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ABSTRACT

SUMMARY: CSF-venous fistula is a relatively novel entity that is increasingly being recognized as a cause for spontaneous intracranial hypotension. Recently, our group published the first series of transvenous embolization of CSF-venous fistulas in this journal. Having now performed the procedure in 60 patients, we have garnered increasing familiarity with the anatomy and how to navigate our way through the venous system to any intervertebral foramen in the cervical, thoracic, and lumbar spine. The first part of this review summarizes the organization of spinal venous drainage as described in classic anatomy and interventional radiology texts, the same works that we studied when attempting our first cases. In the second part, we draw mostly on our own experience to provide a practical roadmap from the puncture site to the foramen. On the basis of these 2 parts, we hope this article will serve to collate the relevant anatomic knowledge and give confidence to colleagues who wish to embark on transvenous spinal procedures.

ABBREVIATIONS: IVC = inferior vena cava; SVC = superior vena cava

Spinal venous anatomy is a lesser-known subject among neurointerventionalists, while we are generally well-adept at navigating the arteries of the central nervous system. Both blood supply and drainage of the spine should be core topics of the training of every neurointerventionalist, especially given the growing interest in transvenous routes for the treatment of CNS diseases.

In 2014, CSF-venous fistulas (Fig 1) were first described as a cause of spontaneous intracranial hypotension.[1] More recently, a novel technique for the treatment of CSF-venous fistulas has been described that depends on navigation of the paraspinal and epidural venous system.[2] Since then, we have noted a steep rise in the number of patients referred for embolization at our center and have seen the procedure performed at multiple additional centers in North America and Europe.

With the emergence of these new procedures comes a need to revive a part of our knowledge that, in recent years, has been neglected for lack of clinical need. A thorough review of spinal and paraspinal venous anatomy is, therefore, both timely and relevant.

Here we seek to draw on previously published anatomic studies within the fields of anatomy and neurointervention, combined with the lessons we have learned in the process of performing our first 60 transvenous embolizations of CSF-venous fistulas. Rather than taking a purely anatomic approach, the aim was to provide the neurointerventionalist with a practical roadmap from a common femoral vein to any intervertebral foramen in the cervical, thoracic, or lumbar spine.

Historical Anecdote

We are not the first generation of neurointerventionalists to require transvenous access to the spine. Decades ago, venography of the epidural venous plexus was frequently used to diagnose mass lesions such as intervertebral disc prolapses and tumors.[3] The advancement of cross-sectional imaging rendered invasive diagnostic spinal venographic techniques obsolete. Nevertheless, the anatomic lessons learned in the past by the masters of that art still hold true today and provide an invaluable foundation for our current knowledge.

When embarking on our first transvenous embolization of a CSF-venous fistula in 2020, we needed to plot an anatomic route of access. Having found a distinct lack of recent publications on the topic, we leaned quite heavily on the seminal texts of Théron and Moret[4] as well as articles from Théron and Djindjian,[5] published in the 1970s. These texts must have been labors of love produced by physicians with a deep understanding of classic, embryologic, and radiologic anatomy. They cannot be recommended highly enough for the interested reader.

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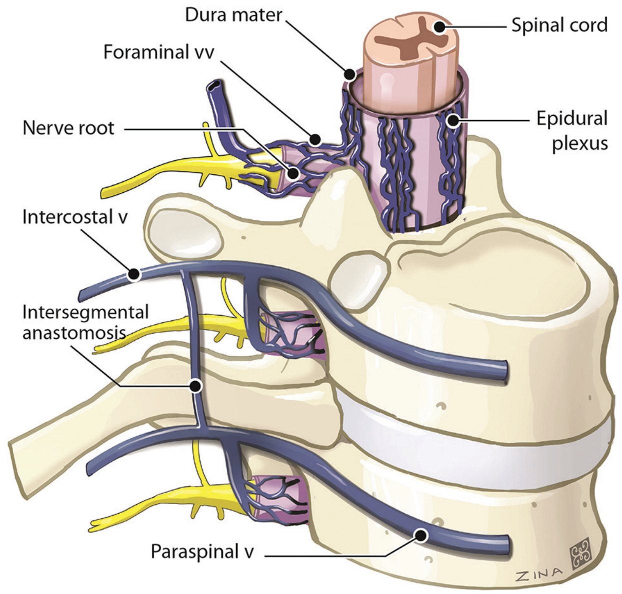

FIG 1. The site of the CSF leak in the patients with CSF-venous fistula is the nerve root foramen. The nerve root is covered with a dural sleeve, which, in turn, is surrounded by a plexus of veins that forms the foraminal vein. This joins the segmental vein above to form the paraspinal vein. There may be anastomotic veins running perpendicular to the segmental veins that provide a direct connection between adjacent levels. v indicates vein; vv, veins.

