The diploic venous system: surgical anatomy and neurosurgical implications

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Object. There are few systematic investigations of the dissected surgical anatomy of the diploic venous system (DVS) in the neuroanatomical literature. The authors describe the DVS relative to different common neurosurgical approaches. Knowledge of this system can help avoid potential sources of unacceptable bleeding and may impact healing of the cranium.

Methods. Using a high-speed drill with a 2-mm bit, the authors removed the outer layer of the compact bone in the skull to expose the DVS in 12 formalin-fixed cadaver heads. Pterional, supraorbital, and modified orbitozygomatic craniotomies were performed to delineate the relationship of the DVS.

Results. The draining point of the frontal diploic vein (FDV) was located near the supraorbital notch. The draining point of the anterior temporal diploic vein (ATDV) was located in all pterional areas; the draining point of the posterior temporal diploic vein (PTDV) was located in all asterional areas. The PTDV was the dominant diploic vessel in all sides. The FDV and ATDV could be damaged during supraorbital, modified orbitozygomatic, and pterional craniotomies. The anterior DVS connected with the sphenoparietal and superior sagittal sinus (SSS). The posterior DVS connected with the transverse and sigmoid sinuses and was the dominant diploic vessel in all 24 sides. Of all the major diploic vessels, the location and pattern of distribution of the FDV were the most constant. The parietal bone contained the most diploic vessels. No diploic veins were found in the area delimited by the temporal squama.

Conclusions. The pterional, orbitozygomatic, and supraorbital approaches place the FDV and ATDV at risk. The major anterior diploic system connects the SSS with the sphenoparietal sinus. The posterior diploic system connects the SSS with the transverse and sigmoid sinuses. (DOI: 10.3171/2009.8.FOCUS09169)

KEY WORDS • diploic channel • diploic venous system • surgical anatomy • cadaver dissection

THE DVS is located between two hard, compact layers of bone, and is immersed in the cancellous bone called the diploë. It is a source of bleeding and potential complications such as air emboli. The French anatomist and surgeon Guillaume Dupuytren discovered the DVS in the 19th century (Fig. 1). In 1829 Gilbert Breschet described the anatomy of this system in his works *Essai sur les Veines du Rachis* and *Recherches Anatomiques, Physiologiques et Pathologiques sur le Système Nerveux* (Fig. 2), and diploic channels are still sometimes referred to as Breschet veins or Breschet canals. In 1840, Khristian Salomon proposed the use of wax for cranial bone hemostasis.^{33,36,54} In 1864, Henri Ferdinand Dobleau (Fig. 3) described a notable operation in which wax was used for aggressive bleeding.^{13,52} In 1892, Sir Victor Horsley (Fig. 4)²⁵ was popularized as the first user of bone wax as a practical solution to bleeding from the skull bones, but

this claim is not warranted. Interestingly, in all the time since then, neurosurgeons still possess few other options for obtaining bone hemostasis.²²

Reports of the location, pattern, and distribution of the DVS have varied considerably in different anatomical texts and atlases, with the vast majority of depictions being grossly inaccurate and unrealistic.^{1,8,21,67,70} This variability may reflect difficulty in accessing the diploic veins, the lack of use of fine and precision instruments such as contemporary high-speed drills in anatomical dissections, and the lack of adequate imaging until relatively recently.^{3,7,27,30,59,64,68,69} Indeed, the anatomy of the DVS is so variable that it was once considered a “fingerprint” of the skull.²⁴ Using linear x-ray film, however, Hershkovitz et al.²⁴ demonstrated the patterns of distribution and localization of the DVS in a systematic fashion, and classified the DVS into 7 types: bonsai, spider, coronal, serpentine, thousand lakes, mixed, and undetermined. The goal of this study was to describe the origin, course, and destination of the primary diploic vessels relative to the regions of common neurosurgical approaches. Such information could be important to predict bleeding when bur holes

Abbreviations used in this paper: ATDV = anterior temporal diploic vein; DVS = diploic venous system; FDV = frontal diploic vein; PTDV = posterior temporal diploic vein; SSS = superior sagittal sinus.

FIG. 1. Portrait of Guillaume Dupuytren, 1777–1835. Dupuytren would become one of the richest physicians in France. He was a known as a spellbinding lecturer, his vast knowledge highlighted by his dazzling ability for total recall of case stories, clinical studies, and medical details of any kind. His reputation included obsessive-compulsive personality traits and he was a perfectionist. He was possessed of enormous energy, drive, and intellectual ability, but was also known for his ruthless ambition and cynical disregard for the sensibilities of his students and colleagues. His contemporaries had various terms for him, including “Le Brigand d’Hôtel-Dieu,” “first among surgeons and last among men,” and the “Napoleon of surgery.” In like fashion, Dupuytren held high regard for his country; when the enemy stood at the gates of Paris, Dupuytren was there with his students to help the wounded. He meticulously studied the disease process, along with correlations to anatomy. Dupuytren disliked writing, and many accounts of his lectures and investigations were published by his students and acolytes; for example, *Leçons Orales de Clinique Chirurgicale, Faites à l’Hôtel-Dieu de Paris; rec. et publ. par une Société de Médecins*, which was first published in 1832. (Portrait downloaded from Wikipedia—http://en.wikipedia.org/wiki/Guillaume_Dupuytren; public domain.)

are placed and when craniotomies are performed. Furthermore, it could help avoid unacceptable bleeding when bone structures must be drilled. Also, the diploic venous system has direct involvement and connection in some areas with the cerebral venous system, making it relevant as a potential target for the treatment of certain clinical conditions.

