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IMAGING CASE

Transvenous Approaches to the Vertebral-Venous Plexus for Endovascular Treatment of Cervical Epidural Arteriovenous Fistulas: Anatomy and Technique

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BACKGROUND: Spinal epidural arteriovenous fistulas (seAVF) are a rare subset of vascular lesions that are most commonly found in the cervical levels. Unlike spinal dural AVF, seAVF are typically supplied by multiple arteries, including direct branches from the vertebral artery, which increases the risk of nontarget embolization using a transarterial endovascular approach. In these cases, transvenous embolization may be a preferable option, but accessing the cervical epidural venous space, also termed the internal vertebral venous plexus, can be challenging and requires advanced foreknowledge of cervical venous channels.

METHODS: The authors review salient neurovascular anatomy and present 2 techniques for endovascular access of the cervical epidural space to treat seAVF.

RESULTS: The physiology and structure of the cervical internal vertebral venous plexus is briefly reviewed. Next, the authors describe 2 complementary methods for transvenous access to the cervical internal vertebral venous plexus via the jugular vein (cranial-caudal) and the vertebral vein (caudal-cranial). The first approach involves retrograde microcatheterization via the jugular bulb and condylar veins. The second approach involves direct antegrade approach via the vertebral vein, arising from the brachiocephalic vein. Both approaches enable stable catheter positioning for coil embolization at remote cervical levels to treat a wide spectrum of seAVF.

CONCLUSIONS: Accessing the cervical epidural venous space is technically demanding and requires effective planning and knowledge of relevant spinal venous anatomy. These techniques are important tools for safe and effective endovascular treatment of seAVF.

Key Words: cervical spine arteriovenous fistula ■ endovascular ■ interventional neurology ■ transvenous intervention

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Nonstandard Abbreviations and Acronyms

DSA	digital subtraction angiography
IVVP	internal (intracanalicular) vertebral venous plexus
seAVF	spinal epidural arteriovenous fistulas
VA	vertebral artery

CLINICAL PERSPECTIVE

- Epidural fistulas of the cervical spine are difficult to treat.
- Transvenous endovascular treatment is safe but technically challenging.
- We review key venous anatomy and 2 distinct approaches for safe transvenous access to the cervical vertebral venous plexus.

Spinal epidural arteriovenous fistulas (seAVF) are a rare class of shunting lesions with variable clinical presentation and natural history.[1] Unlike the more common Spetzler Type I *dural* spinal AVF, seAVF are distinguished by extradural fistulous connection and drainage.[2] Over half of all seAVF are located in the cervical spine and most of these are symptomatic; a typical presentation includes a sensory deficit (46%) or radicular weakness (20%), but up to 13% of cases present with hemorrhage, making these lesions potentially high risk.[3]

The angioarchitecture of seAVF differs by spinal level; most cervical lesions harbor exclusively extradural drainage whereas intradural/perimedullary reflux is more frequent in thoracolumbar locations.[4] Cervical seAVF are characteristically supplied by numerous small direct arterial feeders of the vertebral artery (VA) in 80% of cases with additional thyrocervical or costocervical branch feeding arteries in 24% of cases.[3] These shunts drain via a rete of epidural veins known collectively as the internal (intracanalicular) and external (extracanalicular) vertebral venous plexus (IVVP and EVVP).[5] Unlike dural spinal AVF, symptoms are not directly due to venous hypertension but rather to the mass effect of the engorged epidural veins.[1]

Open surgical ligation and endovascular treatment strategies are feasible in cervical seAVF though the latter is the favored modality by a 2:1 ratio.[3] Transarterial embolization with liquid embolic agents is well described[6] but potentially hazardous at the cervical levels, owing to the risk of nontarget VA embolization. Moreover, the typical cervical seAVF thus has multifocal, high-flow arterial supply, resulting in higher rates of incomplete treatment, need for multiple treatment sessions, and recruitment of new feeders when a transarterial endovascular approach is employed.[1,4,7] Several authors have described transvenous approaches to cervical seAVF although, in aggregate, this approach is used far less frequently (11% in a 2013 systematic review including all spinal levels).[3] Although this approach is conceptually appealing, the technical logistics of transvenous navigation presents a formidable challenge, particularly in the cervical region.[7,8] The authors recently encountered 2 cases of cervical seAVF and present 2 distinct approaches to transvenous endovascular obliteration of these shunts with attention to anatomy and technique.

