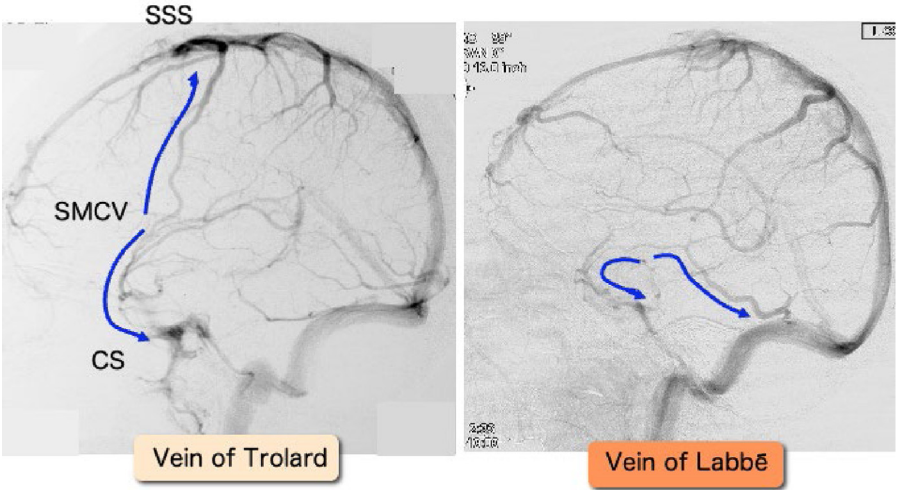

Fig. 9. (*A*, *B*) Lateral views of carotid artery angiograms, venous phase, show cortical veins and major anastomotic veins. The vein of Trolard (*A*) connects the superior sagittal sinus (SSS) to the superficial middle cerebral vein (SMCV) which eventually drains into the cavernous sinus (CS). The vein of Labbé (*B*) connects the posterior aspect of the SMCV to the sigmoid sinus.

drains into the cavernous sinus (**Fig. 9**). The vein of Labbé may originate from the posterior aspect of the MCV (**Fig. 10**).

All other hemispheric cortical veins are organized as several groups of cortical bridging veins that are fed by multiple small superficial veins of the surface of the medial and lateral surfaces of the frontal, parietal and occipital lobes, which eventually drain into the SSS at an acute angle[25] and with some degree of tortuosity (**Fig. 11**).[26] Large veins that course within the subarachnoid space are superficial to companion arteries, while subpial veins run under their corresponding arteries.[27] Although identical in terms of structure and function, cortical veins have been differentiated by Padget into a mediodorsal group that drains into the superior and inferior sagittal sinuses, and a posteroinferior and lateroventral group that drains into the transverse and cavernous sinuses.[7] Cortical veins are valveless, have thin walls with a minimal muscular layer and course through the subarachnoid space and the meningeal dural layer to reach dural sinuses (see **Figs. 9–11**).[25–27] Because of their thin walls and relationship to dural sinuses, large cortical veins may collapse when the intracranial pressure is elevated, leading to ischemia. Sadighi and colleagues have provided a detailed discussion of anatomic variants of the cerebral veins.[28]

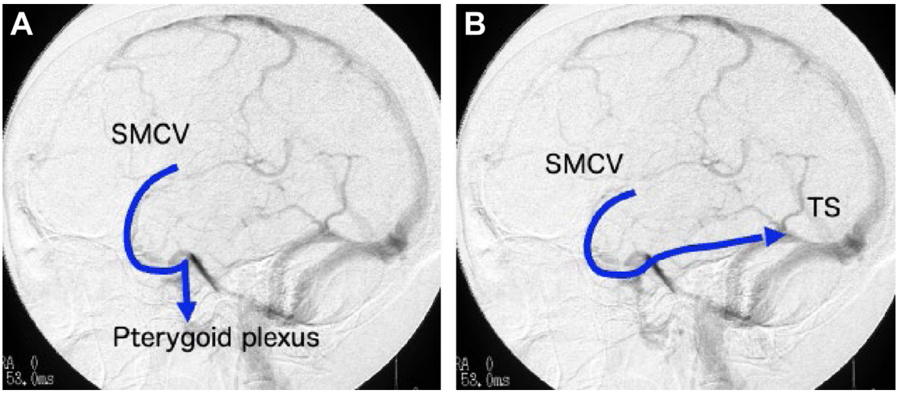

Fig. 10. (*A*, *B*) Lateral views of carotid artery angiograms, venous phase, show cortical veins. Alternate routes of SMCV extracranial drainage are seen whereby the SMCV drains inferiorly into the pterygoid plexus in a sphenobasal pattern (*A*, *blue arrow*), and whereby the SMCV drains posteriorly into the transverse sinus in a sphenopetrosal pattern (*B*, *blue arrow*).

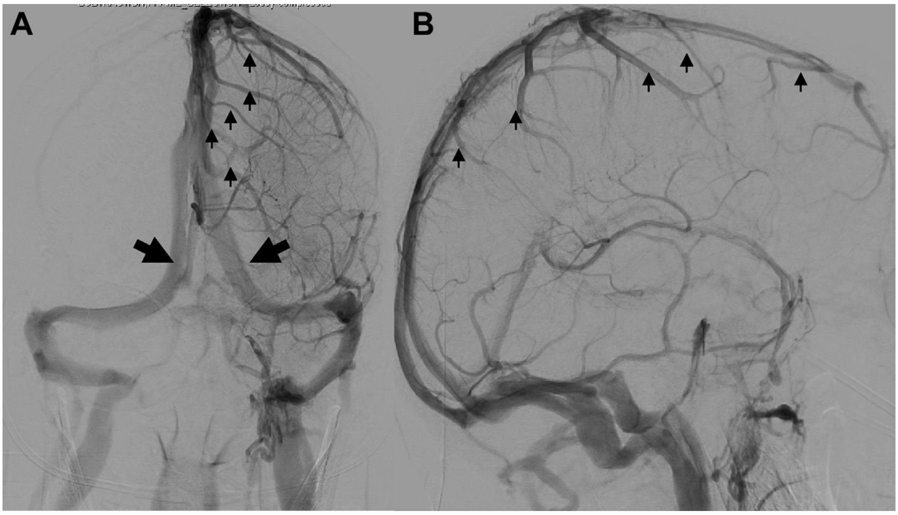

Fig. 11. (*A*, *B*) Cortical veins. Left internal carotid artery angiogram, anteroposterior (*A*) and lateral (*B*) views, late venous phase, show cortical veins draining into the superior sagittal sinus at an acute angle (*small arrows*). Note a duplicated posterior aspect of the superior sagittal sinus (*large arrows*). An incidental right mastoid emissary vein is also present.

Deep Venous System

In the early embryo, the venous drainage of deep cerebral structures is exclusively centrifugal in the direction of the maturing encephalon. Such deep drainage is via medullary veins, which have long been identified and well described by Duret in 1874.[29] As the diencephalon, telencephalon, and the ventricular system gradually develop, centripetal venous flow toward the increasingly structured deep venous system starts to develop (**Fig. 12**).[30] This leads to the dual configuration of a deep cerebral venous system which drains deep gray matter and deep and periventricular white matter blood through medullary veins in a centripetal fashion toward the subependymal veins, the internal cerebral veins and the basal vein of Rosenthal, then the vein of Galen, while venous flow within superficial medullary veins moves centrifugally toward pial (transcortical) veins, then into cortical veins, eventually draining into the dural sinuses. Importantly, connecting channels are interposed between deep and superficial medullary venous networks in the form of anastomotic medullary veins and transcerebral veins (**Fig. 13**).[31] Deep medullary veins may reach subependymal veins either directly or via collecting veins,[32] the largest and most recognized being the longitudinal caudate vein of Schlesinger,[33] the embryologic origin of which is the subependymal glial substance of the germinal matrix; this vein is continuous in the fetal brain and may remain so in the adult brain (**Fig. 14**).

The general arrangement of medullary veins, although related to deep perforating arteries, appears to primarily follow the organization of white matter tracts in their various directions, whether commissural, association, or projection fibers.[34]

Medullary vein flow disposition has clinical implications: for instance, various patterns of cerebral venous thrombosis, particularly in neonates and children result from this anatomic arrangement, especially as transmedullary venous flow remains bidirectional in infants (see **Fig. 13**).[35]

The main venous collector of the deep venous system is the vein of Galen, which may be likened to a "hub." Medullary veins radiate from the internal border zone to drain into subdependymal and thalamostriate veins, eventually draining via the 2 main components of the deep venous system: the paired internal cerebral veins and basal veins of Rosenthal, which join in a confluence at the level of the vein of Galen and then drain into the straight sinus and the confluence of the sinuses (torcular Herophili). The deep venous system also includes tributaries of the inferior sagittal sinus. Medullary veins may serve as major collaterals in case of occlusion of a major deep vein, which may result in marked enlargement (**Fig. 15**).

A - The internal cerebral vein (ICV) courses through the roof of the third ventricle in the velum interpositum. The ICV is a marker of midline shift, such that a deviation from the midline of 2 mm or more is considered abnormal.

The internal cerebral veins and their tributaries constitute the transcerebral venous system which

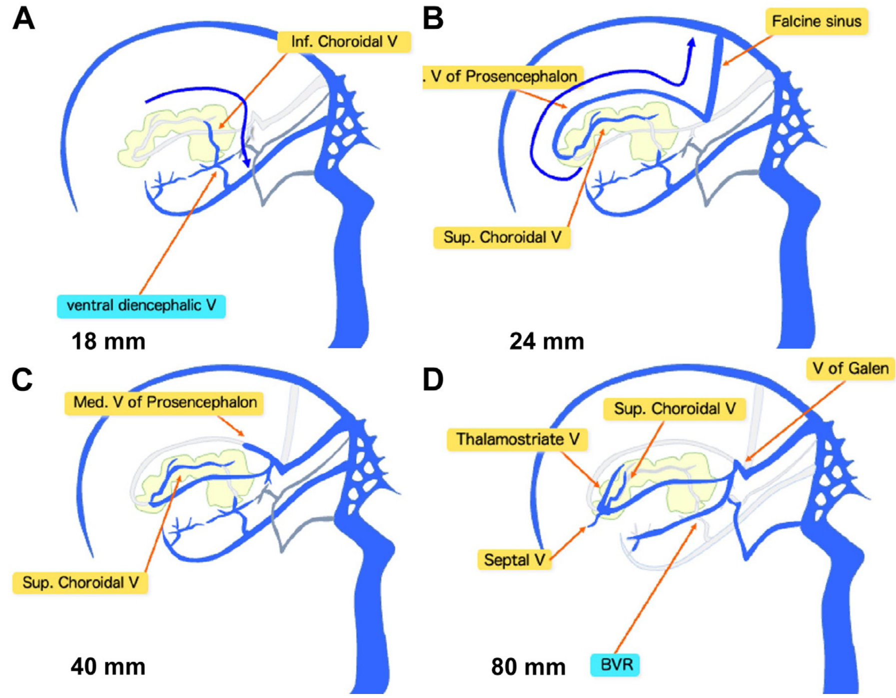

Fig. 12. (*A–D*) Embryologic development of the deep venous system. (*A*): in the 18 mm embryo, the ventral diencephalic vein and the inferior chroroidal vein drain into the tentorial sinus; (*B*): 24 mm embryo: superior choroidal vein continues as a vein of prosencephalon, drains into falcine sinus, while the tentorial sinus continues to drain diencephalic structures; (*C*): 40 mm embryo: regression of the vein of the prosencephalon, leaving the medial vein of the prosencephalon (vein of Markowski) which continues as falcine sinus; (*D*): 80 mm embryo: final configuration: septal and thalamostriate veins, and basal vein of Rosenthal are formed, join the vein of Galen and drain into the straight sinus; at this stage, both the falcine and tentorial sinuses should have regressed.