Methods

Definitions of Concepts

The following concepts are defined to help clarify the anatomy of the DVS.³⁹

Pacchionian granulations are large formations of arachnoid villi. Their shape, density, and agglomeration can change over time. Foveolae granulares are skull bone defects formed by the pacchionian granulations. They are distributed over the skull bones and seldom are connected with the venous sinuses. Fossae lacunares are larger agglomerations of foveolae granulares. They can be located on either side of the dural sinuses, with which they communicate via short channels. They also can be located in regions far from the venous sinuses. Diploic channels are small grooves or tunnels in the diploë of the cranial bones. They form the corridors for the diploic veins and emissary veins that connect the circulatory system with

FIG. 2. Portrait of Gilbert Breschet, 1784–1845. Breschet made seminal contributions to the study of comparative anatomy, including some of the first works on zoonoses. In 1813 with François Magendie (1783–1855), he demonstrated that rabies can be transmitted from the saliva of humans to dogs. Breschet’s anatomical foundation led to his interest in becoming a physician. One of his major topics of investigation was the vascular system of vertebrates: he discovered the rete mirabile in whales and dolphins, which is critical to these species’ ability to survive and adapt at ocean depths. He did extensive anatomical studies of veins of the cranium and spine, wrote extensively on aneurysm formations in humans, and made important investigations of the auditory system in vertebrates. Breschet has several anatomical terms named after him, including the following: Breschet canals (the canals in the cranial diploë that actually house the diploic veins); Breschet sinus (also known as the sphenoparietal sinus); and Breschet veins (the diploic veins connected with the cerebral sinuses by emissary veins). His most famous works pertaining to cranial and spinal anatomy and pathology include *Essai sur les Veines du Rachis*, 1819; and *Recherches Anatomiques, Physiologiques et Pathologiques sur le Système Nerveux*, Paris, 1827–1829. (Portrait downloaded from Wikipedia—http://en.wikipedia.org/wiki/File:Gilbert_Breschet.png; public domain.)

the CSF system. The diploic veins form a valveless network of small vessels located between the two compact bone layers in the skull and run inside the diploic channels. These veins communicate with the dural sinuses and pachymeningeal veins, and with pericranial veins via emissary veins.^{9,11} With their corresponding foramina, emissary veins connect the extracranial venous system, intracranial sinuses, and meningeal veins, which return cranial venous flow to the general circulation.⁵⁰

Dissection Procedure

Twelve formalin-fixed, latex-injected cadaver heads (24 sides) (mean age 69 years; range 53–73 years) were dissected. The calvarial bone was carefully exposed bilaterally. With the aid of the surgical microscope and using a high-power light source, a high-speed drill with a 2-mm diamond bit was used to remove cortical bone. After the diploë was exposed, meticulous drilling along the diploic channels was needed to visualize the origin, distribution, branching pattern, and relation of the diploic veins with anatomical landmarks relative to placement of

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FIG. 3. Portrait of Henri Ferdinand Dolbeau, 1830–1877. In 1840, Khristian Khristianovich Salomon (1796–1851), head of the Academy Surgical Clinic in Russia at that time, proposed the use of wax to arrest bleeding from cranial bones (see also the works by Karavayeva, Kondakov, and Rukovodstvo), although there were problems using candle or modeling wax because of the lack of sterility and malleability. Around the same time, clinicians such as Magendie in France had proposed the use of wax in experimental animal surgery to close venous sinuses. Henri Ferdinand Dolbeau, a distinguished French surgeon, was one of the first physicians to operate successfully on an osteoma of the frontal sinus in 1864. At the September 1866 meeting of the Paris Academy of Medicine, a report was read that described Dolbeau's use of wax for uncontrolled bleeding during the case (see Richet), which report stated: "we were obliged to play with a ball of wax in the orifice of a major artery lying on the surface where the tumor was implanted which gushed blood." (Reprinted with permission from Gupta G, Prestigiacomo CJ: From sealing wax to bone wax: predecessors to Horsley's development. *Neurosurg Focus* 23(1):E16, 2007; Fig. 1 [right].)

bur holes⁵¹ and trajectories of the craniotomy associated with the pterional, orbitozygomatic, and mini-orbitozygomatic approaches. These approaches were performed in a standard fashion as described elsewhere.^{16,19,41} Each approach was performed on both sides of 4 heads (8 sides/approach).