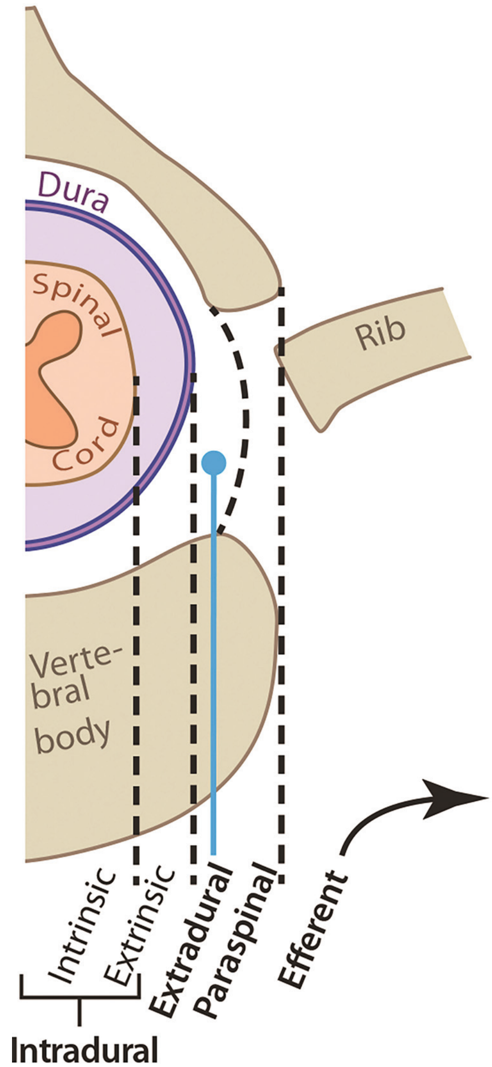

FIG 2. The venous drainage of the spine can be separated into 3 compartments, from medial to lateral. The intradural compartment is further subdivided into intrinsic and extrinsic components. The extradural compartment refers to the epidural venous plexus, also referred to as the internal vertebral plexus. The paraspinal compartment is also called the external vertebral plexus. Efferent pathways are arranged in a segmental fashion, carrying venous blood toward the great veins and on to the right atrium.

Spinal Venous Compartments

The veins draining the spinal cord and vertebral column can be conceptually divided into 3 compartments: intradural (intrinsic and extrinsic), extradural, and paraspinal (Fig 2). The intrinsic system refers to veins within the spinal cord itself, and the extrinsic system comprises the pial venous networks, the longitudinally-oriented venous system, and the intradural radiculomedullary veins. This intradural compartment has been described in high-quality articles elsewhere[6-8] and for now remains beyond the reach of our microcatheters.

The scope of this review extends to the extradural and paraspinal compartments, specifically the efferent pathways that connect the spine to the great veins that ultimately drain into the heart. The first part summarizes the organization of the venous system, while the second part focuses on the practicalities and nuances of navigating these routes.

Understanding the Extradural and Paraspinal Compartments

In 1940, Batson[9] described a plexus of valveless veins that runs the entire length of the spine and serves as an important route for hematogenous spread of pelvic metastases to the spine. This plexus also serves a number of important physiologic roles. It can drain venous blood from the brain in cases of internal jugular vein occlusion or compression and can provide an alternate route of venous return in the setting of inferior vena cava (IVC) obstruction or when intrathoracic or intra-abdominal pressure is increased. While Batson's plexus serves as a single unit functionally, it encompasses both the epidural and paravertebral venous plexuses described below. The nomenclature of the subdivisions of Batson's plexus and the onward efferent pathways merits some clarification in the interest of standardization.

Extradural Compartment. The extradural compartment described in the previous section refers to the internal vertebral venous plexus, also known as the epidural plexus. It sits within the spinal canal, embedded in the epidural fat that surrounds the main thecal sac, and drains the spinal cord and the vertebral bodies. Although the internal venous plexus effectively surrounds the dura circumferentially, Gray's *Anatomy of the Human Body* describes 4 longitudinal channels where the plexus is more prominent, 2 anteriorly and 2 posteriorly.[10] Radiologically, superimposition of the anterior and posterior plexuses on a frontal view results in the appearance of 2 "lateral epidural plexuses" running longitudinally on either side of the spinal canal (Fig 3).

Venous rings at the midlevel of each vertebral body allow communication between the 2 anterior and 2 posterior internal plexuses. On a frontal view, these appear as transverse channels connecting the left and right lateral plexuses. These rings also drain the basivertebral veins from the posterior aspect of the vertebral bodies into the epidural plexus. These osteal tributaries are morphologically distinct on fluoroscopy. Awareness of their existence and relationship to the epidural plexus can help distinguish them from epidural veins when they appear during injection of a liquid embolic agent. As mentioned previously, the epidural plexus is both rich and valveless. Both of these features have made it surprisingly straightforward for navigating microcatheters through the epidural space, in our experience.

Paraspinal Compartment. The paravertebral compartment is also referred to as the external vertebral, paravertebral, or paraspinal venous plexus (Fig 4). It is richest in the cervical region and is also divided into 2 anterior and 2 posterior columns that freely communicate with each other. The anterior external plexuses lie adjacent to the vertebral bodies and also drain the aforementioned basivertebral and foraminal veins.[10] The posterior external plexuses run outside the lamina and drain the deep paraspinal muscles via tributaries such as the lateral and posterior muscular veins. They also communicate with the posterior internal plexuses and, in the cervical region, anastomose with the vertebral, occipital, and deep cervical veins.

Foraminal Veins. The internal and external vertebral plexuses are functionally and anatomically connected through each intervertebral foramen via the foraminal veins (Fig 5), which form a plexus surrounding each nerve root. In some texts, these are also referred to by the term "intervertebral vein." In our experience, both microcatheters and embolic agents injected here behave more like a plexus.