may be divided into 3 groups, the medial and lateral subependymal venous groups, and the choroidal and thalamo-callosal group. The medial subependymal group collects the septal, posterior septal, and medial atrial veins (Fig. 16), the lateral subependymal group collects the anterior caudate, longitudinal caudate (vein of Schlesinger), thalamostriate, transverse caudate, direct lateral, terminal, and the inferior ventricular veins (Fig. 17). Lastly, the choroidal and calloso-lateral

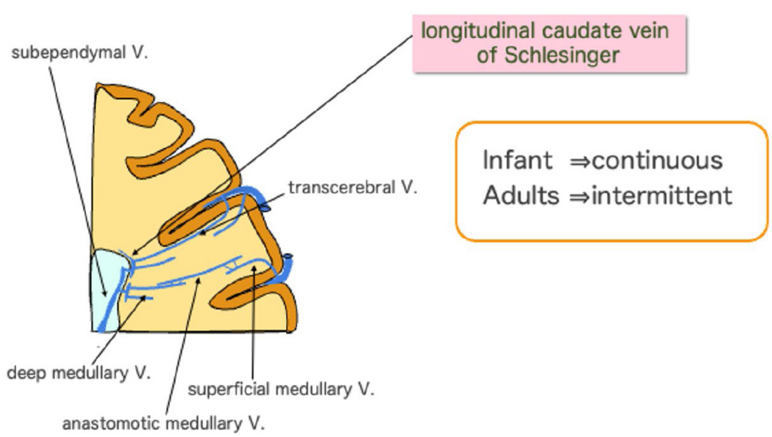

Fig. 13. Transcerebral venous system. Deep medullary and superficial medullary veins are connected by anastomotic medullary veins. Deep veins drain medially into subependymal (ventricular veins) while superficial veins drain into intracortical (transcerebral) veins. Note the longitudinal caudate vein of Schlesinger.

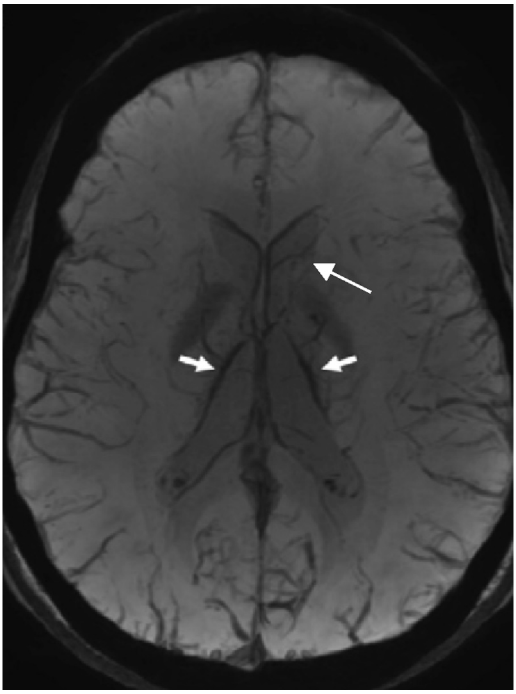

Fig. 14. Axial MR imaging SWAN MinIP (minimum intensity projection) shows dilated deep veins. Direct lateral veins (*short arrows*) and longitudinal caudate vein of Schlesinger (*thin long arrow*).

group collects the superior, inferior medial choroidal, third ventricular choroidal, direct lateral atrial, common atrial, superior thalamic, habenular, and the posterior pericallosal veins (Fig. 18).

B - The basal vein of Rosenthal (BVR), although considered one of the main components of the deep venous system, is actually superficial in location, as it runs over the inferior surface of the temporal lobes and midbrain. The BVR, therefore, collects blood from the basal part of medial encephalic structures, that is, frontal and temporal lobes, the diencephalon, and the midbrain. The BVR normally originates at the junction of the anterior cerebral vein, the deep middle cerebral vein, and the inferior striate veins, and terminates in the vein of Galen. The normal BVR has 3 segments: anteriorly, the striate segment collects the anterior cerebral, deep middle cerebral, and inferior striate veins, then the olfactory, posterior fronto-orbital, chiasmatic, and anterior communicating veins (Fig. 19). The middle (peduncular) segment, which follows the cerebral peduncle contour, then courses more laterally along the optic tract, collects the peduncular, inferior thalamic, inferior ventricular veins, and receives twigs from the optic tract, hypothalamus, and posterior hippocampus (Fig. 20); posteriorly, the mesencephalic segment starts distally to the lateral mesencephalic sulcus, collects the lateral pontomesencephalic vein (receiving blood from the anterior pontomesencephalic vein and the precentral cerebellar vein), tributaries from the atrial vein, the inferior temporo-occipital vein, then courses superiorly and posteriorly before joining to the ICV into the vein of Galen (Fig. 21). Although originally described in 1824 by the German anatomist Friedrich-Christian Rosenthal as a constant vein that terminates consistently into the vein of Galen,[14] it may occasionally be absent in case of incomplete regression of the tentorial sinus (Fig. 22),[36] and it has also been reported to drain into the superior petrosal sinus.[37]

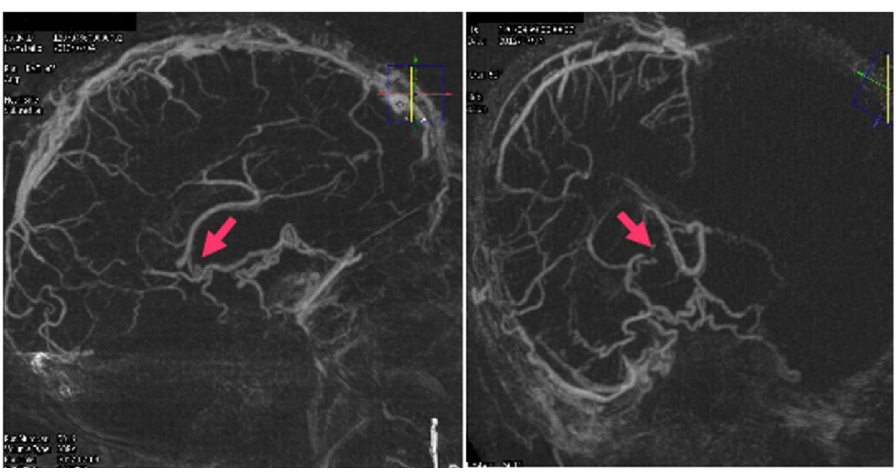

Fig. 15. Patient with an occluded Galenic system: deep venous drainage is via transcerebral veins into markedly dilated deep medullary veins (*red arrows*).

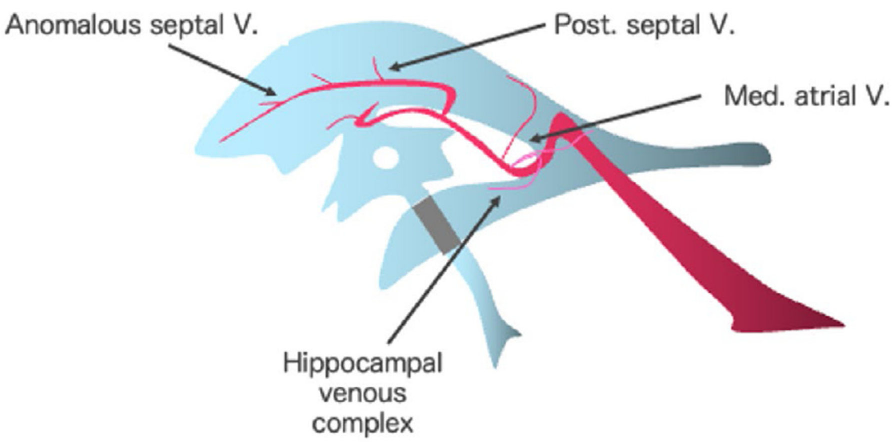

Fig. 16. Internal cerebral vein: Medial subependymal venous group mainly consists of anterior and posterior septal veins and medial atrial vein; note drainage of the posterior hippocampal veins into the posterior aspect of the vein.

Posterior Fossa Veins

Veins of the posterior fossa differ in their embryologic origin, as the brainstem derives directly from the neural tube while the cerebellum originates from the paired metencephalic plates. As a result, brainstem veins have a relatively simple geometric distribution, both longitudinal and transverse relative to the axis of the brainstem. Cerebellar veins, on the other hand, have a complex distribution that can be traced to the various stages of development of the vermis, the fourth ventricle, and the cerebellar hemispheres (**Fig. 23**).[38]

Veins of the Brainstem

The developing dura (meninx primitiva) is not organized, and only starts differentiating between various layers, that is, arachnoid, meningeal and parietal dura. In the 18 mm embryo (see **Fig. 2**), the meninx primitiva contains loose connective tissues that allow large vascular channels to develop. The paired ventral longitudinal veins, which run longitudinally on each side of the midline, are connected to each other by transverse veins that also connect to each other, more lateral longitudinal venous channels, that is, the anterior, middle,

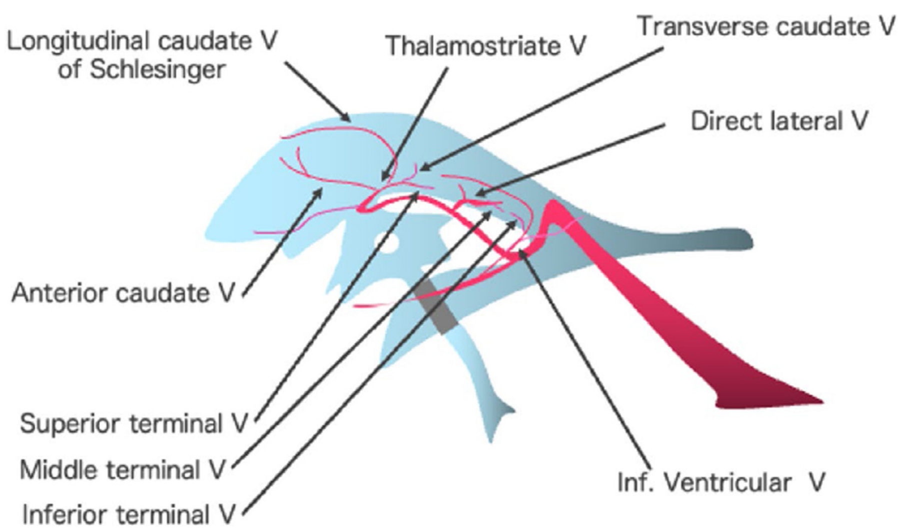

Fig. 17. Internal cerebral vein: Lateral subependymal venous group: Anterior caudate, longitudinal caudate (vein of Schlesinger), transverse caudate, thalamostriate, direct lateral, terminal (superior, middle, and inferior), and inferior ventricular veins.