Primary diploic veins were analyzed for distribution and described relative to the following landmarks: bregma, asterion, pterion, lambda, frontozygomatic suture, supraorbital notch, and glabella (Fig. 5).^{12,34,53} To validate our findings we describe the patterns of distribution of the major diploic vessels according to the system proposed by Hershkovitz et al.²⁴

Results

Table 1 and Fig. 5 show the topographic localization of the diploic veins by areas. The FDV is located only in the anterior area delimited by the bregma, glabella, and pterion. The ATDV is located inside an area delimited by the bregma, frontozygomatic suture, pterion, and asterion. There are some points in the anterior area (Ant 3) where the FDV and ATDV coexist. The PTDV is located in the posterior area delimited by the bregma, pterion, asterion,

TABLE 1: Location of diploic veins by area in cadaver heads (24 sides)

Vein	No. of Veins by Area				
	Ant 1	Ant 2	Ant 3	Pst 1	Pst 2
FDV	24	22	6		
ATDV			24	24	0
PTDV				24	24

and lambda. Finally, we found no diploic veins in the area delimited by the temporal squama. The midline, pterion, and asterion represent the draining points of the major diploic vessels and are more prone to bleeding when performing surgical approaches involving these areas.

The FDV

The localization, symmetry, and distribution pattern of the FDV was the most consistent of all the diploic veins. The FDV has a draining point near the supraorbital notch, and initially coursed almost straight dorsomedially to its termination near midline in the frontal bone. Both FDVs drain into the SSS. In 18 of 24 sides, the origin of the FDV receives a small tributary that runs along the superolateral aspect of the frontal sinus. The FDV is routinely compromised and bleeds during supraorbital, modified orbitozygomatic, and pterional craniotomies (Fig. 6).

The ATDV

The draining point of the ATDV was located in the pterional area in all specimens. The pterion is surrounded by multiple small venous channels (Fig. 7). The vessel can be followed upward almost parallel to the border of

FIG. 4. Portrait of Sir Victor Horsley, 1857–1916. Horsley specifically mentions the case reported by Dolbeau as a primary influence in his introduction of bone wax into the nascent field of neurosurgery. Horsley, it seems, although given credit by M. Allen Starr for "Horsley's Wax," was neither the first to use bone wax in Britain, nor did he come up with the formula for using beeswax instead of modeling wax; credit for those innovations going to P. W. Squire and Rushton Parker, respectively, although in the latter case it seems that Horsley provided the wax (see the article by Gupta and Prestigiacomo). (Portrait downloaded from Wikipedia—http://en.wikipedia.org/wiki/Victor_Horsley; public domain.)

FIG. 5. Anterolateral (A), lateral (B), and posterolateral (C) views of the skull. The diploic veins were described relative to anterior (Ant 1, Ant 2, Ant 3) and posterior (Post 1, Post 2) zones created by lines between landmarks. Blue dots indicate landmarks. As = asterion; Br = bregma; Fz = frontozygomatic suture; Gl = glabella; Ld = lambda; Pt = pterion; SON = supraorbital notch.

the squama and coronal suture. In all 24 sides, it received 1–4 tributaries that anastomosed with the FDV or PTDV. The main trunk of the ATDV was traced to the midline and to where it joined the SSS (Fig. 8).

The PTDV

The PTDV was the dominant diploic vessel in all 24 sides. It drained posteriorly close to the asterion or posterosuperior mastoid area into either the transverse or sigmoid sinuses. The PTDV primarily coursed through the parietal bone, running anteriorly and dorsomedially relative to the midline (Fig. 8). The branches from this vein to the occipital bone varied considerably (Fig. 9A). In 18 of the 24 sides, the PTDV was connected with the petrosquamosal sinus; mastoid emissary vein; and sigmoid, transverse, and superior petrosal sinuses to form a complex system that drained the SSS and formed the communication between the extracranial and intracranial venous systems (Fig. 9). In some cases rich anastomoses are present between the PTDV and ATDV.

Diploic Veins in the Occipital Bone

The PTDV receives diploic tributaries from the occipital bone (Fig. 9). Some occipital diploic veins were located on both sides of midline, and some diploic channels

were near the diploic lacunae in the parietal bone. The occipital bone sometimes housed emissary veins near midline at the level of the superior occipital line.

Patterns of Distribution

In decreasing order, the most common patterns were the bonsai, serpentine, coronal, and spider (Table 2). Thousand lakes, mixed, or undetermined patterns were not observed in our cadaver heads. These are more rare, as HersHKovitz postulated.²⁴

Discussion

The DVS is challenging to study because it is enclosed between two layers of hard compact bone; dissection, preservation, and identification are thus difficult. Consequently, the DVS is poorly understood from anatomical, physiological, and surgical perspectives.⁶¹ The results of our dissections lend further credence to claims that descriptions of the DVS in classic anatomy textbooks are largely inaccurate.^{8,21,24,62,63,67,70} In fact many previous descriptions give the impression of being hypothetical representations of the distribution of the DVS. To the best of our knowledge, the surgical anatomy of this venous system has not previously been reported in the neurosurgical literature.

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FIG. 6. Postdissection photographs showing the FDV in 3 specimens. The FDV was exposed near the supraorbital notch and traced superiorly and dorsomedially to a connection with the SSS. A: Anterolateral view of a head specimen with outer layer of the calvaria removed, exposing diploic channels. Cranial sutures and superior temporal line (STL) have been left intact. B: Anterolateral view of the calvaria of a different specimen with diploic veins exposed. C and D: Anterior view of the calvaria of a third specimen, with diploic veins exposed and bilateral supraorbital craniotomies. A tributary (FDV trib) can be seen running along the superolateral aspect of the frontal sinus. Anterior view (E) and view of the medial edge of the bone flap (F) from the left supraorbital craniotomy shown in C and D. The vein is at risk for injury during pterional, modified orbitozygomatic, and supraorbital craniotomies (red arrowheads). The distribution of this vein is almost symmetrical. CS = coronal suture; SqS = squamosal suture.

