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The Cerebrospinal Venous System: Anatomy, Physiology, and Clinical Implications

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Abstract and Introduction

Abstract

There is substantial anatomical and functional continuity between the veins, venous sinuses, and venous plexuses of the brain and the spine. The term "cerebrospinal venous system" (CSVS) is proposed to emphasize this continuity, which is further enhanced by the general lack of venous valves in this network. The first of the two main divisions of this system, the intracranial veins, includes the cortical veins, the dural sinuses, the cavernous sinuses, and the ophthalmic veins. The second main division, the vertebral venous system (VVS), includes the vertebral venous plexuses which course along the entire length of the spine. The intracranial veins richly anastomose with the VVS in the suboccipital region. Caudally, the CSVS freely communicates with the sacral and pelvic veins and the prostatic venous plexus. The CSVS constitutes a unique, large-capacity, valveless venous network in which flow is bidirectional. The CSVS plays important roles in the regulation of intracranial pressure with changes in posture, and in venous outflow from the brain. In addition, the CSVS provides a direct vascular route for the spread of tumor, infection, or emboli among its different components in either direction.

Introduction

> *"... we begin to wonder whether our conception of the circulation today is completely acceptable. As regards the venous part of the circulation, I believe our present conception is incorrect."* Herlihy[1]
>
> *"It seems incredible that a great functional complex of veins would escape recognition as a system until 1940... In the first four decades of the last century, our knowledge of the vertebral veins was developed and then almost forgotten."* Batson[2]

The existence of both the cranial venous system and the vertebral venous system (VVS) was known in the 16th century, but it was not until Breschet[3] made his detailed drawings depicting the multiple anastomoses of the cranial and vertebral veins in 1819 that the anatomic connection between the intracranial cranial venous system and the VVS was accurately depicted (Figure 1). We now recognize the substantial anatomic and functional continuity that exists between the veins, venous sinuses, and venous plexuses of the brain and the spine. I propose the term cerebrospinal venous system (CSVS) to emphasize this continuity, which is further enhanced by the general lack of venous valves in this network.

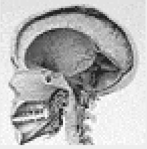

Figure 1. (click image to zoom) The cerebrospinal venous system as depicted by G. Breschet in *Recherches anatomiques physiologiques et pathologiques sur le systáeme veineux*. Paris, France: Rouen fráeres; 1829.

The significance of this venous system was lost until the seminal work of Batson[2] in 1940, and frequently is unrecognized despite a long history of confirming work.[4-8] In a series of experiments involving human cadavers and living monkeys, with corrosion casts, anatomic dissections, and injections of radioopaque dyes viewed with both still and cine radiographs[9-14] Batson demonstrated the continuity of the CSVS from the pelvis to the cranium and established that the CSVS provided a direct vascular route for the spread of tumors, infection, or emboli from the pelvis or spine to the brain. Batson's functional radiographic studies defined many of the physiologic characteristics of this unique venous system, including the critical facts that the veins in this system were valveless and thereby allowed bidirectional flow. In 1947, Herlihy[1] highlighted the significance of this singular discovery of the existence of a major venous system that did not follow Harvey's[15] circular flow paradigm of the circulation.

Batson's discoveries, although they remain largely unknown, have been supported by subsequent studies with a variety of imaging modalities, including angiography, corrosion casting, ultrasound, computed tomography (CT), and magnetic resonance (MR) venography. The functional continuity of the cranial and vertebral venous networks provides a ready explanation for commonly reported patterns of metastases, infection, and embolization.

Anatomy of the CSVS

> *"In brief, the vertebral veins are a valveless plexiform network with a longitudinal pattern. They parallel and communicate with the superior and inferior venae cavae. The plexus extends the entire length of the vertebral column and finds a cranial terminus in the dural sinuses."* Batson[2]

The intracranial venous system, including the dural sinuses, has long been known, but it was Breschet[3] who most clearly and accurately depicted the rich, direct interconnections between the cranial venous sinuses and the vertebral venous plexus (Figure 1).[16] The thin-walled veins of the vertebral venous plexus require special methods to preserve their architecture for postmortem examination. First demonstrated by dissection, newer methods of injection[5,17,18] and imaging with x-ray,[6-8,19-23] CT, and MR[24-27] techniques have established and confirmed both the anatomy and anastomoses of this unique venous system. Moreover, the epidural veins have been referred to as the meningorachidian veins.[2,6]