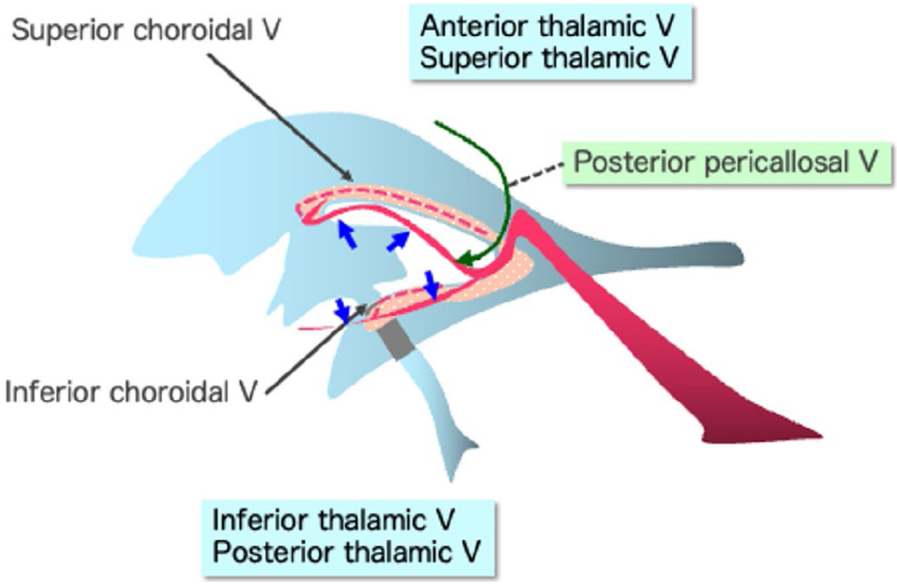

Fig. 18. Internal cerebral vein: Choroidal and calloso-lateral venous group: Superior and inferior medial choroidal veins, thalamic (anterior, posterior, superior, inferior) veins, third ventricular choroidal, direct lateral atrial, common atrial, habenular veins (not depicted), and posterior pericallosal veins.

and posterior dural plexi. The lateral longitudinal venous network demonstrates a distinct anatomic territorial distribution, that is, mesencephalic, metencephalic and myelencephalic. Blood flows always from transverse to longitudinal veins. The transverse veins drain major cranial nerve nuclei, that is, trigeminal, vagal, and hypoglossal (Fig. 24).

The main components of the longitudinal venous system are the anteromedian pontine vein, the anteromedian pontomedullary vein, and the anterolateral pontomedullary vein. Major transverse veins of the brainstem include the superior and inferior transverse pontine veins and the 3 transverse medullary veins (Fig. 25).

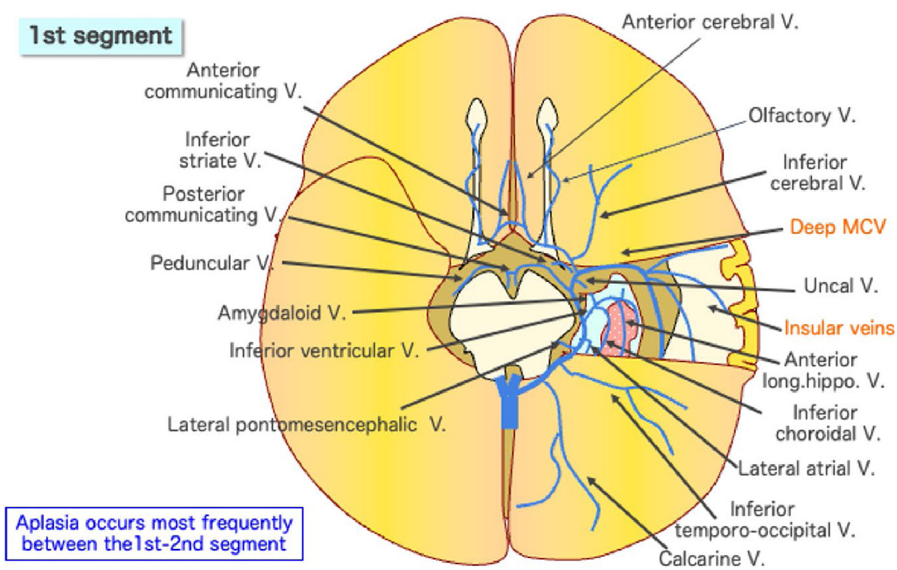

Fig. 19. Basal vein of Rosenthal: first segment. The striate segment collects the anterior cerebral, anterior communicating, inferior cerebral, deep middle cerebral and inferior striate veins, and the olfactory, posterior fronto-orbital, and chiasmatic veins.

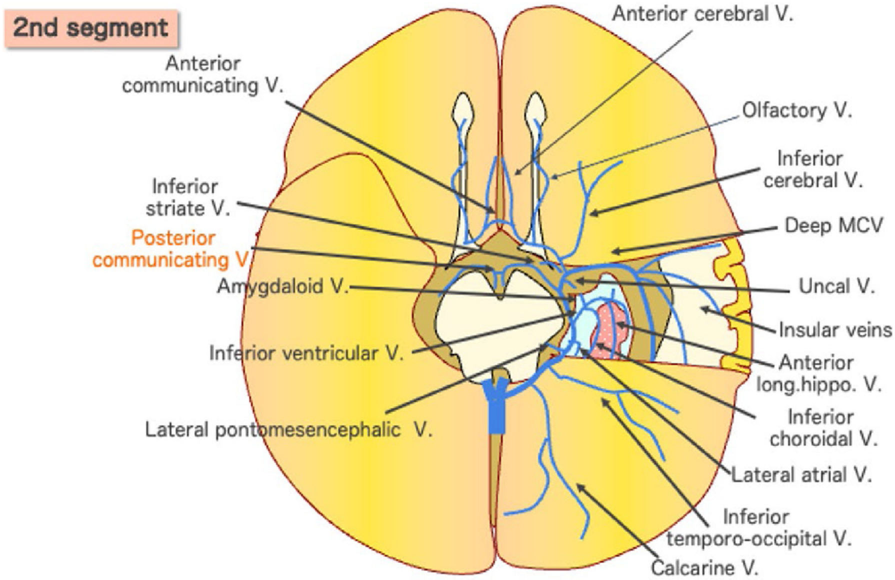

Fig. 20. Basal vein of Rosenthal: second segment. The peduncular segment drains the peduncular, inferior thalamic, inferior ventricular veins, and receives twigs from the optic tract, hypothalamus, and posterior hippocampus. The course of this middle segment of the BVR follows the cerebral peduncle contour before moving more laterally along the optic tract.

Other transverse oriented veins draining the posterior fossa are beyond the brainstem and include the peduncular vein, the posterior communicating vein, the vein of the pontomesencephalic sulcus, and the vein of the pontomedullary sulcus (**Fig. 26**).[38,39]

Deep transmedullary brainstem veins that reach the superficial transverse and longitudinal venous

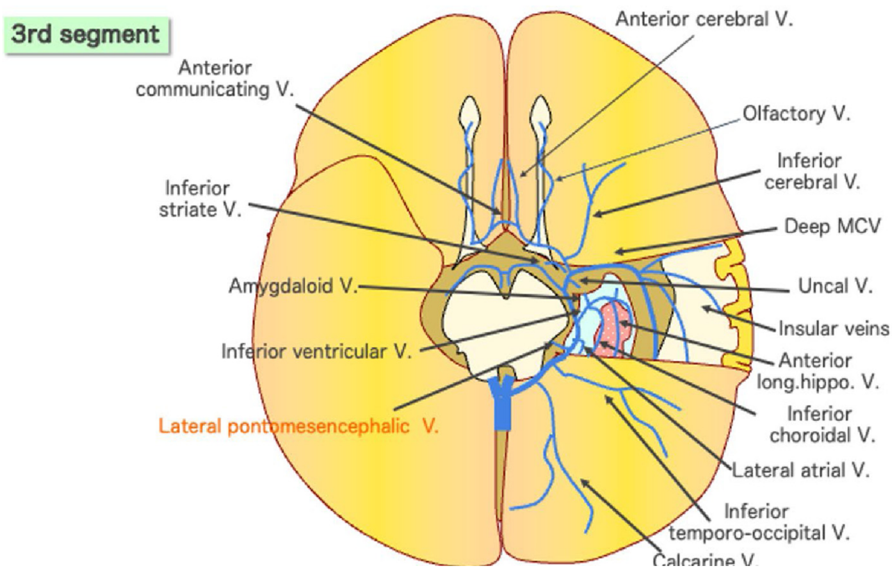

Fig. 21. Basal vein of Rosenthal: third segment. The mesencephalic segment collects the lateral pontomesencephalic vein (fed by both the anterior pontomesencephalic vein and the precentral cerebellar vein), tributaries from the atrial vein, and the inferior temporo-occipital vein before joining the ICV to empty into the vein of Galen.

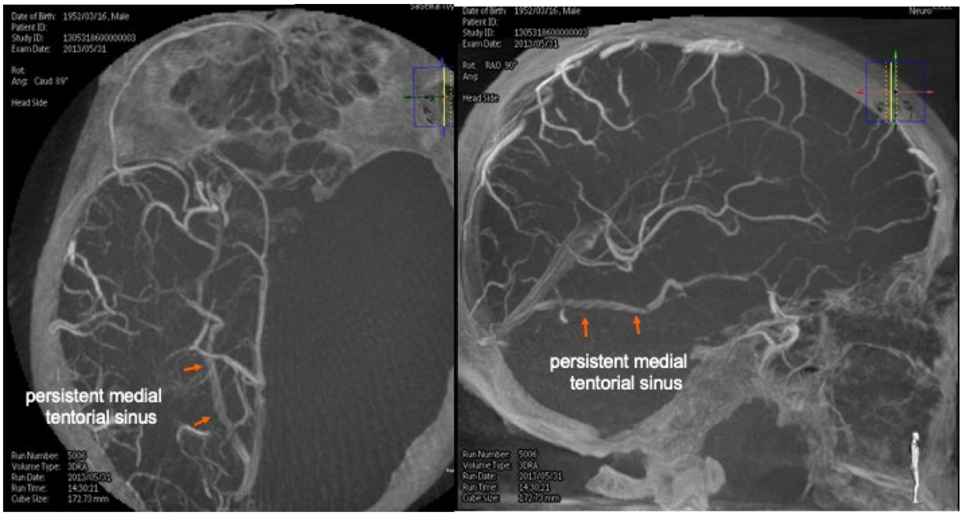

Fig. 22. Persistent tentorial sinus. The draining function of the absent right basal vein of Rosenthal is taken over by a persistent medial tentorial sinus (*orange arrows*).

systems drain in a centrifugal fashion (**Fig. 27**). Also, variability exists in the general configuration of brainstem venous drainage, as either the longitudinal or the transverse venous network may be dominant (**Fig. 28**).