Background to the Study of the DVS

The DVS was first described by Guillaume Dupuytren,¹⁴ who was best known as the first surgeon to perform successful drainage of a brain abscess in a patient with fever and seizures. His special interest in neurosurgical procedures brought his attention to these veins immersed in the diploë. Soon after, Gilbert Breschet described the anatomy of the diploic veins and channels as well the sphenoparietal sinus, giving the first clues about the relationship of this system with the dural sinuses, but does not appear to have proven a direct connection between the diploic channels and the dural sinuses.

We therefore applied the concepts of the anthropological study by Hershkovitz et al.²⁴ to study the anatomy of the DVS from a neurosurgical perspective. Although dissections were not performed by these investigators, the accurate patterns and distribution of the DVS were shown

by Hershkovitz et al. with special radiographic techniques. Our main objective was to provide an anatomical dissection analysis and topography of the main primary vessels and their surgical implications during routine neurosurgical maneuvers such as placement of pins, bur holes, and craniotomies and during bone drilling. Given that any surgical procedure in the skull involves this anatomy, there is no justification for ignoring or tolerating misconceptions about the location and topographic anatomy of the DVS. Our methodology, that is, direct dissection of the diploic veins and channels with the same instruments used in the operating room, corroborates the findings of Hershkovitz et al.

Anatomical Divisions of the DVS

For practical purposes the human DVS can be divided in 2 subsystems that each have a nexus where cerebral,

FIG. 7. Superolateral close-up in the region of the pterion, with the outer shell of the calvaria removed to show diploic channels. The cranial sutures and superior temporal line have been left intact as landmarks. The pattern of distribution corresponds to the coronal type anatomy, and the ATDV runs almost parallel to the squamosal suture and the coronal suture.

dural, and diploic veins link. The FDV and ATDV form an anterior diploic venous subsystem converging in the pterional area, which connects the SSS with the sphenoparietal sinus. Because of the difficulty of filling this low-flow system with silicone latex, a direct connection is difficult to demonstrate by dissection technique; thus we believe corrosion cast models may yield better preservation for study. The emissary veins link the superior orbital vein with the veins of the face, and the superior ophthalmic and middle meningeal veins with the sphenoparietal sinus, and consequently the cavernous sinus. The posterior subsystem converging in the asterion is formed by the PTDV and occipital diploic veins, and connects the posterior SSS with the transverse and sigmoid sinuses. This direct connection was observed in all the dissections performed in our study. Emissary veins such as the emissary mastoid vein and some parietal and occipital emissary veins link the intracranial cerebral, dural, and diploic veins with the veins of the posterior scalp and neck (suboccipital venous system).⁵⁰ These diploic and emissary veins are responsible for air emboli that form during surgery involving the posterior fossa.^{15,50,51,56}

Anatomical and Pathological Relationships of the DVS

The close anatomical, structural, and functional relationships between the arachnoid villi and the endothelium of the great venous sinuses represent a link between the CSF and circulatory systems.^{2,73} Fluid is filtered from the villi and pachionian granulations via the diploic spaces and diploic veins.⁴ It is widely accepted that the DVS, with its connections with the dural and cerebral veins and its relationship with the arachnoid granulations, is the gate that allows communication between the CSF and circulatory systems. The role of the DVS as the link between the venous and CSF system further supports the

need for understanding the anatomy of this system. We found large agglomerations of fossae lacunares and diploic channels in the external surface of the greater wing of the sphenoid bone. These structures were related to the origin of the frontal, anterior, and posterior temporal diploic veins and sphenoparietal sinus. This finding correlates with previous observations by Krmpotić-Nemanić et al.³⁸ These fossae lacunares, which are distal from the major dural sinuses, are closely related to the subarachnoid space (cisternal-like) and sylvian fissure. Their presence explains the need for a vascular network such as the diploic veins that connects both systems.³⁸

The calvarial diploë contains a number of large veins. These veins anastomose with each other and with a network of microscopic venous channels. All diploic veins are lined by a single endothelial layer and are devoid of valves. They communicate with the dural sinuses and pachymeningeal veins and with the pericranial veins via emissary veins.¹⁰

The anatomical relationship of the DVS to the emissary veins, dural sinuses, meninges, skull base, calvarial bone, and skin, and its role in pathophysiological conditions such as air embolism during surgery have been described.^{10,15,17,18,47,50,56,66} However, its potential role in other pathological conditions such as venous sinus thrombosis,²⁰ cancer metastases,⁷¹ infection dissemination, intracranial hypertension,⁴⁰ hydrocephalus,^{31,44,48} intracranial hematomas,^{4,23,66} craniosynostoses, tumors, and pediatric neurosurgical conditions^{32,35,37,39,42} is poorly understood. Some authors have proposed that the connections between arachnoid granulations and the DVS and dural sinuses might function as valves to control blood flow between the cranial diploë and sagittal sinus and between the cerebral veins and dural sinuses.^{10,11} Improving knowledge about the role of the DVS in certain physiological and pathological conditions could enable it to become a target for some treatment options such as those related to venous thrombosis and arteriovenous fistulas, hydrocephalus, and intracranial hypertension (Fig. 10).^{4,5,20,23,40,44,48}