The Vertebral Venous Plexuses: Internal, External, and Basivertebral Veins

Breschet's detailed description of the anatomy of the VVS was confirmed by Bock,[4] via the dissections, corrosion studies, and injection studies of Batson[2,9,10,12-14] in human cadavers and living monkeys, and by angiographic studies in humans carried out by Anderson.[28] These studies have shown that the vertebral venous plexus comprises an interconnected and richly anastomosed system of veins that run along the entire length of the vertebral canal. For descriptive purposes, Groen and colleagues[29] separated the vertebral venous plexus into three intercommunicating divisions: the internal vertebral venous plexuses (anterior and posterior) lying within the spinal canal but external to the dura; the external vertebral venous plexuses (anterior and posterior), which surround the vertebral column; and the basivertebral veins, which run horizontally within the vertebrae. Both the internal vertebral venous plexus and the external vertebral venous plexus course longitudinally along the entire length of the spine, from the sacrum to the cranial vault. Clemens[5] used corrosion casting and injections of *Araldite* to demonstrate that the internal and external vertebral venous plexuses freely intercommunicate, which was also demonstrated by Vogelsang[7] with intraosseous spinal venography. Groen and colleagues[17] used an improved *Araldite* injection technique and confirmed the fact that all 3 divisions of the VVS (internal and external plexuses and the basivertebral veins) freely intercommunicate, and that all divisions of this system lack valves. The internal vertebral venous plexus communicates with the intraspinal and radicular veins and freely communicates with the external vertebral venous plexus via the intervertebral veins (Figure 2).[10,23,29,30]

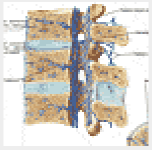

Figure 2. (click image to zoom) The veins of the spinal cord and the vertebral column, as depicted by Netter,[30] used with permission. Note the drainage of the interspinous space by the posterior external vertebral venous plexus.

The Interconnection of the Venous Systems of the Spine and the Brain

> *"When the amount of the injection mass was increased to a total of 200cc, the material attained the base of the skull and entered the cranial cavity."* Batson[2]

The anatomic anastomoses between the vertebral venous plexuses and the intracranial venous system, first depicted by Breschet,[3] have been confirmed by multiple investigators. In particular, Batson's[2,9,10,12-14] injection studies and Anderson's[28] angiographic studies in living humans demonstrated that injection into the VVS leads to visualization of the cranial venous sinuses. More recent investigations have detailed identical findings, and have established the direct functional connection of the vertebral venous plexus with the intracranial venous system, including the suboccipital cavernous sinus, the condylar veins, and the hypoglossal plexus.[17,18,25,31,32] Free communication between the VVS and the intracranial venous system was confirmed by Groen and colleagues,[17] who found *Araldite* distributed in the cranial sinuses (superior sagittal sinus, confluens sinuum, sigmoid sinus, cavernous sinus, and plexus basilaris) and the major cerebral and cerebellar cortical veins after injecting the dye into the VVS.

Communication of the Intracranial Venous System and the Veins of the Scalp, Skull, and Face

> *"Throughout the cranium the veins of the brain, the veins of the meninges (the venous sinuses), and the veins of the skull bones themselves (the diploic veins), and the veins of the various extracranial plexuses anastomose richly."* Batson[2]
>
> *"The facial veins and their important anastomoses with the intracranial venous system are less well appreciated."* Osborn[33]

Angiography has demonstrated communication between the facial veins, ophthalmic and orbital veins, and internal cerebral veins,[33] confirming Batson's[10,11] studies, which used both injection techniques and corrosion casting. Of note, the veins in the cavernous sinuses (lateral sellar compartments) are part of the CSVS.[2,18,28,29] Parkinson[34,35] described the vertebral venous plexus as part of the extradural neural axis compartment, which extends from the spine to the lateral sellar compartment (cavernous sinus) and the orbital veins. Anastomoses of the CSVS with veins of the skull, the scalp, and the face, and the possibility of bidirectional flow have led Zenker and Kubik[36] to speculate that one of the normal physiologic functions of these anastomoses is to enable cooling of the brain and spinal cord. Because this entire interconnected system is valveless, blood can flow in any direction, either to or from the brain, the ophthalmic veins, the cavernous sinuses, the spinal cord, or the vertebrae.