Veins of the cerebellum

The veins of the cerebellum and the veins of the brainstem join into bridging veins which eventually drain into three collecting venous systems, petrosal, galenic, and tentorial that respectively drain into the petrosal sinuses, the vein of Galen, and the torcular/transverse sinuses. The petrosal group drains the cerebellar petrosal surface, the cerebellopontine and cerebellomedullary fissures, the lower part of the roof of the fourth ventricle and lateral recesses, and the lateral aspects of the pons and medulla. The galenic group drains the tentorial surface of the cerebellum, the upper part of the fourth ventricle, and the cerebellomesencephalic fissure. The tentorial group drains the infratentorial cerebellar surface. In addition to those major collecting systems, inconsistent direct bridging veins may be present which may connect to the cavernous sinuses, the basilar plexus, the marginal sinus, the sigmoid sinus, or the jugular bulb.[39]

Petrosal draining group

The petrosal group drains into the superior and inferior petrosal sinuses. This group drains deep cerebellar veins, that is, the cerebellopontine, cerebellomesencephalic fissure and

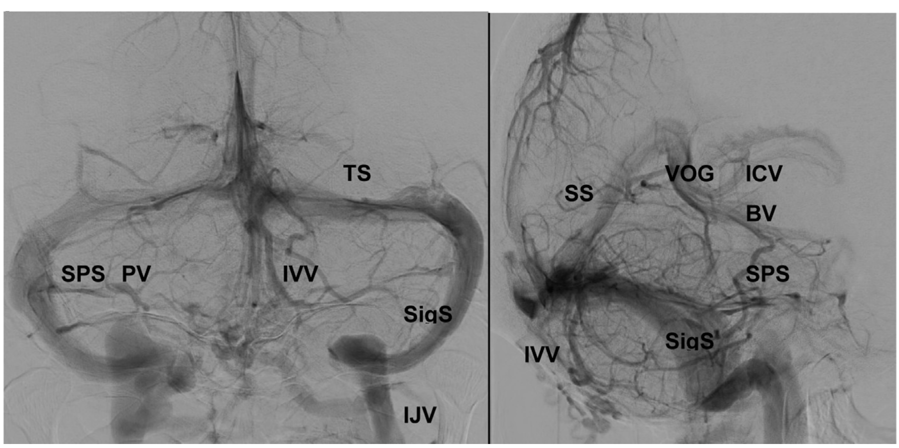

Fig. 23. Posterior fossa veins seen on left vertebral artery angiogram, venous phase. Few veins are reliably identified. BVR, basal vein of rosenthal; ICV, internal cerebral vein; IVV, inferior vermian vein; PV, Petrosal vein; SigS, sigmoid sinus; SPS, Superior petrosal sinus; SS, straight sinus; TS, transverse sinus; VOG, vein of galen.

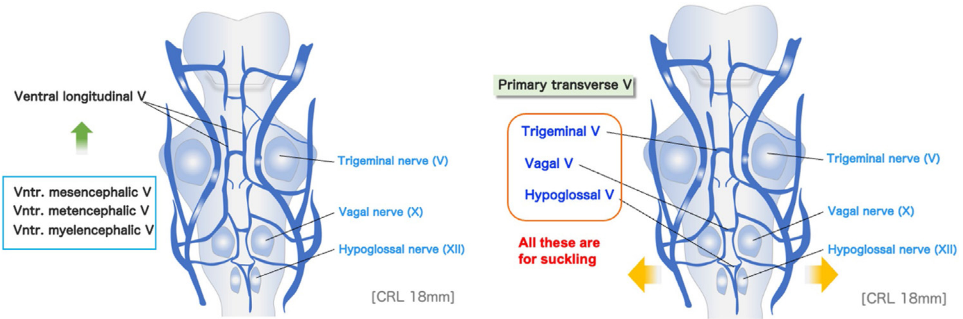

Fig. 24. Embryologic development of brainstem veins. Veins of the brainstem veins have a relatively simple geometric distribution, both longitudinal and transverse relative to the axis of the brainstem. This is because the brainstem derives directly from the neural tube. A prominent longitudinal and transverse venous network organizes throughout, prominent around major nuclei involved in the feeding function (trigeminal, vagus, and hypoglossal).

cerebellomedullary veins, the veins of the lower part and lateral wall of the fourth ventricle, superficial cerebellar veins, that is, superficial and lateral hemispheric cerebellar veins, and brainstem veins. The veins of the cerebellopontine fissure joining the transverse pontine vein to form the superior petrosal vein are the main culprits when causing neurovascular conflicts of venous origin with the cisternal segments of the trigeminal nerves (**Fig 29**).[40] The superior petrosal vein, which drains into the superior petrosal sinus, one of the largest and most constant posterior fossa veins, was named after Walter Dandy, a famous neurosurgeon who pointed out to the risk of major venous ischemia during surgery on the trigeminal nerve (**Fig. 30**), and is, therefore, referred to as Dandy's vein, or simply as the petrosal vein.[41]

Galenic draining group Posterior fossa veins that converge on the vein of Galen include deep cerebellar veins, that is, the paired veins of the

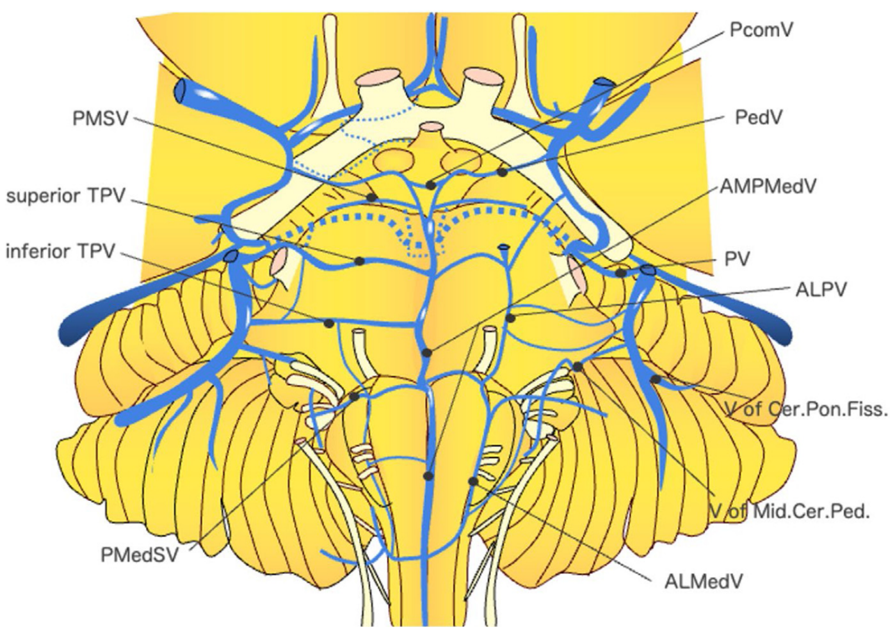

Fig. 25. Posterior fossa veins, anteroposterior view. Longitudinal brainstem venous system. ALMedV, anterolateral medullary vein; ALPV, anterolateral pontmesencephalic vein; AMPMedV, anteromedial pontomedullary vein; PcomV, posterior communicating vein; PmedSV, osterior medullary sulcus vein; PMSV, Pontomesencephalic vein Superior/inferior; TPV, transverse pontine vein; V of Cer.Pont.Fiss, Vein of the cerebellopontine fissure; V of Mid.Cer.Ped, Vein of the Middle cerebellar peduncle.

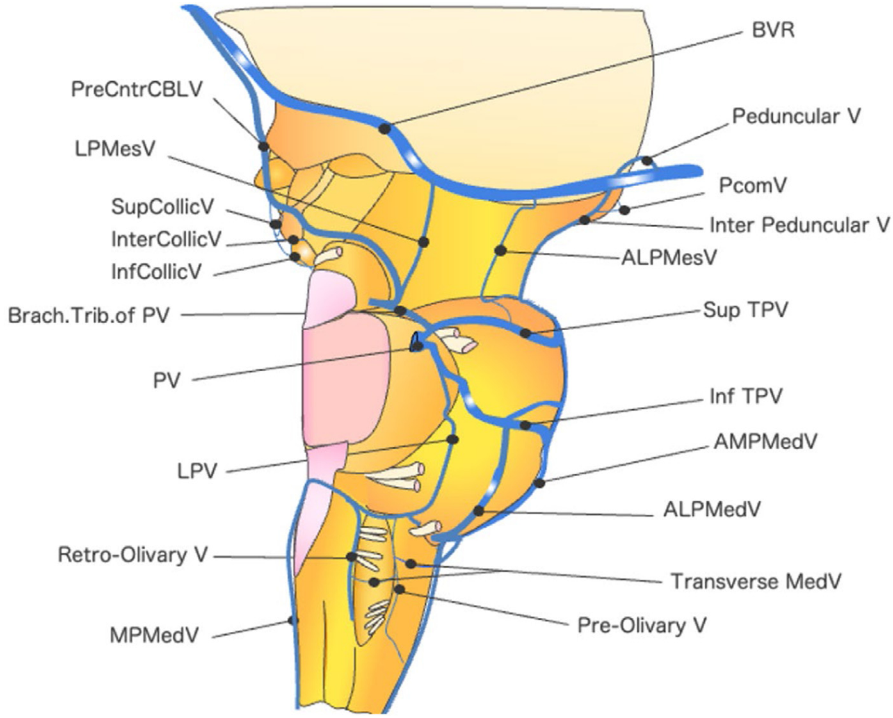

Fig. 26. Posterior fossa veins, lateral view. Transverse brainstem venous system. A Med V, anterior medullary vein; APMV, Anterior Pontine Mesencephalic Vein; Bra V, brachial vein; BVR, basal vein of rosenthal; CS, cavernous sinus; GHFV, greater horizontal fissure vein; ICV, internal cerebral vein; IJV, internal jugular vein; IPS, inferior petrosal sinus; IRTV, inferior retrotonsillar vein; IVV, inferior Vermian Vein; LPMV, lateral pontine mesencephalic vein; PedV, peduncular vein; PV, petrosal vein; Sgmd S, sigmoid sinus; SPS, superior petrosal sinus; SRTV, superior retrotonsillar vein; Strgt sinus, Straight sinus; SVV, superior Vermian Vein; Tento S, tentorial sinus; TPV, transverse pontine vein; VLR, vein of the lateral recess of the fourth ventricle.

cerebellar peduncles and the vein of the cerebellomesencephalic fissure, superficial cerebellar veins, that is, the anterior group of superficial hemispheric cerebellar veins and the superior vermian vein, and brainstem veins, all of which join the posterior aspect of the basal vein of Rosenthal (with the exception of the tectal vein that drains either into the superior vermian vein or the vein of the cerebellomesencephalic fissure) (**Fig. 31**). The precentral cerebellar vein is formed by the union of the veins of the superior cerebellar peduncle and originates deep within the cerebellomesencephalic fissure after which it is sometimes named (**Fig. 32**).[38,39,41]

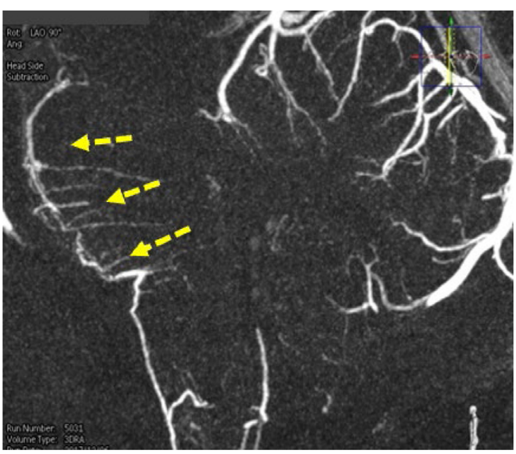

Fig. 27. CT angiogram, venous phase, shows brainstem veins draining into the pontmesencephalic venous system in a centrifugal pattern (*yellow arrows*).