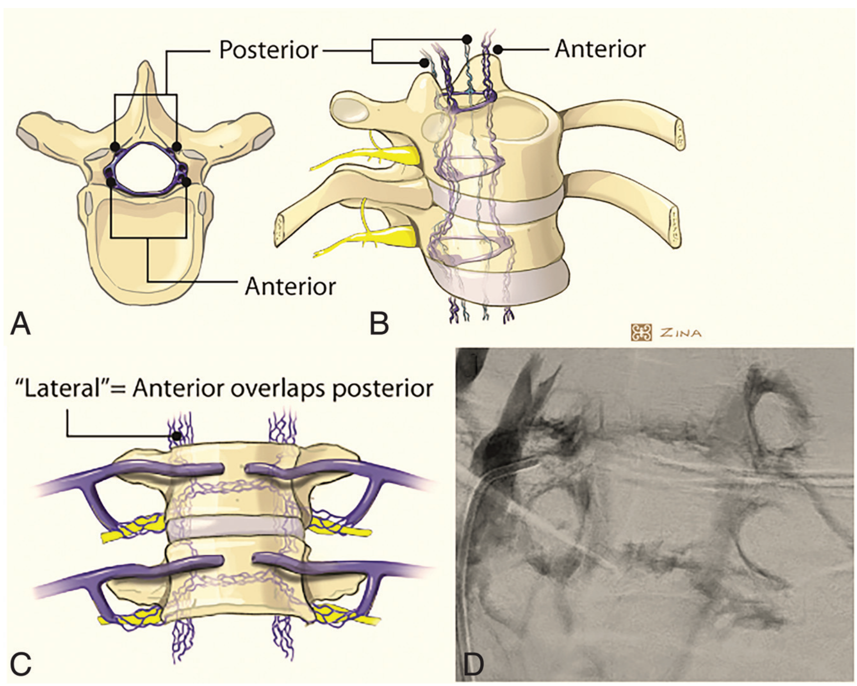

FIG 3. *A–C*, The epidural plexus is richest in 2 anterolateral and 2 posterolateral columns. The 4 columns are joined by circumferential rings surrounding the thecal sac at the midlevel of each vertebral body. When viewed from anterior to posterior, the 4 columns, rings, and foraminal veins form a characteristic hexagonal shape. *D*, The composite view of the anterior and posterior columns on a frontal view is referred to as the lateral epidural plexus.

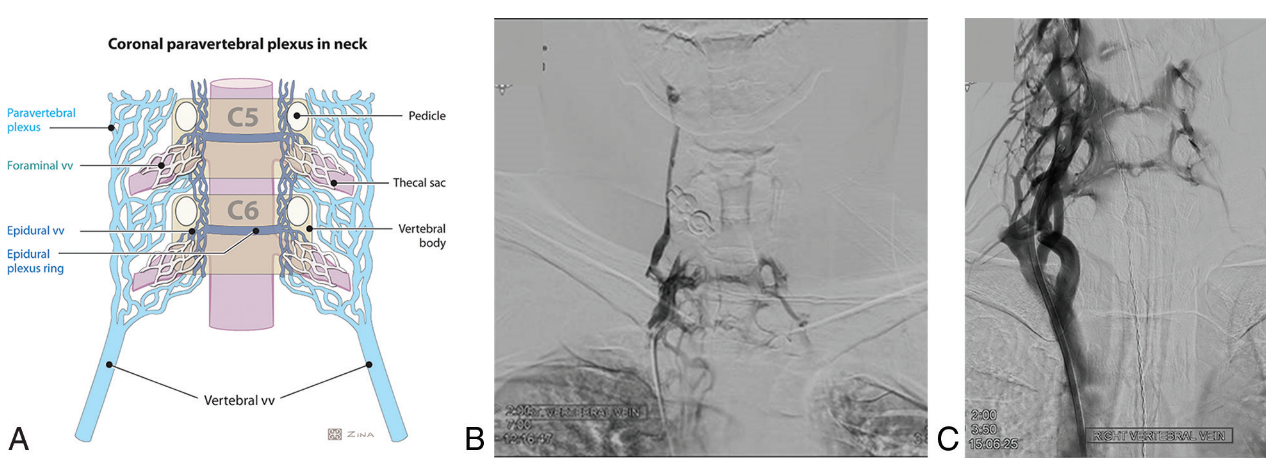

FIG 4. *A*, Coronal view in the cervical region showing that the rich plexus adjacent to the vertebral bodies is anatomically continuous and functionally analogous to the epidural plexus. Inferiorly, the paravertebral plexus condenses into the vertebral veins. *B* and *C*, Vertebral venograms rapidly opacify the paravertebral plexus, foraminal veins, and epidural plexus. Filling defects just adjacent to the vertebral bodies represent the pedicles. The more lateral filling defects represent the vertebral artery running through transverse foramina. Between adjacent pedicles is the foraminal vein. Lateral to the pedicle is the paravertebral plexus; medial to it is the epidural plexus, with its characteristic hexagonal shape. v indicates vein; vv, veins.