Communication of the Vertebral Venous Plexuses and the Veins of the Back and Thoracoabdominal Wall

> *"These vertebral veins have many and rich communications with the veins in the spinal canal, the veins around the spinal column, and those within the bones of the column. This system communicates with the segmental (intercostal) veins of the thoracico-abdominal wall (including those of the breast) and with the azygous system of veins."* Batson[2]
>
> *"Structures posterior to the transverse processes of the vertebrae drain their blood into the valveless postvertebral veins."* Batson[12]

In the same way that the intracranial venous system communicates with the superficial veins of the scalp, head, and face, the VVS freely communicates with other superficial valveless veins in the back and thoracoabdominal wall.[12,17] Batson[2,10,12] injected radioopaque dye into the subcutaneous breast veins of human cadavers and demonstrated flow into the VVS and the cranial dural sinuses, including the transverse sinus and the superior longitudinal sinus. The external vertebral venous plexus connects directly with veins overlying the posterior spinous processes, veins draining the interspinous space, and veins draining the deep back muscles (Figure 2).[5,7,14,29,30]

Anastomoses of the VVS With the Azygous, Pulmonary, and Caval Venous Systems

In addition, via anastomosis, the vertebral venous plexus communicates with the systemic venous system, including the azygous system of veins (and thereby the posterior bronchial vein and the parietal pleural veins), the left renal and suprarenal veins, the portal venous system, and both the inferior and superior vena cava, thereby providing a venous system that both bypasses and communicates with the valve-bearing systemic venous system.[12,17,29]

Communication of the Vertebral Venous Plexuses and the Pelvic, Prostatic, and Sacral Veins

> *"After a total of 200cc. of the diodrast had been injected into the deep dorsal penile vein, skull films were obtained... there is an accumulation of the opaque media in the superior sagittal sinus and in addition the confluens sinuum... and many of the superior cerebral veins are filled... the straight sinus is well filled... the great cerebral vein, the petrosal sinuses and a portion of the basilar plexus of veins are outlined."* Anderson[28]

At the caudal end, the vertebral venous plexus freely communicates with the pelvic and prostatic veins and the sacral venous plexus.[2,17,29]

In summary, multiple anatomic investigations have confirmed that the CSVS is an interconnected valveless venous system that runs from the pelvis to the cranium, and within which the venous drainage of the brain, the spinal cord, the spine, and the vertebral bodies intermix. As Batson[14] stated, "the cranial dural veins are the uppermost terminus of the vertebral veins." The CSVS has connections to both the deep systemic, valved venous system (including the inferior and superior vena cava) and to valveless superficial veins in the face, head, back, and thoracoabdominal wall. The rich anastomoses and important functional connections between the cranial venous system and the VVS support naming this venous network the CSVS.

Physiology

The 4 Fluid Systems That Communicate Between the Intra- and Extracranial Compartments

Conceptually, one can divide the fluid systems that communicate between the intra- and extracranial compartments into 4 categories: the cerebrospinal fluid (CSF), the arteries, the jugular venous system, and the VVS. According to the Monroe-Kellie hypothesis, the sum of the volume of the various components of the intracranial cavity (blood, brain, and CSF) always remains constant.[37] Changes in intra- and extracranial distribution of the CSF are limited because the dura lack distensibility. Therefore, because the intracranial contents are not compressible under physiologic conditions, changes in cranial arterial blood volume would need to be compensated by correspondingly opposite changes in the cranial venous volume. Because cranial blood flow is continuous, cranial arterial influx must equal cranial venous efflux. The jugular venous system, however, is poorly suited to this task on its own, because it tends to collapse with changes in posture, acting like a Starling resistor.[37,38] Hence, an important physiologic role of the VVS concerning the rate of venous flow from (and to) the brain comes into play.