Tentorial draining group The tentorial draining group includes veins that drain primarily into the transverse sinuses and the torcular Herophili, though some veins may drain into the straight sinus or a persistent tentorial sinus (**Fig. 33**). Those veins include inferior hemispheric cerebellar veins (**Fig. 34**), inferior vermian veins, and the posterior groups of the superior hemispheric and superior vermian veins.[38,39,41,42]

Emissary veins and persistent sinuses

Emissary veins are important pathways of extracranial venous drainage that become particularly relevant in cases of dural sinus stenosis or occlusion.

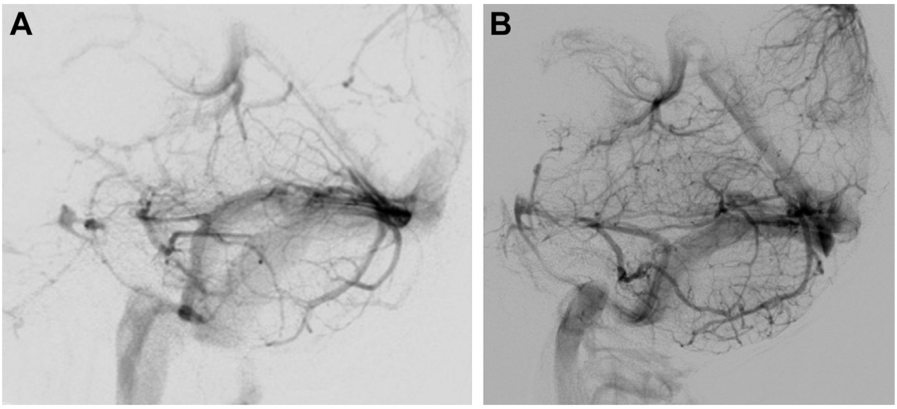

Fig. 28. Patterns of brainstem drainage. Dominant longitudinal brainstem venous drainage (*A*) manifests as paucity of venous opacification on lateral vertebral artery angiogram, venous phase. In contrast (*B*) significant venous brainstem venous opacification is seen with the dominant transverse drainage pattern.

Because they are valveless, emissary veins allow for bidirectional flow, which plays a role in maintaining stability in intracranial pressures, and in providing selective cooling of intracranial structures.[43–45] Emissary veins may propagate extracranial infections into the intracranial compartment, prompting Sir Frederick Treves (a prominent early 20th-century surgeon) to state that "If there were no emissary veins, injuries and diseases of the scalp would lose half their seriousness."[43]

Anterior and middle cranial fossa emissary veins include the superior and inferior ophthalmic veins,

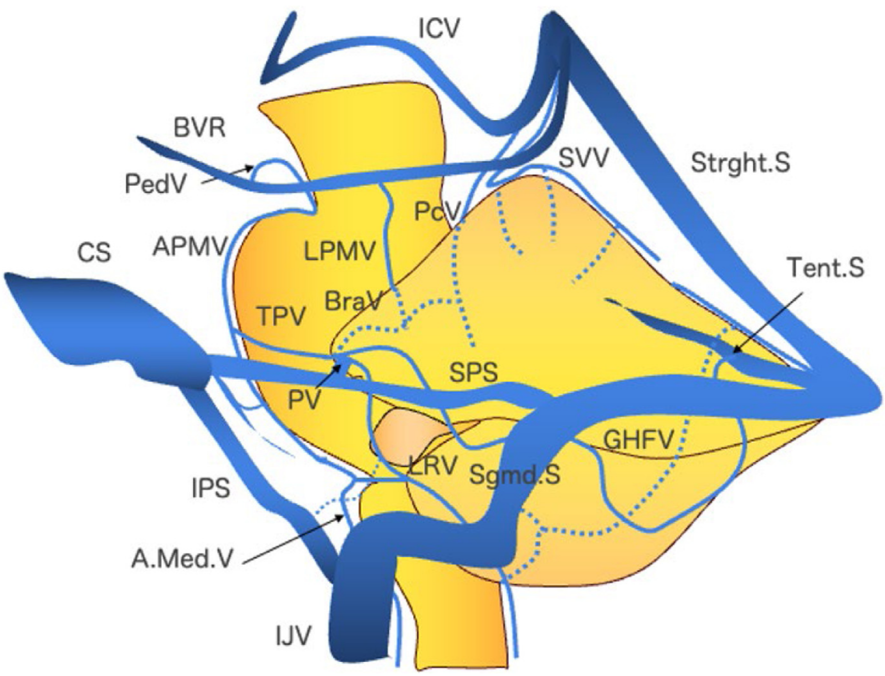

Fig. 29. Cerebellar veins, petrosal draining group. A Med V, anterior medullary vein; APMV, Anterior Pontine Mesencephalic Vein; Bra V, brachial vein; BVR, basal vein of rosenthal; CS, cavernous sinus; GHFV, greater horizontal fissure vein; ICV, internal cerebral vein; IJV, internal jugular vein; IPS, inferior petrosal sinus; IRTV, inferior retrotonsillar vein; IVV, inferior Vermian Vein; LPMV, lateral pontine mesencephalic vein; PedV, peduncular vein; PV, petrosal vein; Sgmd S, sigmoid sinus; SPS, superior petrosal sinus; SRTV, superior retrotonsillar vein; Strgt sinus, Straight sinus; SVV, superior Vermian Vein; Tento S, tentorial sinus; TPV, transverse pontine vein; VLR, vein of the lateral recess of the fourth ventricle.

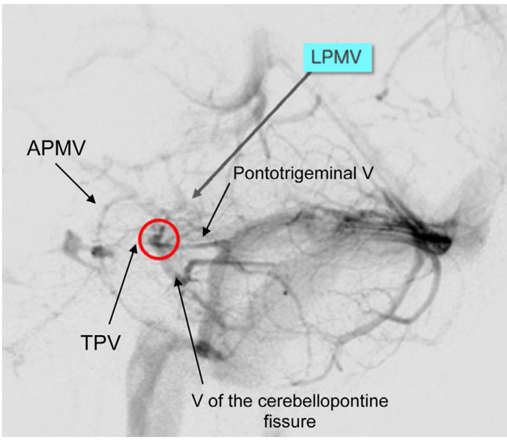

Fig. 30. Petrosal vein (vein of Dandy, also referred to as the superior petrosal vein) and tributaries. The petrosal vein (*red circle*) empties into the superior petrosal sinus, and normally receives between 3 and 5 tributaries, including: (1) the transverse pontine vein (TPV) from anterior pontine mesencephalic vein (APMV), (2) the vein of the cerebellopontine fissure, (3) the pontotrigeminal vein (from the posterior mesencephalic group), (4) the anterior lateral marginal vein, and (5) the vein of the middle cerebellar peduncle.

which connect facial veins to the cavernous sinus via the superior orbital fissure, the sphenoidal emissary vein of the foramen of Vesalius, the emissary vein of the foramen ovale, and the emissary veins of the foramen lacerum, all of which connect the pterygoid plexus to the cavernous sinus. The emissary vein of the foramen cecum connects the nasal cavity to the anterior cranial fossa, the internal carotid venous plexus connects the internal jugular vein to the cavernous sinus, and the emissary veins of the clivus may spread pharyngeal infections to the basilar plexus. In addition, the superior petrosal emissary vein connects infratemporal veins to the petrosal vein via the stylomastoid foramen (along with the facial nerve). The petrosquamosal sinus (which typically involutes before birth, but may persist) also connects the transverse-sigmoid junction to the antero-lateral temporal lobe, and the temporal emissary vein may connect the persistent petrosquamosal sinus to the deep temporal vein.[43,44]

Posterior fossa emissary veins include the posterior condylar emissary vein (which may connect occipital, marginal, and sigmoid sinuses), the anterior condylar vein within the hypoglossal canal, the

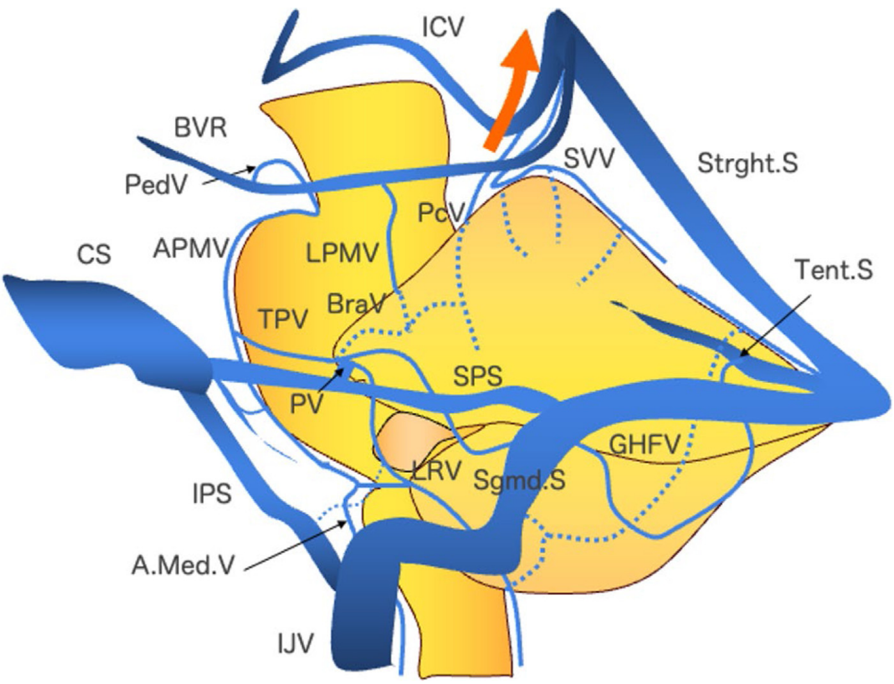

Fig. 31. Cerebellar veins, galenic draining group. A Med V, anterior medullary vein; APMV, Anterior Pontine Mesencephalic Vein; Bra V, brachial vein; BVR, basal vein of rosenthal; CS, cavernous sinus; GHFV, greater horizontal fissure vein; ICV, internal cerebral vein; IJV, internal jugular vein; IPS, inferior petrosal sinus; IRTV, inferior retrotonsillar vein; IVV, inferior Vermian Vein; LPMV, lateral pontine mesencephalic vein; PedV, peduncular vein; PV, petrosal vein; Sgmd S, sigmoid sinus; SPS, superior petrosal sinus; SRTV, superior retrotonsillar vein; Strgt sinus, Straight sinus; SVV, superior Vermian Vein; Tento S, tentorial sinus; TPV, transverse pontine vein; VLR, vein of the lateral recess of the fourth ventricle.