Under normal physiological circumstances, the diploic veins are rarely visualized, but in certain pathological states that compromise the normal venous draining pathways, the diploic system may show increased flow. Huang et al.²⁶ reported a case of segmental stenosis in the SSS with prominent venous drainage through the diploic system, and Smith⁶⁵ reported another case of idiopathic bilateral sigmoid sinus occlusion in a child with partial caput medusae of Lermoyez that resulted in dilation of the diploic veins and scalp vessels. Diploic fistulas have been found to be associated with hypercoagulable states, such as the postpartum period and sinus thrombosis.⁴⁵ Prominent diploic channels may also be associated with meningiomas, sinus thrombosis, trauma, and dural arteriovenous fistulas, and in these cases the diploic system may offer treatment access.^{5,26,28,29,55} Sakuma et al.⁵⁷ reported a case of a large right parasagittal meningioma with important collateral flow running from the SSS into the jugular vein through an enlarged posterior diploic venous system. Three months after removal of the tumor, the patient developed pulsatile tinnitus, and a dural arteriovenous fistula in the posterior fossa was demonstrated involving the middle meningeal

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FIG. 8. A: Right lateral view showing the PTDV, which is visible through the external lamina. A dural vein is visible through the temporal squama. B: Lateral view exposing the ATDV and the PTDV. The PTDV courses near the asterion. It can join the transverse sinus, sigmoid sinus, or both. C: Close-up of the same exposure, showing the anastomosis between the ATDV and PTDV (green arrowhead). The ATDV courses dorsocaudally near the pterion, and it receives anterior and posterior tributaries. D: Superolateral view of the left side, showing no anastomosis between ATDV and PTDV, and showing the anastomosis of the ATDV with the lacunae of the SSS. Superior (E) and posterior (F) views demonstrating diploic lacunae (DL) lateral to the midline in the anterior and posterior parietal bones and midline occipital bone. Both vessels terminate near the midline. Ant trib = anterior tributary; post trib = posterior tributary.

and occipital arteries, with venous drainage involving a dilated posterior diploic system. The venous component was embolized through the jugular bulb, which also provided access to the posterior diploic system. Burger et al.⁵ reported on a patient with headaches and pulsatile tinnitus who had a spontaneous diploic fistula in the parietal area that fed from multiple superficial temporal and middle meningeal artery branches, with venous drainage through the parietal diploic and retroauricular veins. Initially the fistula was excised via a craniectomy, but postoperatively

the fistula recurred. An endovascular approach through the mastoid emissary vein was performed, followed by embolization of the venous component of the fistula. The key to success in these cases was knowledge of the anatomical relationship between the internal jugular vein and the sigmoid sinus, which allowed access to the posterior diploic system.

Head-holder pin placement may cause complications related to injury to the diploic veins and the development of epidural hematomas and air embolism. Some authors

TABLE 2: Patterns of distribution of DVS

Authors & Year	Type of DVS (%)						
	Bonsai	Serpentine	Coronal	Spider	Thousand Lakes	Mixed	Undetermined
present study	58.3	25.0	8.3	8.3	0	0	0
Hershkovitz et al., 1999	55.0	12.9	8.23	8.23	3.7	2.6	9.3

have reported the development of epidural hematomas secondary to pin placement.^{6,46,51,72} For this reason, it is probably best to avoid the asterional and pterional areas when placing head-holder pins in patients. Our data regarding the topographic relationship between the diploic veins, emissary veins, and dural sinuses is supported by case reports of “unusual” sources of air embolism that was caused by the punctures made by the head-holder pins in patients placed in the sitting position.^{51,72}

The diploic channels have also been implicated in dissemination of infection. Ramos et al.⁴⁹ reported on a patient with frontal sinusitis who developed extradural empyema, with infection spread through the intact sinus wall via the diploic veins. The proximity of the frontal sinus to the FDV and tributaries may be important here.

We performed a previous investigation of the mastoid emissary vein complex, which is directly connected to the diploic system in the asterional region.⁵⁰ This complex of veins may offer therapeutic opportunity as well as poten-

tial hazard for the neurosurgeon. A review of the images from cadaver dissections performed at that time now impresses on us the extensive network of diploic channels associated with the sigmoid sinus.

Challenges and Limitations to DVS Study

Our dissections were challenging because the diploic veins were difficult to perfuse with silicone latex. Furthermore, the diploic veins and channels are delicate and easily damaged, even with a delicate diamond drill bit. Despite this limitation, our technique identified the anatomy of the DVS. Unfortunately, analysis of the DVS with contemporary imaging also has disadvantages.^{27,30} The diploic channels can be confused with meningeal veins, and inner surface grooves can be difficult to distinguish from dural veins and arteries. Artifacts (mainly partial volume effect) on MR imaging make it difficult to differentiate between diploic and dural veins.^{27,30} Digital subtraction angiography usually does not show these veins because of

FIG. 9. A: Posterolateral view of the skull in the region of the left asterion showing a PTDV connecting with the transverse sinus (TS). The PTDV has a tributary from the occipital bone (that is, the occipital diploic vein [ODV]). The petrosquamosal sinus (PSS) and mastoid emissary vein (MEV) can be seen connecting with the sigmoid sinus (SS). B: Superior view of the skull base showing the petrosquamosal sinus with a completely intradiploic segment connecting to the sigmoid sinus. Note the PTDV totally inside the diploë. C: Posteroinferior view of the occipital bone showing a mastoid emissary vein, occipital emissary veins (OEV), and occipital diploic vein (also known as the asterional diploic vein). SPS = superior petrosal sinus.