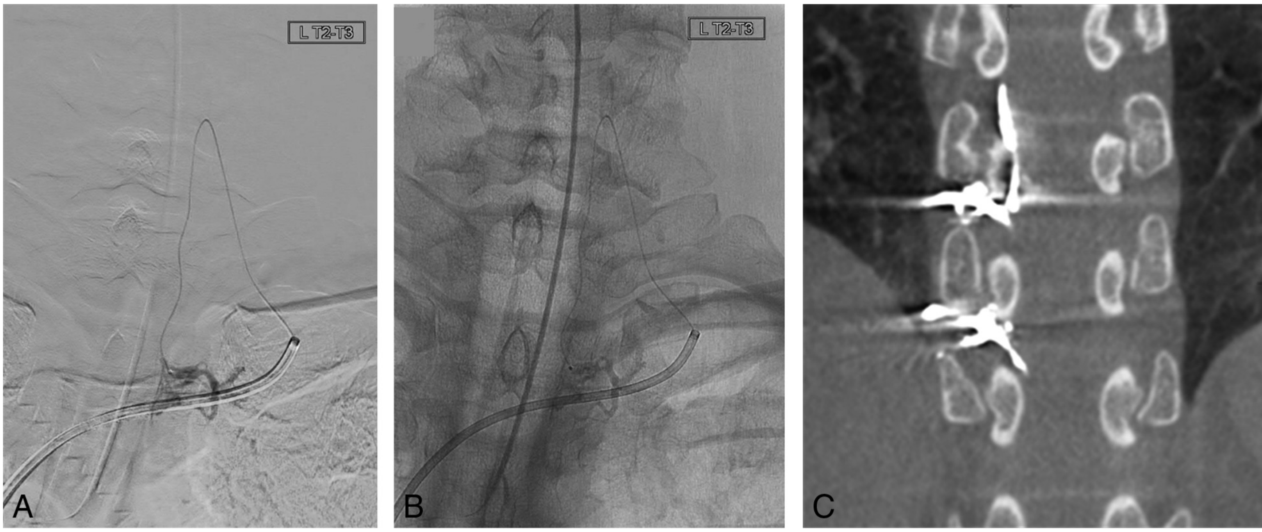

FIG 5. Examples of the appearance of the lateral epidural space at different levels. Subtracted (*A*) and unsubtracted (*B*) microcatheter venography performed at the left T2 lateral epidural plexus fills the foraminal veins. In this case, the guide catheter is in the left brachiocephalic vein. The microcatheter enters the left C6 foramen via the vertebral vein, before forming a hairpin turn and traveling caudally across 3 levels through the lateral epidural plexus. *C*, Postembolization conebeam CT in a different patient shows the embolic agent within the right T8 and T9 foraminal veins and the adjacent lateral epidural plexus.

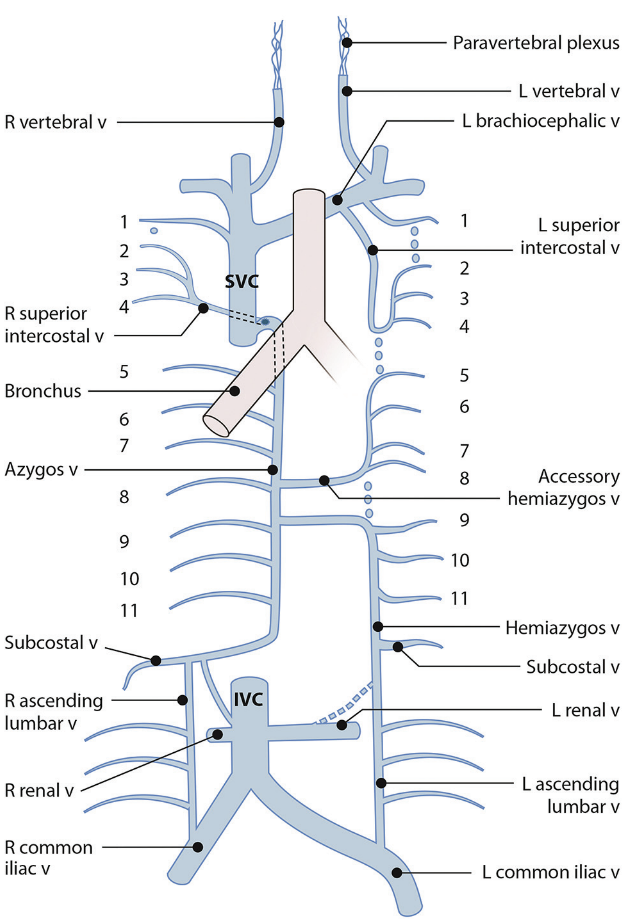

FIG 6. Overview of the azygos system and its main tributaries. The right mainstem bronchus is included as a landmark for the arch of the azygos vein. R indicates right; L, left; v, vein.

Most important, in the thoracolumbar spine, these veins drain directly into the adjacent segmental vein (such as an intercostal vein) at each level. Their role is, therefore, crucial in navigating a microcatheter or liquid embolic agent as close as possible to the nerve root sleeve, the site of pathology in patients with CSF-venous fistulas (Fig 1).

Efferent Pathways. The term "segmental vein" is a general term encompassing the posterior intercostal, subcostal, and lumbar veins. "Paraspinal vein" refers to the part of the segmental vein that runs adjacent to the vertebral body. It effectively begins medial to where the foraminal vein joins the intercostal or lumbar vein and ends by draining into a larger vein such as the azygos vein (Fig 1).

Although textbooks usually describe this segmental arrangement, in practice, we have found the arrangement to be slightly more complex, with intersegmental veins anastomosing adjacent segments. This subtle point is worth remembering when injecting liquid embolic agents, lest the operator be caught out by the unexpected appearance of an unfamiliar structure. We have had several cases in which Onyx (Medtronic) injected at 1 level (eg, T10) traveled a level above or below via this pathway. Occasionally, we have traversed this vein with a microcatheter when a more direct route to the foramen was challenging. The onward drainage of each segmental vein varies in different parts of the spine. The next section covers the gross organization of efferent pathways from segmental veins at various levels toward the superior vena cava (SVC).