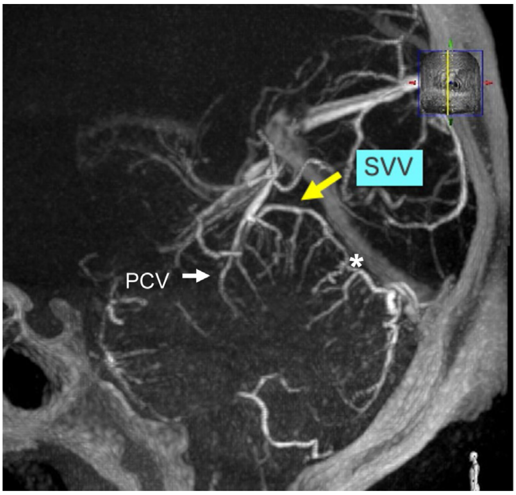

Fig. 32. Cerebellar veins, Galenic group. CT angiogram, sagittal view. PCV, precentral cerebellar vein (*white arrow*), which anastomoses with the petrosal group superiorly; SVV, superior vermian vein; Asterisk indicates anastomotic point between superior vermian vein and inferior vermian vein (tentorial draining group).

occipital emissary vein between the transverse sinus and the occipital vein, the parietal emissary vein that connects the superior sagittal sinus and the occipital vein, and the mastoid emissary vein that connects the sigmoid (or transverse) sinus to the posterior auricular or occipital veins and the vertebral plexus (Fig. 35).[43,45,46] The occipital emissary vein was found to be enlarged in patients with idiopathic intracranial hypertension (pseudotumor cerebri).[45] Also, enlarged posterior fossa emissary veins have been linked to benign pulsatile tinnitus.[46]

An occipital sinus is a persistent venous channel between the torcular Herophili and a draining venous system at the foramen magnum level, whether the marginal sinus or the vertebral plexus (Fig. 36). The occipital sinus, a remnant of the medial channel of the posterior dural plexus, is normally present at birth and destined to involute and close by 2 years of age.[47–49] Tubbs and colleagues have provided a detailed discussion of anatomic variants of the emissary veins.[50]

The falcine sinus, which is derived from the cranialmost portion of the sagittal plexus, is normally only present during the embryonic period and is

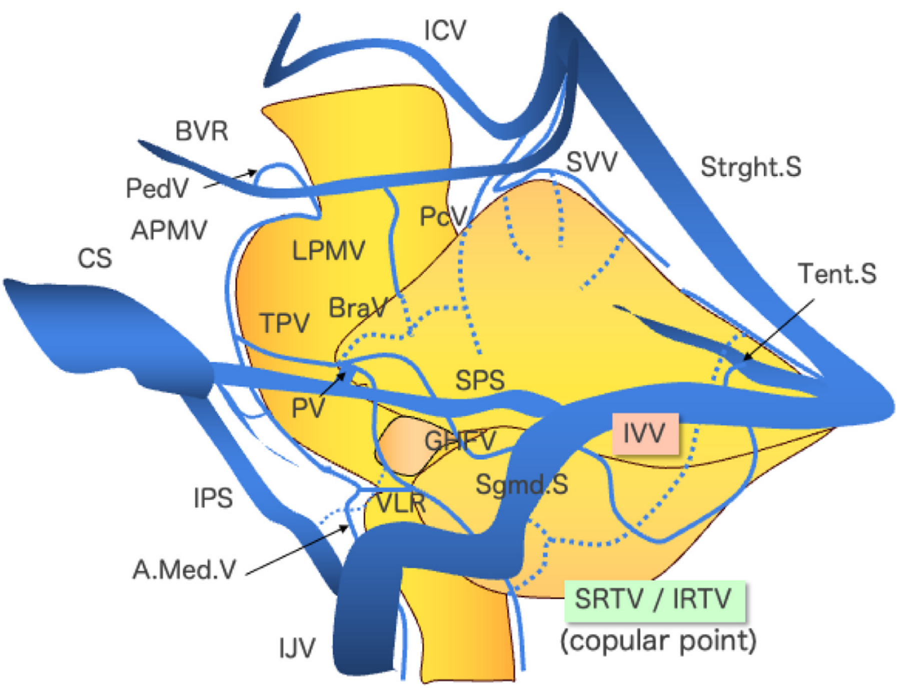

Fig. 33. Cerebellar veins, Tentorial group. A Med V, anterior medullary vein; APMV, Anterior Pontine Mesencephalic Vein; Bra V, brachial vein; BVR, basal vein of rosenthal; CS, cavernous sinus; GHFV, greater horizontal fissure vein; ICV, internal cerebral vein; IJV, internal jugular vein; IPS, inferior petrosal sinus; IRTV, inferior retrotonsillar vein; IVV, inferior Vermian Vein; LPMV, lateral pontine mesencephalic vein; PedV, peduncular vein; PV, petrosal vein; Sgmd S, sigmoid sinus; SPS, superior petrosal sinus; SRTV, superior retrotonsillar vein; Strgt sinus, Straight sinus; SVV, superior Vermian Vein; Tento S, tentorial sinus; TPV, transverse pontine vein; VLR, vein of the lateral recess of the fourth ventricle.

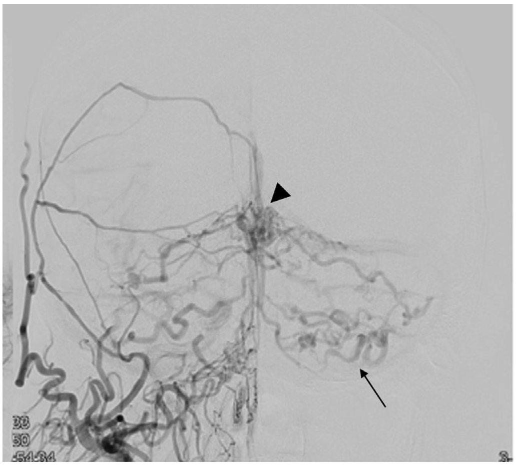

Fig. 34. Dilated tentorial veins (*arrow*) in a patient with a dural arteriovenous fistula (DAVF) of the torcular Herophili (*arrowhead*) seen on a right external carotid artery angiogram.

supposed to regress before birth.[51,52] The function of the falcine sinus is to connect the deep cerebral venous system to the posterior third of the superior straight sinus. The prevalence of a persistent falcine sinus is estimated at 1% to 2%.[51,52] Although commonly associated with other anomalies of development, that is, Chiari II malformations, vein of Galen aneurymal malformation, corpus callosum agenesis, encephalocele (**Fig. 37**), acrocephalosyndactyly or tentorial dysplasia, a persistent falcine sinus may be isolated.[51]

Diploic Veins

The diploic venous system is a complex network of veins enclosed within cancellous bone (the diploe) between the outer and inner tables of the skull made of compact bone. The French anatomist Gilbert Breschet is credited with the first anatomic description of the diploic venous system in 1829.

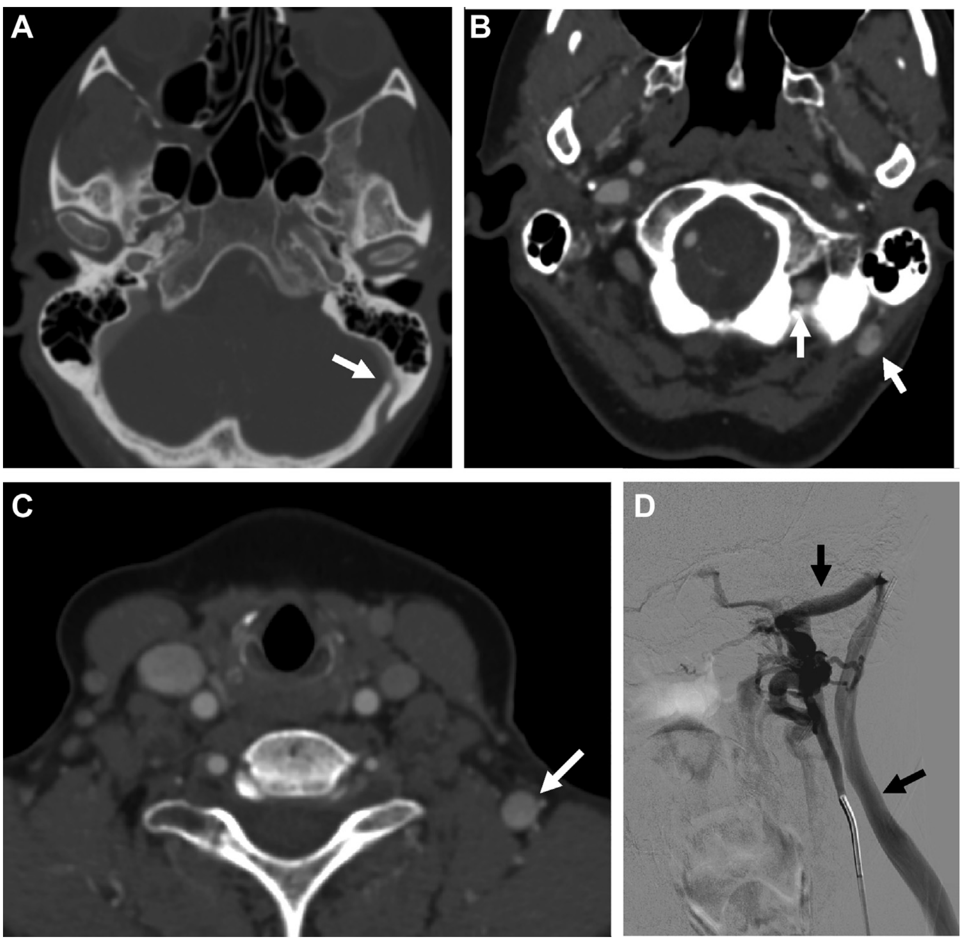

Fig. 35. (*A–D*) Mastoid (or retromastoid) emissary vein. CTA shows a large curved emissary foramen (remnant of the left occipitomastoid suture) in the left occipital bone (*A*, *white arrow*) which allows the passage of a mastoid emissary vein (*B*, *arrows*) that courses posteriorly and inferiorly to drain into the left subclavian vein (*C*, *arrow*). Angiographic view from left internal jugular vein injection demonstrates the lateral course of the mastoid emissary vein (*D*, *arrows*).