Venous Outflow From the Brain

> *"... we are correct in regarding the vertebral veins as the largest and by far the most important accessory pathway for venous return from the cranium."* Herlihy[1]
>
> *"These studies demonstrate that the vertebral venous plexus is an important cerebral venous outflow tract in the supine position, and in the erect position it appears to be the major pathway of exit of cerebral blood."* Epstein, et al.[20]
>
> *"... the vertebral venous plexus provides one of the major circulatory compensations that allows man to remain conscious while sitting or standing."* Eckenhoff[19]

The jugular venous system is commonly recognized as the main route of venous efflux from the brain. However, the jugular venous system has important flow limitations occurring with changes in posture.[38,39] In 1966, Eckenhoff[40] postulated that the vertebral venous plexus may provide a significant route for venous efflux from the brain. In 1970, Epstein and colleagues[20] provided scientific evidence to support this by demonstrating that when the sagittal sinus was injected with contrast media in rhesus monkeys in the upright position, the VVS was the main route of venous efflux from the brain, and the VVS continued to be an important venous outflow tract even in the supine position. They suggested that the vertebral venous plexus may act as a siphon, facilitating the flow of blood across the brain when the body is upright. Thus, the CSVS may compensate for the flow limitations inherent in the jugular venous system. Neuroscientists have demonstrated that venous outflow from the brain occurs predominantly through the CSVS when one is standing.[19-21,38,41-44]

Valdueza and colleagues[45] used color-coded duplex sonography to measure cerebral venous outflow in 23 healthy human volunteers, and found that internal jugular flow decreased from 700 mL/minute in the supine position to 70 mL/minute at 90° elevation. They also found a corresponding increase in vertebral vein flow from 40 mL/minute at 0° elevation to 210 mL/minute at 90°, with the remainder of the unmeasured flow probably passing through the internal vertebral venous plexus, which was inaccessible to Doppler measurement.

Schreiber and colleagues[46] also investigated human cerebral venous blood drainage with color-coded duplex ultrasound. In their first study, they reported that total venous blood flow at rest was 766 ± 226 mL/minute in healthy human volunteers in the supine position, with the majority of flow through the internal jugular veins (720 ± 232 mL/minute) and a small amount of flow (47 ± 33mL/ minute) through the vertebral veins.[46] In a later study, they found that 6% of healthy human volunteers had a predominantly nonjugular pattern of cerebral venous drainage when in the supine position.[41] Gisolf and coworkers[38] used Doppler to measure cerebral blood flow and ultrasound to measure the cross-sectional area of the internal jugular vein in healthy human volunteers in the supine and standing positions, and before and during a Valsalva maneuver. Their calculations suggested that cerebral venous flow depends on posture and central venous pressure. When standing, without an increase in central venous pressure induced by a Valsalva, the jugular veins are collapsed, and venous efflux from the brain occurs through the VVS. The Valsalva, with the attendant rise in central venous pressure, opens the jugular veins and allows flow through this system. In the supine position, the jugular veins open; the cross-sectional area of their lumen widens; and the internal jugular veins are the main route of venous egress from the cranium.[38] Gisolf's calculations agreed with Valdueza's study, which reported a large drop in internal jugular flow even at a 15° elevation from the horizontal position. Zippel and coworkers,[47] using corrosion casting and fluoroscopy to study the CSVS in snakes, concluded that the CSVS is important for maintaining cerebral blood supply in climbing snakes and other upright animals. From all these studies in humans and other vertebrates, the anastomoses between the cranial and vertebral portions of the CSVS appear to serve an important function in providing pressure homeostasis to the intracranial venous system with changes in posture.

Bidirectional and Retrograde Venous Flow in the CSVS

> *"... a vast intercommunicating system of veins which on the basis of anatomic injections, animal experiments, and simple logic, is constantly and physiologically the site of frequent reversals of flow. During these reversals a pathway up and down the spine exists which does not involve the heart or the lungs."* Batson[2]
>
> *"The vertebral vein system is a provision of Nature to equalize pressure, to redistribute blood, and in pathologic conditions of either of the two venae cavae, to act as an alternative path for the continuation of the circulation... we must regard the venous system as being composed of five strata, of which the main two are the caval and vertebral systems... I wish to draw special attention to the pool of blood in the vertebral veins... In and out of this plexus blood runs, not unlike the earliest conceptions of an 'ebb and flow.'"* Herlihy[1]
>
> *"... due to the absence of valves, venous backflow from the internal vertebral venous plexus into the cerebral venous system occurs under physiologic conditions."* Groen[29]