Gross Organization of Spinal Venous Drainage

Venous blood from the posterior aspect of the axial skeleton of the trunk, including the spine, drains chiefly via the azygos system, which comprises the azygos vein itself and the hemiazygos and accessory hemiazygos veins (Fig 6). Spinal venous drainage is

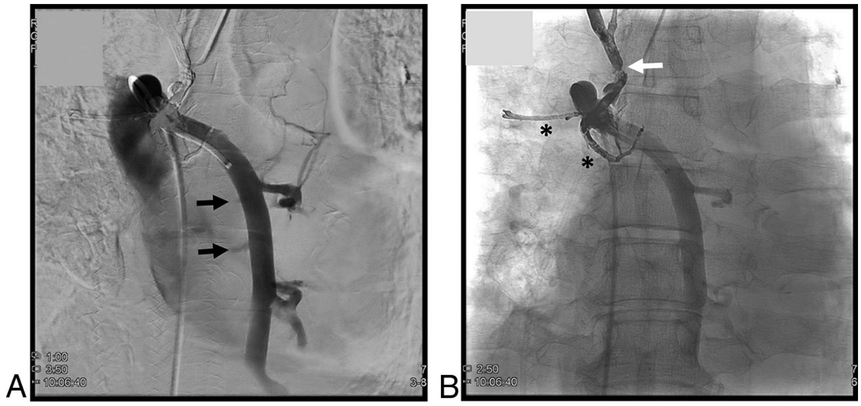

FIG 7. Subtracted (*A*) and unsubtracted (*B*) views of azygos venography. To the right of the vertebral bodies, the guide catheter is seen to ascend from the IVC to the SVC, before coursing backward into the azygos vein. The trachea and carina are seen in relation to the arch of the azygos vein. Numerous venous stumps (*black arrows*) along the azygos vein represent reflux into paraspinal veins at each level. In this image, an embolic agent cast is seen filling the right superior intercostal vein (*white arrow*), which drains into the superior aspect of the arch of the azygos. There is also some opacification of 2 bronchial veins (*asterisks*).

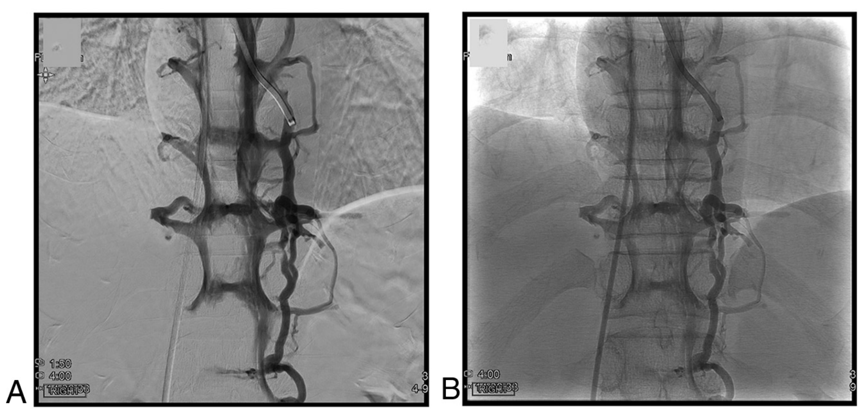

FIG 8. Subtracted (*A*) and unsubtracted (*B*) images showing a 6F guide catheter crossing the midline from the azygos to the hemiazygos vein at the level of T9. Also apparent is the hexagonal shape of the epidural plexus, with a central filling defect at the level of the intervertebral disc. The subtracted image below shows the corresponding bony landmarks.

segmental, more uniformly so in the trunk than in the neck. In the thoracolumbar spine, segmental veins drain directly or indirectly into the azygos system, which, in turn, drains into the SVC.

In the cervical spine, a rich paravertebral venous plexus drains into the paired vertebral veins, themselves tributaries of the innominate veins, and, in turn, the SVC. The anatomy of cervical spinal venous drainage is, therefore, addressed separately from the thoracolumbar spine.

Azygos System. The azygos system comprises the azygos vein on the right and the hemiazygos (lower thoracic) and accessory hemiazygos (upper thoracic) veins on the left. It connects the SVC and IVC and serves as an alternative route for venous return to the heart when either the SVC or IVC is compromised.

The azygos vein is a right-sided longitudinal paravertebral structure in the thorax.[11] It is formed by the union of the right ascending lumbar vein with the right subcostal vein at the level of T12. From there, it ascends in the posterior mediastinum before coursing anteriorly to form an arch above the right main bronchus and draining into the posterior aspect of the SVC (Fig 7). Conventionally, there is a single channel, though primitive duplicate channels can persist. Although classically described as a right-sided structure, we have observed several cases in which the azygos vein ran in the midline or even slightly to the left.

Apart from draining the right side of the posterior trunk, the azygos vein also carries the burden of draining blood from its left-sided counterparts into the SVC. On the left, the hemiazygos vein drains the ascending lumbar vein, left subcostal, and 9th-to-11th intercostal veins, usually coursing around the anterior aspect of the T9 vertebral body to drain into the azygos vein (Fig 8). The accessory hemiazygos vein usually drains the fifth-to-eighth intercostal veins on the left, before also crossing the midline at the level of T8 to drain into the azygos vein. The hemiazygos and accessory hemiazygos veins may also be directly connected to each other.

Variability exists with regard to the level at which the hemiazygos and accessory hemiazygos veins join the azygos vein. The interventionalist must, therefore, keep an open mind, use venography to obtain a roadmap, and review prior cross-sectional venous imaging.

Azygos Tributaries Above. On the right, the second-to-fourth intercostal veins drain into the superior intercostal vein, which, in turn, drains into the arch of the azygos vein close to its junction with the SVC just above the right main bronchus. The left superior intercostal vein usually drains the second-to-fourth intercostal veins into the left innominate vein but may also communicate with the accessory hemiazygos vein (Fig 6). The supreme (or highest) intercostal veins on each side may drain into the innominate, superior intercostal, or vertebral veins.

Azygos Tributaries Below. In the lumbar spine, the segmental veins converge to form the ascending lumbar veins on either side of the midline (Fig 6). While the right ascending lumbar vein almost always ends in the origin of the azygos vein, the left ascending lumbar vein can either cross the midline to drain directly into the azygos vein or remain to the left of the midline to join the left subcostal vein in forming the hemiazygos vein.