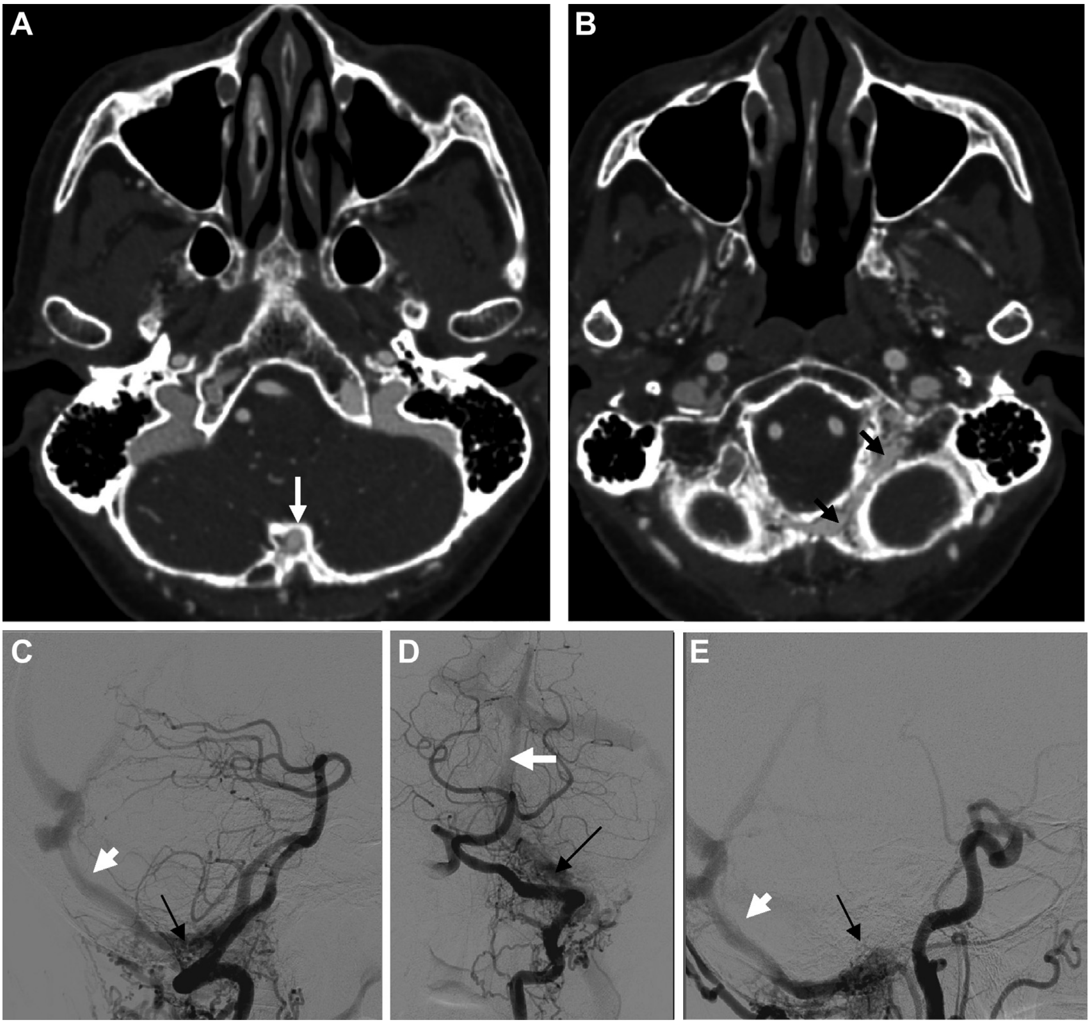

Fig. 36. (*A–E*) Occipital sinus. CTA obtained in an 82-year-old female patient who presents with tinnitus from a left posterior condylar foramen dural arteriovenous fistula (DAVF). An intraosseous occipital sinus is present (*A*, *arrow*), which connects to the left posterior condylar venous plexus (*B*, *arrows*). Left vertebral artery injection, lateral (*C*) and anteroposterior views (*D*) and left common carotid injection, lateral view (*E*) show occipital sinus (*short white arrows*) and posterior condylar foramen DAVF (*long black arrows*).

Although there is significant variability in the anatomic arrangement of diploic veins, the 3 main components of the diploic venous system are the frontal, the anterior temporal, and the posterior temporal diploic veins, with numerous focal areas of venous ectasia referred to as diploic lacunae or lakes.[53,54] Large main diploic veins anastomose extensively with each other, and with a network of microscopic venous channels. All those diploic veins, which are valveless and are lined by a layer of single endothelial cells, communicate freely with the large meningeal veins, the dural sinuses, and emissary veins. The diploic venous system, which is, therefore, in contact with the dural sinuses, the cerebral veins, and the CSF system, is considered to be an important communication pathway between the venous and CSF systems.[55] Tsutsumi has provided a detailed discussion of anatomic variants of the diploic veins.[56]

The clinical significance of diploic venous channels is multiple. They may serve as alternate drainage pathways in case of dural sinus stenosis, occlusion, congenital malformation, thrombosis, or trauma (see **Fig. 37**).[57,58] Arteriovenous fistulas with diploic venous drainage may develop spontaneously, that is, in patients with thrombophilia,[59] after meningioma resection[60] or trauma.[61] Diploic veins can also be a source of bleeding during neurosurgical procedures that require bone

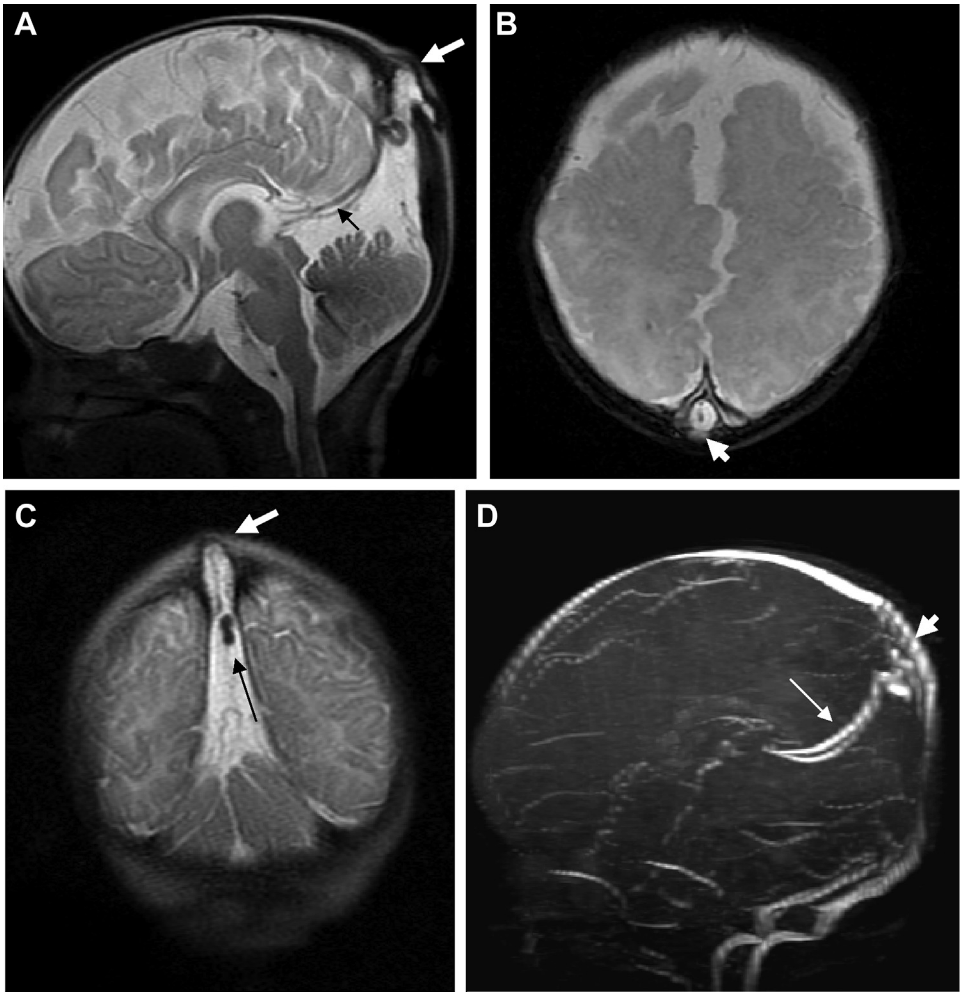

Fig. 37. *(A–D)* Persistent falcine sinus draining a hypoplastic deep venous system into a sinus pericranii continuous with the diploic venous system associated with atretic parietal cephalocele in a neonate (*thick arrow*). Sagittal (*A*), axial (*B*), and coronal (*C*) T2 MR imaging show sinus pericranii within parietal cephalocele (*short large arrows*) that drains extracranially a hypoplastic deep venous system (*thin long arrow*).

drilling, that is, craniotomies, burr holes, and pin placement. Epidural hematomas have been reported after head-holder pin placement.[62] Air emboli embolism can also occur after craniotomy or pin placement.[63,64] Diploic veins may promote the spread of infection[62,65] Spontaneous arteriovenous fistulas can occur between scalp arteries and diploic veins.[66]

CLINICS CARE POINTS

- Thrombosis of dural sinuses or cortical veins is an uncommon but significant cause of morbidity and mortality
- The understanding and management of intracranial arteriovenous and venous lesions requires a good understanding of the venous system
- The proximity of eloquent cerebral regions to intracranial veins, and technological advances in signal transmission through increasingly miniaturized transvenous devices will increasingly allow for therapeutic approaches, that is, neuromodulation for epilepsy, motor control of exoskeletons and robotic limbs in paralyzed patients, the enabling of speech paradigms in patients with poststroke and many more.

DISCLOSURE

The authors have no disclosures to declare in relation to this article.