The fundamental feature that distinguishes the CSVS from the systemic (caval) venous system is the lack of venous valves. In 1940, Batson[2] demonstrated that the VVS was angiographically linked to the cranial venous system, and that retrograde flow from the VVS into the brain was possible because of the lack of venous valves. Anderson's[28] experiments in living humans similarly demonstrated that contrast material injected into the VVS reached the intracranial venous sinuses and the internal cerebral veins in retrograde fashion. Groen and colleagues[17] confirmed the lack of valves and the connection of the vertebral venous plexus with the cranial sinuses, the subcutaneous cranial veins, the intercostal veins, and the sacral venous plexus, thus demonstrating "the existence of a wide communication of the vertebral venous system with the intracranial, intrathoracic and intra-abdominal veins." Later, angiographic studies by Lasjaunias and Berenstein[23] verified retrograde flow into the radicular veins, and showed that retrograde flow into the nerve roots, the spine, and the vertebral bodies was possible. According to Gisolf's[38] mathematical model, one could also anticipate that increased central venous pressure would result in caudal-to-cranial venous blood flow via the VVS, which is exactly what Batson[2,13] postulated more than a half century before. Thus, retrograde and bidirectional flow are inherent characteristics of all elements of the CSVS, made possible by the lack of venous valves.

This ability to enable retrograde and bidirectional flow is a critical distinction between the CSVS and the systemic venous system, one so important that Herlihy[1] divided the venous systems of the human body into two major parts, with one of these being the structures that I am naming the CSVS. This distinction highlights the fact that the CSVS is a venous system capable of bidirectional flow, which does not function to return blood to the heart, a characteristic that is essential to its physiologic functions in both health and disease.

This bidirectionality is a fundamental concept that runs counter to the prevailing notion that the circulatory system is circular and unidirectional. This formulation began with Andrea Cesalpino (1519-1603) who preceded Harvey in describing the circular motion of the blood in the caval-heart-aortic pathway, and then continued with Harvey's seminal *de Motu Cordis* in 1628.[15] In this work, Harvey described the significance of the venous valves in allowing the flow of venous blood in the caval system only in the direction of the heart, and stated that "the blood in the animal body moves around in a circle continuously." This last statement, so accurate in describing the flow of blood in the systemic circulation, is fundamentally inaccurate with regard to the CSVS, which rather than being a part of the circular, unidirectional caval-aortic system, is, as Herlihy[1] discussed, an "ebb-and-flow" system that is predominantly linear and bidirectional.

This ebb-and-flow formulation explains much: the unusually large capacity of this venous system (200-1000 mL;[1,2,37] by contrast, the total volume of the CSF is 150 mL[48]); the lack of valves; the variable flow through this system with changes in posture;[19-21,26,37,38,41-46] and the ability of tumor cells, emboli, and infection to travel in both directions along this system, both to the brain and from it. This valveless, ebb-and-flow system enables the CSVS to provide pressure homeostasis for the cerebral circulation, because the CSVS functions, as Batson[9,12,14] and Epstein and colleagues[20] have described, as a large-capacity "venous lake," out of which blood may flow into the brain and into which blood may flow from the brain, depending on variations in posture and intrathoracic or intra-abdominal pressure.

A Unique Bidirectional Valveless Venous System Connecting the Brain, Cavernous Sinuses, Eyes, Spine, Spinal Cord, and Pelvis

Historically, only portions of the complete CSVS have been recognized. For example, the prostatic veins are widely appreciated to be directly connected to the VVS, which supplies the anatomic route for the spread of prostatic carcinoma to the spine.[49-51]

However, it is not widely appreciated that the cavernous sinus and the orbital vessels within are connected to the VVS, as Parkinson[34,35] explained. The CSVS provides a direct anatomic route from the pelvis to the eyes and the brain, and vice versa, a route with numerous anastomoses to the systemic venous circulation, including the venous circulation of the lungs, the renal veins (particularly the left renal vein[1]), and the veins of the breast.[2,14,52] It is therefore reasonable to conceptualize the CSVS as a valveless venous system connecting the eyes, brain, spine, and pelvis, with links to the subcutaneous veins of the face, the perispinal space, and the spinal musculature.

Clinical Correlations

In addition to the experimental evidence, which includes corrosion casting; fluoroscopic and radiographic injection studies; ultrasound flow studies; and angiographic, CT, and MRI, additional clinical and experimental evidence supports the concepts discussed herein that involve the CSVS. This additional evidence is found in 3 predominant areas: patterns of metastasis, patterns of infection, and patterns of embolization.