FIG 9. Venography performed with a catheter in the superior aspect of the left internal jugular vein (larger and more lateral, *black arrow*) shows contrast draining via the condylar vein (*asterisk*) into the vertebral vein (medial and smaller, *white arrow*), which inferiorly drains into the junction of the internal jugular vein with the left brachiocephalic vein. Along its course, multiple tributaries drain into the vertebral vein from the paravertebral plexus and foraminal veins. A catheter and wire are angled medially and superiorly from the junction of the brachiocephalic vein with the internal jugular vein to select the vertebral vein from below.

Since publishing the first transvenous embolizations, we have embolized 78 fistulas in 60 patients. Our experience has shown that in the thoracic spine, right-sided fistulas are more common than left-sided ones, which is fortuitous because they are more easily accessible than their left-sided counterparts. In the cervical spine, they do not seem to be biased for one side over the other. Fortunately, again, access is reasonably straightforward on both sides.

Access to the SVC. We have approached most of our cases via a common femoral vein puncture. The antecubital vein can be used to access the azygos system, lending itself well to upper thoracic lesions. Overall, our preference remains for groin access, which is better suited to the layout of our neurointervention suites, the length of our usual catheters, and the general familiarity of our team with this setup.

All the efferent pathways draining the spine converge on the SVC before draining into the right atrium. The first part of each procedure is, therefore, virtually always the same, navigating from the groin sheath to the SVC by directing the wire and catheters through the abdomen, through the right atrium, and out again in a straight trajectory directed cranially.

The following sections group the neural foramina by their common venous drainage (or endovascular access) pathways. Numbers in parentheses represent the number of fistulas embolized in our first 60 patients.

Right T5–12 (41 Fistulas, 52.6%). The most common site for CSF-venous fistulas is the right T5–12, and fortunately, we have generally found access to the draining vein to be relatively straightforward.

Recalling that the azygos vein courses over the right main bronchus to drain into the posterior aspect of the SVC, when the guide catheter reaches the level of the right main bronchus in the lower part of the SVC, one would direct an angled intermediate catheter posteriorly and advance a curved wire. The wire is seen to curve over itself and head inferiorly, posteriorly, and to the left toward the midline. Once enough wire has been advanced to ensure stability, the intermediate catheter and guide catheter follow into the azygos vein.

A common obstacle when accessing the azygos vein is the presence of a valve at its junction with the SVC.[12] In most cases, this can be crossed just by advancing the wire, but at other times, it requires a few tries and inhalational maneuvers in awake patients. Once the guide is inside the azygos vein, venography is

Vertebral Veins. Unlike in the thorax and abdomen, the skeletal arteries and veins in the neck are not arranged in a strictly metameric fashion. A rich venous network surrounds the cervical spine and communicates with the internal jugular vein and the venous plexuses surrounding the foramen magnum and skull base. The vertebral veins are paired longitudinal paravertebral structures that drain the cervical intervertebral foramina and paravertebral plexuses. In the lower neck, each vertebral vein usually exists as a uniform single channel, but higher up, its configuration consists of a rich, confluent, and valveless paravertebral plexus (Figs 4 and 9). This plexus begins at the level of C1, surrounds the vertebral artery within the transverse foramina of C2–C6, and funnels inferiorly into a large, single channel at the level of C6. Medially, the paravertebral plexus is continuous with the epidural plexus within the spinal canal via the foraminal veins.

Road to the Foramen

The spinal nerve root sleeve is a recognized site of CSF absorption into venous blood under normal physiologic conditions. In patients with a CSF-venous fistula, this mechanism appears to be exaggerated at ≥1 level for reasons that are as yet unclear.