REFERENCES

1. Hufnagle JJ, Tadi P. Neuroanatomy, brain veins. In: StatPearls [Internet]. Treasure Island (FL: StatPearls Publishing; 2021. PMID: 31536212.
2. Kiliç T, Akakin A. Anatomy of cerebral veins and sinuses. Front Neurol Neurosci 2008;23:4–15.
3. Stolz E. Cerebral veins and sinuses. In: Baumgartner RW. Handbook on neurovascular ultrasound. Front Neurol Neurosci Karger, Basel, Switzerland. 21:2006;182–93.
4. Kretzer RM, Crosby RW, Rini DA, et al. Dorcas Hager Padget: neuroembryologist and neurosurgical illustrator trained at Johns Hopkins. J Neurosurg 2004;100(4):719–30.
5. McBain L, Goren O, Tubbs RS. The embryology of the dural venous sinus: an overview (Chapter 1), anatomy, imaging and surgery of the intracranial dural venous sinuses. Elsevier Ed 2020;p. 1–7, 10.1016/B978-0-323-65377-0.00001-5.
6. Streeter GL. The development of the venous sinuses of the dura mater in the human embryo. Am J Anat 1915;18:145–78.
7. Padget DH. The cranial venous system in man in reference to development, adult configuration, and relation to the arteries. Am J Anat 1956;98:307–56.
8. Padget DH. The development of the cranial venous system in man from the viewpoint of comparative anatomy. Contrib Embryol 1957;36:81–139.
9. Kretschmann HJ, Weinrich W. Cranial neuroimaging and clinical neuroanatomy: magnetic resonance imaging and computed tomography. 3rd edition. Stuttgart (Germany): Georg Thieme Verlag; 2004. p. 451.
10. FCAT. Federative committee on anatomical terminology. terminologia anatomica. international anatomical terminology. 1st edition.292 Stuttgart (Germany): Thieme Medical Publishing; 1999. p. 1999.
11. Osborn AG. Diagnostic neuroradiology. Mosby; 1994. ISBN 0801674867, 9780801674860.
12. Huber P. Cerebral angiography. 2nd edition. Stuttgart (Germany): Georg Thieme Verlag; 1982.
13. Lasjaunias P, Berenstein A, ter Brugge KG. Surgical neuroangiography: clinical vascular anatomy and variations. 2nd edition. Berlin (Germany): Springer; 2001.
14. Huang YP, Wolf BS. The basal cerebral vein and its tributaries. In: Newton TH, Potts DG, editors. Radiology of the skull and brain, Vol. 2. Saint Louis (MO): Mosby; 1974. p. 2111–54.
15. Matsushima T, Rhoton AL Jr, de Oliveira E, et al. Microsurgical anatomy of the veins of the posterior fossa. J Neurosurg 1983;59:63–105.
16. Ono M, Rhoton AL Jr, Peace D, et al. Microsurgical anatomy of the deep venous system of the brain. Neurosurgery 1984;16:621–57.
17. Oka K, Rhoton AL Jr, Barry M, et al. Microsurgical anatomy of the superficial veins of the cerebrum. Neurosurgery 1985;17:711–48.
18. Yasargil MG. MicroneurosurgeryIIIA. Stuttgart (Germany): Thieme; 1987.
19. Macdonald RL. Neurosurgical operative atlas. vascular neurosurgery. 2nd edition. Rolling Meadows (IL): American Association of Neurological Surgeons; 2009.
20. Nowinski WL. Proposition of a new classification of the cerebral veins based on their termination. Surg Radiol Anat 2012;34(2):107–14.
21. Fan AP, Bilgic B, Gagnon L, et al. Quantitative oxygenation venography from MRI phase. Magn Reson Med 2014;72(1):149–59.
22. Available at: https://radiopaedia.org/cases/brain-venous-vascular-territories-diagram?lang=us.
23. Joseph SC, Rizk E, Tubbs RS. Dural venous sinuses. In: Tubbs RS, Shoja MM, Loukas M, editors. Bergman's Comprehensive encyclopedia of human anatomic variation. Hoboken (NJ): John Wiley & Sons; 2016. p. 775–99.
24. Yong SW, Bang OY, Lee PH, et al. Internal and cortical border-zone infarction: clinical and diffusion-weighted imaging features. Stroke 2006;37:841–6.
25. Yedavalli V, Telischak NA, Jain MS, et al. Three-dimensional angles of confluence of cortical bridging veins and the superior sagittal sinus on MR venography: does drainage of adjacent brain arteriovenous malformations alter this spatial configuration? Clin Anat 2020;33(2):293–9.
26. Telischak NA, Yedavalli V, Massoud TF. Tortuosity of superior cerebral veins: Comparative magnetic resonance imaging morphometrics in normal subjects and arteriovenous malformation patients. Clin Anat 2021;34(3):326–32.
27. Mortazavi MM, Denning M, Yalcin B, et al. The intracranial bridging veins: a comprehensive review of their history, anatomy, histology, pathology, and neurosurgical implications. Child's Nervous Syst 2013;29:1073–8.
28. Sadighi A, Cikla U, Kujoth GC, et al. Cerebral veins. In: Tubbs RS, Shoja MM, Loukas M, editors. Bergman's comprehensive encyclopedia of human anatomic variation. Hoboken (NJ): John Wiley & Sons; 2016. p. 800–16.
29. Duret H. Recherches anatomiques sur la circulation de l'encéphale. Arch Physiol Norm Pathol 1874;6:316–53.
30. Jimenez JL, Lasjaunias P, Terbrugge K, et al. The transcerebral veins: normal and non-pathologic angiographic aspects. Surg Radiol Anat 1989;11:63–72.
31. Okudera T, Huang YP, Fukusumi A, et al. Micro-angiographical studies of the medullary venous system of the cerebral hemisphere. Neuropathology 1999;19:93–111.

32. Huang YP, Wolf BS. Veins of the white matter of the cerebral hemispheres (the medullary veins). Am J Roentgenol Radium Ther Nucl Med 1964;92:739–55.
33. Schlesinger B. The venous drainage of the brain, with special reference to the Galenic system. Brain 1939;62(3):274–91.
34. Taoka T, Fukusumi A, Miyasaka T, et al. Structure of the medullary veins of the cerebral hemisphere and related disorders. Radiographics 2017;37(1): 281–97.
35. Khalatbari H, Wright JN, Ishak GE, et al. Deep medullary vein engorgement and superficial medullary vein engorgement: two patterns of perinatal venous stroke. Pediatr Radiol 2021;51:675–85.
36. Chung JI, Weon YC. Anatomic variations of the deep cerebral veins, tributaries of basal vein of rosenthal: embryologic aspects of the regressed embryonic tentorial sinus. Interv Neuroradiol 2005;11:123–30.
37. Gutierrez S, Iwanaga J, Dumont AS, et al. Direct drainage of the basal vein of Rosenthal into the superior petrosal sinus: a literature review. Anat Cell Biol 2020;53(4):379–84.
38. de Miquel MA. Posterior fossa venous drainage. Front Neurol 2021;12:680515.
39. Rhoton AL Jr. The posterior fossa veins. Neurosurgery 2000;47(3 Suppl):S69–92.
40. Dumot C, Sindou M. Trigeminal neuralgia due to neurovascular conflicts from venous origin: an anatomical-surgical study (consecutive series of 124 operated cases). Acta Neurochir (Wien) 2015; 157(3):455–66.
41. Bender B, Hauser TK, Korn A, et al. Depiction of the Superior petrosal vein complex by 3D contrast-enhanced MR angiography. AJNR Am J Neuroradiol 2018;39(12):2249–55.
42. Hu HH, Campeau NG, Huston J 3rd, et al. High-spatial-resolution contrast-enhanced MR angiography of the intracranial venous system with fourfold accelerated two-dimensional sensitivity encoding. Radiology 2007;243(3):853–61.
43. Mortazavi MM, Tubbs RS, Riech S, et al. Anatomy and pathology of the cranial emissary veins: a review with surgical implications. Neurosurgery 2012; 70(5):1312–8 [discussion: 1318-1319].
44. Ide S, Kiyosue H, Shimada R, et al. Petrobasal vein: a previously unrecognized vein directly connecting the superior petrosal sinus with the emissary vein of the foramen ovale. AJNR Am J Neuroradiol 2021. https://doi.org/10.3174/ajnr.A7345. Epub ahead of print. PMID: 34949590.
45. Hedjoudje A, Piveteau A, Gonzalez-Campo C, et al. The occipital emissary vein: a possible marker for pseudotumor cerebri. AJNR Am J Neuroradiol 2019;40(6):973–8.
46. Abdalkader M, Nguyen TN, Norbash AM, et al. State of the art: venous causes of pulsatile tinnitus and diagnostic considerations guiding endovascular therapy. Radiology 2021;300(1):2–16.
47. Mizutani K, Miwa T, Akiyama T, et al. Fate of the three embryonic dural sinuses in infants: the primitive tentorial sinus, occipital sinus, and falcine sinus. Neuroradiology 2018;60:325–33.
48. Sener RN. Association of persistent falcine sinus with different clinicoradiologic conditions: MR imaging and MR angiography. Comput Med Imaging Graph 2000;24:343–8.
49. Kobayashi K, Suzuki M, Ueda F, et al. Anatomical study of the occipital sinus using contrast-enhanced magnetic resonance venography. Neuroradiology 2006;48:373–9.
50. Tubbs RS, Watanabe K, Loukas M. Emissary veins. In: Tubbs RS, Shoja MM, Loukas M, editors. Bergman's comprehensive encyclopedia of human anatomic variation. Hoboken (NJ): John Wiley & Sons; 2016. p. 817–20.
51. Ryu CW. Persistent falcine sinus: Is it really rare? Am J Neuroradiol 2010;31:367–9.
52. Smith A, Choudhary AK. Prevalence of persistent falcine sinus as an incidental finding in the pediatric population. Am J Roentgenol 2014;203:424–5.
53. Segawa T, Shirai M, Izumikawa E. Contribution to the knowledge on the morphology of the diploic veins. Yokohama Med Bull 1960;11:158–62.
54. Jivraj K, Bhargava R, Aronyk K, et al. Diploic venous anatomy studied in-vivo by MRI. Clin Anat 2009;22: 296–301.
55. Krmpotić-Nemanić J, Vinter I, Kelović Z, et al. The fate of the arachnoid villi in humans. Coll Antropol 2003;27:611–6.
56. Tsutsumi S. Diploic veins. In: Tubbs RS, Shoja MM, Loukas M, editors. Bergman's comprehensive encyclopedia of human anatomic variation. Hoboken (NJ): John Wiley & Sons; 2016. p. 770–4.
57. Huang KL, Chang YJ, Chen CH. Dural sinus hypertension due to segmental stenosis. Eur J Radiol Extra 2005;53:91–3.
58. Habash AH, Sortland O, Zwetnow NN. Epidural haematoma: pathophysiological significance of extravasation and arteriovenous shunting. An analysis of 35 patients. Acta Neurochir (Wien) 1982;60:7–27.
59. Mironov A. Classification of spontaneous dural arteriovenous fistulas with regard to their pathogenesis. Acta Radiol 1995;36:582–92.
60. Sakuma I, Takahashi S, Ishiyama K, et al. Multiple dural arteriovenous fistulas developing after total removal of parasagittal meningioma: a case successfully treated with transvenous embolization. Clin Radiol Extra 2004;9(7).
61. Ishii R, Ueki K, Ito J. Traumatic fistula between a lacerated middle meningeal artery and a diploic vein: case report. J Neurosurg 1976;44:241–4.
62. García-González U, Cavalcanti DD, Agrawal A, et al. The diploic venous system: surgical anatomy and

neurosurgical implications. Neurosurg Focus 2009; 27(5):E2.
63. Wilkins RH, Albin MS. An unusual entrance site of venous air embolism during operations in the sitting position. Surg Neurol 1977;7:71–2.
64. Pang D. Air embolism associated with wounds from a pin-type head-holder. Case report. J Neurosurg 1982;57:710–3.
65. Ramos A, Rayo JI, Martín R, et al. Empiema epidural; una complicación de sinusitis frontal [Epidural empyema; a complication of frontal sinusitis]. Acta Otorrinolaringol Esp 1989;40(6):451–3.
66. Burger IM, Tamargo RJ, Broussard J, et al. Combined surgical and endovascular treatment of a spontaneous diploic arteriovenous fistula. Case report. J Neurosurg 2005;103:179–81.