The CSVS as a Route Facilitating Metastasis to and From the Brain and the Spine

> *"Clinicians and some pathologists alike once were content to propose that tumor cells somehow escaped the filtering function of the pulmonary capillaries and thus entered the systemic arterial circulation. Admittedly, that explanation did not account for the absence of grossly demonstrable pulmonary lesions nor for the fact that there was only one site of metastasis and that one in an unusual location. It remained for Batson to solve that riddle in his description of the structure and function of the vertebral venous system."* Hussey[53]
>
> *"I was able to see in the vertebral veins and their intrapelvic communications, a parallel to the distribution pattern of metastatic carcinoma of the prostate. Pathologists were realizing that metastases could be borne by veins. These veins furnished the only anatomic pattern that coincided with the distribution of the prostatic metastases."* Batson[12]

The CSVS provides a direct anatomic route between the brain, eyes, spine, and pelvic organs. Patterns of metastasis provide further evidence of retrograde flow within the CSVS, and of free communication between all elements of the CSVS, including the brain, facial veins, cavernous sinuses, ophthalmic veins, and spine.

Metastasis in the Cranial (Retrograde) Direction via the CSVS

Nishijima and colleagues[49] injected a suspension of tumor cells into the tail vein of mice with vena caval occlusion, which resulted in reproducible metastatic tumor growth in the lumbar region of the vertebral column. At the time, the investigators attributed the metastasis to the passage of tumor cells via the VVS.[50] In all, 90% of prostate cancer metastases involve the spine, and 15% to 30% of prostate cancer metastases have been directly attributed to passage through the VVS to the lumbar spine.[51,54,55] In addition, metastasis of prostate cancer to the skull base and the brain, likely via the CSVS, has been reported, and leptomeningeal spread is well known.[55]

Other examples of the possible spread of tumor cells in the (retrograde) cranial direction within the CSVS include a report by Ryan and coworkers,[52] who described metastasis to the cavernous sinus as the initial presentation of metastatic breast carcinoma. A case of malignant melanoma that metastasized to the ethmoid sinus[56] may be an example of the free anastomoses between the CSVS and the venous plexuses of the nose and the sinuses previously demonstrated by Batson.[11] Raymond and Balaa[57] reported a patient presenting with a brain mass that was found to be an ileal carcinoid tumor by biopsy, without evidence of bony, pulmonary, or hepatic metastases, suggesting metastatic spread via the CSVS. Isaka and coworkers[58] reported a small-cell neuroendocrine carcinoma of the bladder metastatic to the left frontal lobe. Sakata and coworkers[59] reported 7 cases of brain metastasis from esophageal carcinoma, all without evidence of pulmonary involvement, with the CSVS as the possible route of metastasis.

Metastasis in the Caudal (Anterograde) Direction via the CSVS

Tumor cells can also be carried via the CSVS in the caudal, or anterograde, direction. For example, Zhu and colleagues[60] recently reported metastasis to the cauda equina and cavernous sinus of a squamous cell carcinoma of the face. During a 5-year period, the patient developed successive trigeminal neuropathies, right cavernous sinus syndrome, and right and left facial paresis, followed by left lower extremity weakness. MRI confirmed cavernous sinus, orbital, and cauda equina metastases; biopsy of the cavernous sinus mass confirmed metastatic squamous cell carcinoma. Zorlu and colleagues[61] reported metastasis of dermatofibrosarcoma protuberans of the forehead to the cavernous sinus. Both of these cases are compatible with anterograde tumor spread via the facial veins to the cavernous sinus and then to the CSVS. Rochkind and colleagues[62] reported a consecutive series of 30 patients with extracranial metastastases from medulloblastoma with a literature review, and documented a rate of 7.1%, with bone as the most frequent site of metastasis (77%). They discussed the possible routes of metastasis, including tumor invasion of the dural veins, and noted 2 cases of intramedullary metastases to the spinal cord. More recently, Barai and coworkers[63] presented the case of a 21-year-old man who presented with pain in his hip and lower back with a 3-month history of difficulty walking. Brain MRI revealed a cerebellar medulloblastoma, confirmed by brain biopsy. MRI of the lumbar spine and hip revealed metastases to all lumbar vertebrae and both hips, and CT-guided biopsy of the L3 vertebrae revealed metastatic medulloblastoma.[63] Most recently, Rajagopalan and colleagues[64] reported glioblastoma multiforme of the brain, which metastasized to the bone marrow of the lumbar spine.