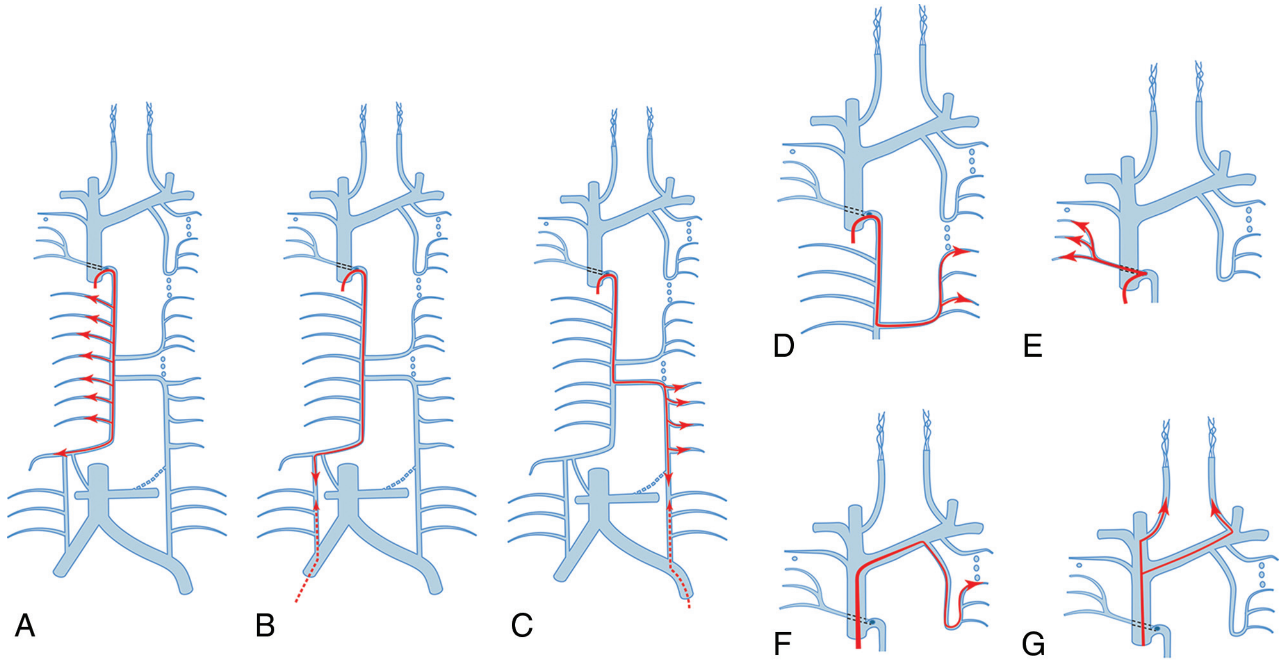

FIG 10. Roadmaps to each foramen, grouped by common venous drainage pathways. *A*, Right T5–12. *B*, Right lumbar. *C*, Left T9–12 and lumbar. *D*, Left T5–8. *E*, Right T1–4. *F*, Left T1–4. *G*, Cervical.

performed, providing a roadmap for further navigation. Usually, a stump is seen at the level of each segmental tributary. A microwire and microcatheter are then navigated into the stump of interest and pushed out laterally (Fig 10*A*).

In cases in which a stump is not seen at the desired level, directing a curved microwire to the right of the azygos vein at the level of the target intervertebral foramen usually results in the wire finding the segmental vein. The microcatheter is then tracked into the segmental vein before advancing the wire further. As the segmental vein courses from the anterior to the lateral aspect of the vertebral body, the trajectory of the wire turns to run anterior-to-posterior. At this point, advancing the wire forward a few centimeters at the hub results in the tip appearing to move either very slowly or not at all on a frontal view. Pushing further is usually enough to see the wire start to course laterally again as the vein wraps around from the vertebral body to the rib. If one is in doubt, an oblique projection can provide better visualization of the wire tip and its behavior.

Once the microcatheter tip is close to the intervertebral foramen, microcatheter venography is performed to show the intercostal vein and foraminal venous plexus. This is then used as a roadmap for injection of the liquid embolic agent.

As we have gained experience and confidence with the procedure, we have tried to direct the microcatheter tip further into the foramen, usually by directing a sharply shaped microwire inferiorly from the segmental vein adjacent to the foramen. Although by no means essential, when this step succeeds it allows the foraminal plexus to be embolized by using a smaller volume of embolic agent in a more controlled fashion and minimizing the risk of reflux into the azygos vein.

The ideal cast aims to obliterate any possible route for CSF egress by filling the foraminal plexus circumferentially around the nerve root with modest extension into the lateral epidural plexus, intercostal vein, and paraspinal vein. Extension into the basivertebral veins is harmless and should not preclude further injection. Extension into intersegmental anastomoses also does not appear to carry any clear risk and may even provide further confidence that the pathway for CSF leak has been adequately obliterated. Despite seeming initially unnerving, injecting into the epidural plexus on a regular basis has so far not resulted in the development of any neurologic deficits from the procedure, though we accept that only time (and more procedures) will give us a fuller idea of the safety profile of the procedure.

T5 itself deserves a note of caution. The fifth intercostal vein drains into the azygos vein close to its junction with the SVC, meaning that there is only a short segment of the azygos vein for the guide catheter to sit in, which makes it harder to obtain a stable position. In addition, the guide catheter is expected to make a sharp turn as it transits from the SVC to the azygos vein; soon after this, a microcatheter is expected to make another sharp turn to the right (combining to make a 270° turn clockwise on an anterior-posterior projection, from heading cranially to heading right lateral) into the fifth intercostal vein. This turn is less of an issue at T6, where the additional length of the catheter within the azygos vein provides better stability. From T7 on, this essentially becomes a nonissue.

Right Lumbar (1 Fistula, 1.3%). The right ascending lumbar vein is caudally contiguous with the azygos vein (Fig 10*B*). The route of access to the azygos vein is described in the section above. Once azygos venography is acquired, the microcatheter and wire are directed caudally, staying out of the segmental veins and the hemiazygos vein, to the level of the target vein. Note that the lumbar segmental veins can join the ascending lumbar vein at an oblique angle. Any uncertainty over the direction required to reach the target can be resolved by performing venography from the lowermost part of the azygos vein at the level of T12. Once inside the

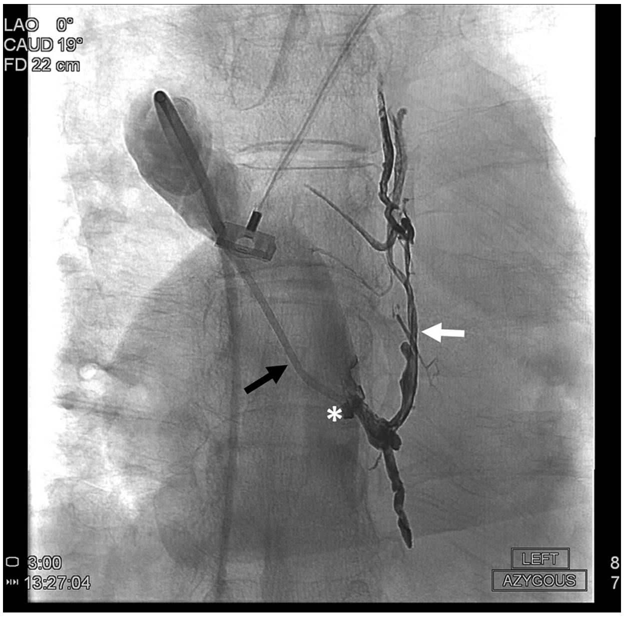

FIG 11. Postembolization image showing the liquid embolic agent in the accessory hemiazygos vein (*white arrow*) in a patient with multiple left-upper-thoracic CSF-venous fistulas. The catheter is seen to ascend in the SVC, course around the arch down the azygos vein (*black arrow*), and then cross the midline (*asterisk*) to enter the accessory hemiazygos vein.

lumbar segmental vein, onward navigation toward the foramen follows the route described in the previous section.