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FIG. 10. A: An MR venogram obtained in a patient with thrombosis of the SSS shows no flux within the sinus. A digital subtraction angiography study corroborates the diagnosis of SSS thrombosis. The blockage allowed venous drainage toward the sphenoparietal sinus and caused the two anterior temporal diploic veins (B and C) to enlarge. D: The bone window view confirms that the enlarged vessels are true diploic and not dural veins. StS = straight sinus.

their low flow, but may demonstrate them when there are pathological flow circumstances like venous sinus thrombosis in which the venous flow is directed to an alternative pathway such as the DVS (see Fig. 10). Computed tomography angiography studies demonstrated the minor dural sinuses like the sphenoparietal and petrosquamosal sinuses, but not the diploic channels.^{43,58,60}

Conclusions

The brain surgeon should be aware of the topographic anatomy of this system mainly when performing surgical approaches involving the pterional, asterional, and parietal areas, because those are the areas with major numbers of diploic veins and are more likely to bleed.

Disclaimer

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

References

1. Agur AMR, Dalley AF (eds): **Grant's Atlas of Anatomy**. Philadelphia: Lippincott Williams & Wilkins, 2005

2. Baruffaldi O, Dalla Bernardina L: [Breschet's sphenoparietal sinus; anatomoradiological study.] **Riv Anat Patol Oncol** **6**:901–956, 1953 (Ital)
3. Baruzzi AG: [Radiological aspect of the canal of the frontal diploic vein.] **Ann Radiol Diagn (Bologna)** **25**:26–29, 1952 (Ital)
4. Benndorf G, Lehmann TN: Bilateral diploic arteriovenous fistula causing scalp hematoma. **J Neurosurg** **100**:950–955, 2004
5. Burger IM, Tamargo RJ, Broussard J, Gailloud P: Combined surgical and endovascular treatment of a spontaneous diploic arteriovenous fistula. Case report. **J Neurosurg** **103**:179–181, 2005
6. Cabezedo JM, Gilsanz F, Vaquero J, Areitio E, Martinez R: Air embolism from wounds from a pin-type head-holder as a complication of posterior fossa surgery in the sitting position. Case report. **J Neurosurg** **55**:147–148, 1981
7. Carriero A, Cuonzo G, Iezzi A, Tartaro A, Sicuro A, Bonomo L: [Magnetic resonance venogram of the intracranial circulation. Technique, anatomy, indications.] **Radiol Med** **83**:182–191, 1992 (Ital)
8. Clemente C: **Anatomy: A Regional Atlas of the Human Body**. Baltimore: Urban and Schwarzenberg, 1981
9. Cooper ER: Cranial diploic channels and their communications. **Acta Anat (Basel)** **47**:345–362, 1961
10. Coppini L, Sciascia R: [Recent contribution to the knowledge