Leptomeningeal Carcinomatosis and the CSVS

Hematogenous spread is probably the most common mechanism underlying the development of leptomeningeal metastases, either via arterial seeding or from venous hematogenous access via the CSVS.[65] As originally observed by Batson,[2] pelvic tumors may reach the CSVS via the valveless pelvic venous plexus, which freely anastomoses with the VVS. This mechanism could explain the route of metastasis in some cases of meningeal carcinomatosis originating from intrapelvic tumors, including cervical cancer[66-69] and bladder cancer.[58,70-72] Sugimori and colleagues[73] reported a case of leptomeningeal metastasis from adenocarcinoma of the bladder, with metastases to the right middle frontal gyrus, superior temporal gyrus, and parietal and frontal lobes.

Intramedullary Spinal Cord Metastasis and the CSVS

Intramedullary spinal cord metastasis has been reported from lung carcinoma, breast carcinoma, melanoma, renal cell carcinoma, colorectal tumors, cervical carcinoma, lymphoma, and ovarian carcinoma.[74] Van der Kuip and colleagues[75] demonstrated that venous reflux within the VVS is a physiologic phenomenon; thus, metastasis to the spinal cord could occur via the CSVS, perhaps via retrograde flow (venous reflux) into the intraspinal veins. Concurrent brain and intramedullary spinal cord metastasis, as reported for breast carcinoma,[76] could be explained by tumor spread via the CSVS. Many other cases of tumor metastasis may represent occurrences of tumor cells carried via the CSVS.[77-91]

Transmission of Infection via the Valveless Venous System

Batson[12] discussed the possibility of dissemination of infection via the CSVS. Vertebral osteomyelitis may result from transmission of infection by way of the CSVS following prostate surgery.[92,93] Bacterial sinusitis may spread to the CSVS through the cavernous sinus and then spread intracranially, causing meningitis, subdural empyema, intracerebral abscess, epidural abscess, or superior sagittal sinus thrombosis.[94-98] Septic thrombosis of the dural venous sinuses most frequently involves the cavernous sinuses.[99] Cutaneous infections around the teeth, in the oral cavity, or around the orbit are known to spread to the cavernous sinus.[100-107] These patients may present with diplopia or other signs of cranial neuropathy.[108] Brain abscess may spread from a spinal or other remote source.[109] Parasitic infections that are remote from the head and neck may also spread to the brain via the CSVS, including schistosomiasis and sparganosis.[110,111]

Embolization via the CSVS

Emboli of air, infection, or clot may be transmitted to the brain from the spine or pelvis via the CSVS.[112,113] Cerebral air embolism of venous origin may have devastating consequences; this complication can occur in the absence of intracardiac septal defects, and may be a particular hazard of neurosurgical procedures performed with the patient in the sitting position.[114-116] Vertebral venous air embolism has been reported as a complication of colonoscopy[117] and may occur following spinal surgery.[118-120] Intraoperative irrigation of spinal surgical sites with hydrogen peroxide may be particularly dangerous because of venous air embolism propagated through the CSVS.[121,122] Some complications of percutaneous vertebroplasty and kyphoplasty may have resulted from cement embolization occurring via the CSVS,[29] including cerebral cement emboli,[29] pulmonary cement emboli,[123] and severe pain and sciatica caused by extrusion of cement into the spinal canal.[124] In addition, intracranial and pulmonary emboli reported during hip hemiarthroplasty may have propagated via the CSVS.[125]

Summary

The CSVS extends from the head to the pelvis and consists of a group of veins and venous plexuses that freely communicate because they lack valves. The first of the two main divisions of this system, the intracranial veins, includes the cortical veins, the dural sinuses, the cavernous sinuses, and the ophthalmic veins. The second main division, the VVS, includes the vertebral venous plexuses, which flow along the entire length of the spine. The intracranial veins richly anastomose with the VVS in the suboccipital region.

Caudally, the CSVS freely communicates with the sacral and pelvic veins and the prostatic venous plexus. The CSVS constitutes a unique, large-capacity valveless venous network in which flow is bidirectional. The CSVS plays important roles in the regulation of intracranial pressure with changes in posture and venous outflow from the brain. In addition, the CSVS provides a direct vascular route for the spread of tumors, infection, or emboli among its different components, in either direction. Neurologists, neurosurgeons, spinal surgeons, and oncologists, in particular, should have a thorough familiarity with the CSVS.

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