The right ascending lumbar vein arises from the right common iliac vein below. Sometimes we are able to take a microcatheter directly from the common iliac vein up the ascending lumbar vein, but often this vein has multiple interruptions, which make superior navigation all but impossible beyond a couple of levels.

Left T9–12 and Left Lumbar (11 Fistulas, 14.1%). Left T9–12 all drain into the hemiazygos vein (Fig 10C). The route begins by placing a guide catheter in the azygos vein at the level of T8 or T9 and performing venography. This process usually provides good visualization of the hemiazygos vein crossing the midline and draining into the azygos vein. A microcatheter is taken across the midline and navigated down the hemiazygos vein to the desired level, before performing microcatheter venography and proceeding from there. Alternatively, a microcatheter can sometimes be taken directly from the left common iliac vein into the ascending lumbar vein.

Left T5–8 (6 Fistulas, 7.7%). Getting to the accessory hemiazygos vein starts off again by placing a guide catheter in the azygos vein, this time just above where the accessory hemiazygos vein crosses the midline (usually around the level of T8) to drain into the azygos vein. Venography is acquired within the azygos vein, and a microcatheter is used to cross over to the left and then ascend within the accessory hemiazygos vein to the desired level, from which microcatheter venography is performed (Fig 10*D*).

Right T1-4 (8 Fistulas 10.3%). Fistulas between T2 and T4 on the right drain into the right superior intercostal vein, which itself drains into the superior aspect of the arch of the azygos. From the SVC, the guide catheter is placed just within the azygos vein, which unfortunately limits its stability. The microcatheter and wire are then directed cranially and posteriorly into the superior intercostal vein (Fig 10*E*). The embolic agent cast in Fig 7 illustrates where the superior intercostal vein connects to the arch of the azygos.

Access to the right supreme intercostal vein for the treatment of right T1 fistulas is variable, as described above. Usually, it can be found from the superior intercostal vein. Occasionally, it requires navigating through the vertebral vein. If the supreme intercostal vein cannot be found, a microcatheter can be navigated into the T2 foramen, through the lateral epidural plexus, and cranially toward the T1 foramen.

Left T1–4 (5 Fistulas, 6.4%). The left superior intercostal vein can be accessed from either above or below. Access from below requires navigation through the accessory hemiazygos vein (see the section on the left T5–8) and directing a microcatheter further cranially (Fig 11). Access from above requires navigation from the SVC to the left innominate vein to cross the midline to the left. At approximately the lateral border of the vertebral body, the superior intercostal vein can be found on the posterior and inferior aspects of the innominate vein (Fig 10*F*). Cannulating its origin may require a sharply-angled or even reverse-facing intermediate catheter such as a 5F Mikaelsson catheter (Merit Medical).

Accessing the neural foramen in this region can, at times, be extremely difficult. Lately, we have resorted to accessing the lateral epidural plexus of the cervical spine on the left and navigating downward until we reach the target foramen (Fig 5).

Access to the left supreme intercostal vein is about as variable as it is on the right. It may drain into the innominate, superior intercostal, or vertebral veins and may require some trial and error to get there. Preintervention CT venography can help to plan routes to both the right and left supreme intercostal veins.

Cervical (6 Fistulas, 7.7%). Foraminal veins in the neck, together with their rich adjacent paravertebral and epidural plexuses, converge on the vertebral veins at approximately the level of C6 to drain into the innominate veins bilaterally. From the respective innominate vein, a wire is directed posteriorly, superiorly, and medially (Fig 10*G*). Entering the vertebral vein can be challenging due to the presence of a valve at its junction with the innominate vein and may require a few attempts or even inspiratory maneuvers in self-ventilating patients. Once the vertebral vein is found, venography is performed and serves as a roadmap for onward navigation.

The typical appearance of vertebral venography is complex (Figs 4 and 9). This complexity can serve as an ally to the interventionalist by providing a choice of pathways. In our experience, we have been able to direct microcatheters through the paravertebral plexus (outside the vertebral column) to the desired level before the microcatheter then courses medially toward the foraminal vein. At other times, we have been able to access the foramen above or below our target, enter the lateral epidural plexus, and ascend or descend from there.

It has also been possible to perform embolization from the vertebral vein itself, allowing the embolic agent to travel through its complex system of tributaries and eventually opacify the target foramen. Thus far, we have not encountered any adverse events from embolizing the whole of the vertebral vein, presumably on account of its anastomoses and functional interchangeability with its contralateral counterpart and the venous plexuses around the skull base. The chances of success, however, do diminish if the embolic agent does not travel all the way to the foramen.

CONCLUSIONS

Spinal venous navigation is infrequently performed in most neurointerventional units, including ours until recently. This article provides a comprehensive summary of the organization of venous drainage throughout various regions of the spine, together with practical guidance on navigating microcatheters to each foramen. It is entirely possible that with further experience, we will encounter additional routes to the spine, but we hope that the experience we have garnered so far will serve to provide confidence to any colleagues who may wish to embark on transvenous access to the spine.

Disclosure forms provided by the authors are available with the full text and PDF of this article at www.ajnr.org.

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