- of the venous circulation of the head: Breschet's sphenoparietal sinus.] *Boll Soc Ital Biol Sper* **39**:1305–1309, 1963 (Ital)
11. Coppini L, Sciascia R, Rondanelli E: [The indentation of Breschet's sphenoparietal sinus: Anatomico-radiological study.] *Bull Sci Med (Bologna)* **138**:393–415, 1966 (Ital)
12. Cotton F, Rozzi FR, Vallee B, Pachai C, Hermier M, Guihard-Costa AM, et al: Cranial sutures and craniometric points detected on MRI. *Surg Radiol Anat* **27**:64–70, 2005
13. Dolbeau H: *Leçons de Clinique Chirurgicale, Professées à l'Hôtel-Dieu de Paris par Dolbeau, et Recueillies par J. Besnier*. Paris: Masson, 1867, p 438
14. Dupuytren G: *Leçons Orales de Clinique Chirurgicale Faites à l'Hôtel-Dieu de Paris; Rec. et Publ. par une Société de Médecins*. Paris: Germer-Baillière, 1832
15. Edelman JD, Wingard DW: Air embolism arising from burr holes. *Anesthesiology* **53**:167–168, 1980
16. Figueiredo EG, Deshmukh P, Zabramski JM, Preul MC, Crawford NR, Spetzler RF: The pterional-transsylvian approach: an analytical study. *Neurosurgery* **62**:1361–1367, 2008
17. Fournier HD, Delliére V, Gourraud JB, Mercier P: Surgical anatomy of calvarial skin and bones—with particular reference to neurosurgical approaches. *Adv Tech Stand Neurosurg* **31**:253–271, 2006
18. Gomez-Perals LF, Bayo R, Lorenzana-Honrado LM, Antona-Diaz M, Cabezudo JM: Severe intraoperative air embolism during convexity meningioma surgery in the supine position. Case report. *Surg Neurol* **57**:262–266, 2002
19. Gonzalez LF, Crawford NR, Horgan MA, Deshmukh P, Zabramski JM, Spetzler RF: Working area and angle of attack in three cranial base approaches: pterional, orbitozygomatic, and maxillary extension of the orbitozygomatic approach. *Neurosurgery* **50**:550–555, 2002
20. Gotoh M, Ohmoto T, Kuyama H: Experimental study of venous circulatory disturbance by dural sinus occlusion. *Acta Neurochir (Wien)* **124**:120–126, 1993
21. Gray H: *Gray's Anatomy*. London: 1973
22. Gupta G, Prestigiacomo CJ: From sealing wax to bone wax: predecessors to Horsley's development. *Neurosurg Focus* **23**(1):E16, 2007
23. Habash AH, Sortland O, Zwetnow NN: Epidural haematoma: pathophysiological significance of extravasation and arteriovenous shunting. An analysis of 35 patients. *Acta Neurochir (Wien)* **60**:7–27, 1982
24. Hershkovitz I, Greenwald C, Rothschild BM, Latimer B, Dutour O, Jellema LM, et al: The elusive diploic veins: anthropological and anatomical perspective. *Am J Phys Anthropol* **108**:345–358, 1999
25. Horsley V: Antiseptic wax. *BMJ* **1**(1639):1165, 1892
26. Huang KL, Chang YJ, Chen CH: Dural sinus hypertension due to segmental stenosis. *Eur J Radiol Extra* **53**:91–93, 2005
27. Ikawa F, Sumida M, Uozumi T, Kiya K, Kurisu K, Arita K, et al: Demonstration of the venous systems with gadolinium-enhanced three-dimensional phase-contrast MR venography. *Neurosurg Rev* **18**:101–107, 1995
28. Ikeda H, Niizuma H, Suzuki J, Nagamine Y, Kameyama M: [Chemical embolization using estrogen for aneurysmal bone cyst of the skull: case report.] *No Shinkei Geka* **13**:203–208, 1985 (Jpn)
29. Ishii R, Ueki K, Ito J: Traumatic fistula between a lacerated middle meningeal artery and a diploic vein: case report. *J Neurosurg* **44**:241–244, 1976
30. Jivraj K, Bhargava R, Aronyk K, Quateen A, Walji A: Diploic venous anatomy studied in-vivo by MRI. *Clin Anat* **22**:296–301, 2009
31. Johnston KD, Walji AH, Fox RJ, Pugh JA, Aronyk KE: Access to cerebrospinal fluid absorption sites by infusion into vascular channels of the skull diplo. *J Neurosurg* **107**:841–843, 2007
32. Kaido T, Kim YK, Ueda K: Diagnostic and therapeutic considerations for sinus pericranii. *J Clin Neurosci* **13**:788–792, 2006
33. Karavayeva A: *Operative Manual of Surgery*. Kiev: 1886, p 211
34. Kazkayasi M, Batay F, Bademci G, Bengi O, Tekdemir I: The morphometric and cephalometric study of anterior cranial landmarks for surgery. *Minim Invasive Neurosurg* **51**:21–25, 2008
35. Klein EW, Farhat SM, Hoskins PA, Colvin JT: Radionuclide cerebral angiographic evaluation of a diploic extracranial meningioma: case report. *J Nucl Med* **16**:833–834, 1975
36. Kondakov EN: History of home neurosurgery: Part II, in Kondakov EN (ed): *Saint Petersburg, Russia: Polenov Research Neurosurgical Institute*. St. Petersburg, Russia: 2005
37. Koshu K, Takahashi S: Laterally situated sinus pericranii. Report of two cases with marked diploic veins. *Neuroradiology* **21**:219–221, 1981
38. Krmpotić-Nemanić J, Vinter I, Kelović Z, Suknaić S: The fate of the arachnoid villi in humans. *Coll Antropol* **27**:611–616, 2003
39. Kunz AR, Iliadis C: Hominid evolution of the arteriovenous system through the cranial base and its relevance for craniosynostosis. *Childs Nerv Syst* **23**:1367–1377, 2007
40. Leksins EN: [The pathogenesis of increased intracranial pressure as a sequels of closed cranio-cerebral injury.] *Vopr Neirokhir Nov-Dec*:31–34, 1975 [Russian]
41. Lemole GM Jr, Henn JS, Zabramski JM, Spetzler RF: Modifications to the orbitozygomatic approach. Technical note. *J Neurosurg* **99**:924–930, 2003
42. Marras C, McEvoy AW, Grieve JP, Jager HR, Kitchen ND, Villani RM: Giant temporo-occipital sinus pericranii. A case report. *J Neurosurg Sci* **45**:103–109, 2001
43. Marsot-Dupuch K, Gayet-Delacroix M, Elmaleh-Berges M, Bonneville F, Lasjaunias P: The petrosquamosal sinus: CT and MR findings of a rare emissary vein. *AJNR Am J Neuroradiol* **22**:1186–1193, 2001
44. Massicotte EM, Del Bigio MR: Human arachnoid villi response to subarachnoid hemorrhage: possible relationship to chronic hydrocephalus. *J Neurosurg* **91**:80–84, 1999
45. Mironov A: Classification of spontaneous dural arteriovenous fistulas with regard to their pathogenesis. *Acta Radiol* **36**:582–592, 1995
46. Pang D: Air embolism associated with wounds from a pin-type head-holder. Case report. *J Neurosurg* **57**:710–713, 1982
47. Prabhakar H, Ali Z, Bhagat H: Venous air embolism arising after removal of Mayfield skull clamp. *J Neurosurg Anesthesiol* **20**:158–159, 2008
48. Pugh JA, Tyler J, Churchill TA, Fox RJ, Aronyk KE: Intraosseous infusion into the skull: potential application for the management of hydrocephalus. *J Neurosurg* **106**:120–125, 2007
49. Ramos A, Rayo JJ, Martin R, Pardal JL, Gomez JL, del Canizo A: [Epidural empyema; a complication of frontal sinusitis.] *Acta Otorrinolaringol Esp* **40**:451–453, 1989 (Span)
50. Reis CV, Deshmukh V, Zabramski JM, Crusius M, Desmukh P, Spetzler RF, et al: Anatomy of the mastoid emissary vein and venous system of the posterior neck region: neurosurgical implications. *Neurosurgery* **61**:193–200, 2007
51. Ribas GC, Rhoton AL Jr, Cruz OR, Peace D: Suboccipital burr holes and craniectomies. *Neurosurg Focus* **19**(2):E1, 2005
52. Richet C: Rapport sur un travail de M. Dolbeau intitulé: mémoire sur les exostoses du sinus frontal. *Bull de l'Acad Med* **36**:564–599, 1871
53. Richtsmeier JT, Paik CH, Elfert PC, Cole TM III, Dahlman HR: Precision, repeatability, and validation of the localization of cranial landmarks using computed tomography scans. *Cleft Palate Craniofac J* **32**:217–227, 1995

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54. Rukovodstvo SL: **A Manual of Operative Surgery**. St. Petersburg, Russia: 1840
55. Saba MI, King RB: Extravasation of angiographic contrast material from a torn middle meningeal artery into the diploic. Case report. **J Neurosurg** **38**:89–91, 1973
56. Sakamoto T, Kawaguchi M, Furuya H, Ohnishi H, Karasawa J: Preoperative evaluation for risk of venous air embolism in the sitting position. **J Neurosurg Anesthesiol** **7**:124–126, 1995
57. Sakuma I, Takahashi S, Ishiyama K, Tomura N, Watarai J, Yanagisawa T, et al: Multiple dural arteriovenous fistulas developing after total removal of parasagittal meningioma: a case successfully treated with transvenous embolization. **Clin Radiol Extra** **9**:7, 2004
58. San Millán Ruíz D, Fasel JH, Gailloud P: The petrosquamosal venous channel. **AJNR Am J Neuroradiol** **23**:739–740, 2002
59. San Millán Ruíz D, Fasel JH, Rufenacht DA, Gailloud P: The sphenoparietal sinus of breschet: does it exist? An anatomic study. **AJNR Am J Neuroradiol** **25**:112–120, 2004
60. San Millán Ruíz D, Gailloud P, Yilmaz H, Perren F, Rathgeb JP, Rufenacht DA, et al: The petrosquamosal sinus in humans. **J Anat** **209**:711–720, 2006
61. Segawa T, Shirai M, Izumikawa E: Contribution to the knowledge on the morphology of the diploic veins. **Yokohama Med Bull** **11**:158–162, 1960
62. Shukla V, Hayman LA, Ly C, Fuller G, Taber KH: Adult cranial dura I: intrinsic vessels. **J Comput Assist Tomogr** **26**:1069–1074, 2002
63. Shukla V, Hayman LA, Taber KH: Adult cranial dura II: venous sinuses and their extrameningeal contributions. **J Comput Assist Tomogr** **27**:98–102, 2003
64. Skrzat J: Modelling the calvarium diploe. **Folia Morphol (Warsz)** **65**:132–135, 2006
65. Smith KR Jr: Idiopathic bilateral sigmoid sinus occlusion in a child: case report. **J Neurosurg** **29**:427–430, 1968
66. Snyder HS, Salo D: Epidural hematoma: an unusual presentation. **Am J Emerg Med** **8**:538–541, 1990
67. Sobotta J, Putz R, Pabst R, Taylor A: **Sobotta Atlas of Human Anatomy**. Baltimore: Williams & Wilkins, 1997, pp 77, 256
68. Stenzel E: [Importance and use of the diploic veins in cranial roentgenography.] **Nervenarzt** **25**:11–20, 1954 (Ger)
69. Stuart C, Migliorini M: [Anatomo-radiographic study of the diploic venous circulation in man.] **Rass Studi Psichiatr** **43**:415–448, 1954 (Ital)
70. Testut JL: **Traite d'Anatomie Humaine**. Doin Editeur, 1893
71. West MS, Russell EJ, Breit R, Sze G, Kim KS: Calvarial and skull base metastases: comparison of nonenhanced and Gd-DTPA-enhanced MR images. **Radiology** **174**:85–91, 1990
72. Wilkins RH, Albin MS: An unusual entrance site of venous air embolism during operations in the sitting position. **Surg Neurology** **7**:71–72, 1977
73. Zouaoui A, Hidden G: [The cervical vertebral venous plexus and anastomoses with the cranial venous sinuses.] **Bull Assoc Anat (Nancy)** **71**:7–13, 1987 (Fr)

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