METHODS

Technique 1: Cranial-Caudal Transvenous Approach

One approach to the cervical epidural venous plexus is to obtain access in a *cranio-caudal* manner. The internal jugular vein presents a possible avenue to access this space as it contains a number of relatively consistent connections to the IVVP at the skull base including indirect connections via the marginal sinus, basilar plexus, and suboccipital venous plexus and direct connections via the condylar confluence and lateral condylar vein via an unnamed anastomotic vein.[9–11] We used this method, a variation on the technique described by Dabus et al.,[8] to treat a case of left C4–C5 and C5–C6 seAVF that presented with several months of position-related left neck pain, left leg pain, and progressive clumsiness of the left hand. Magnetic resonance imaging revealed dilated epidural veins at the C4–C6 levels in the region of the anterior IVVP (Figure 1A); time-resolved contrast kinetic showed a high-flow seAVF that was confirmed on digital subtraction angiography (DSA). Complete 6-vessel DSA was performed using a 5Fr Angled Vert diagnostic catheter (Codman Neuro, Raynham, MA) showing arterial supply with multiple small direct feeders from the left VA and the deep cervical artery; there was no direct intradural venous drainage but epidural reflux to the marginal sinus and prepontine cortical veins.

Heparin was administered to target activated clotting time >250 for the duration of the procedure to limit thromboembolic complications arising from the diagnostic catheter positioned in the VA. Ultrasound-guided 6Fr access of the right common femoral vein

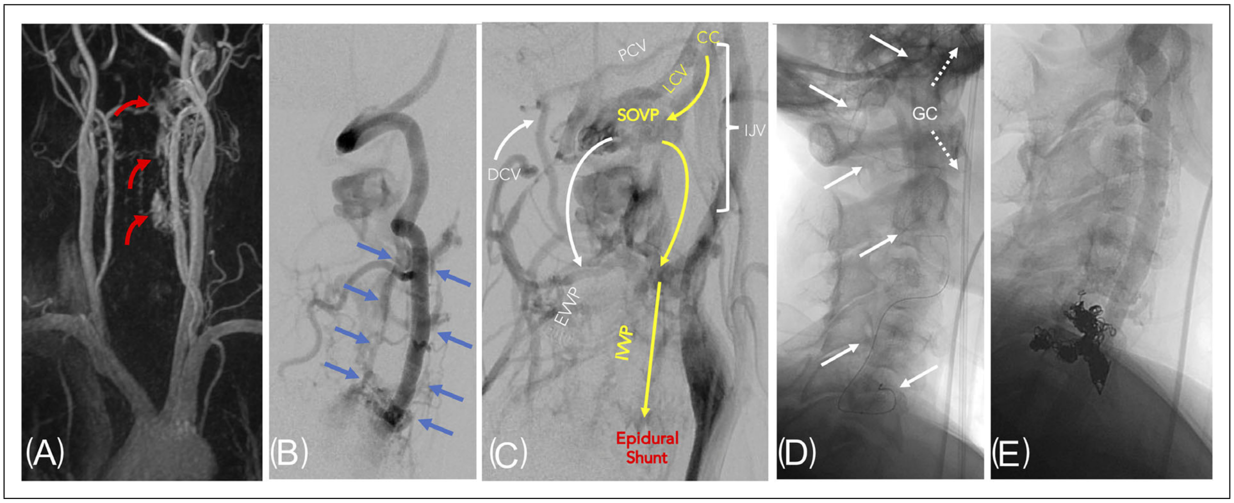

FIGURE 1. A high-flow cervical spinal epidural fistula (seAVF) at the left C4–C5 and C5–C6 levels shown on contrast-enhanced magnetic resonance angiography (red arrows, A). DSA shows multiple feeders from the vertebral artery with epidural venous reflux opacifying the IVVP (blue arrows) (**B**). Planning DSA from the subclavian artery shows access route via "cranio-caudal" approach; venous channels shown by arrows with yellow arrows indicating channel for endovascular approach. Endovascular approach is shown in (**C**, **D**); 6-French guide catheter (GC) was positioned in the IJV with tip in the LCV and anastomotic vein; the microcatheter course (white arrows) to the level of the caudal-most aspect of the recipient pouch at C-6). Post coil embolization appearance is shown in (**E**) note the coil pack conforms to the exiting nerve root at the neural foramen. CC indicates condylar confluence; DCV, deep cervical vein; DSA, digital subtraction angiography; EVVP, external vertebral-venous plexus; IJV, internal jugular vein; IVVP, internal vertebral venous plexus; LCV, lateral condylar vein; PCV, posterior condylar vein; seAVF, spinal epidural arteriovenous fistulas; SOVP, suboccipital venous plexus; and VA, vertebral artery.

and 5Fr access of the left common femoral artery were obtained. Next, under fluoroscopic guidance, a 6-French MPC Envoy guide catheter (Codman Neuro) was advanced over a 5Fr Select Angled-tip catheter (Penumbra, Alameda, CA) over a Terumo Glidewire (Microvention/Terumo, Aliso Viejo, CA), through the vena cava into the left internal jugular vein to the jugular bulb. A Headway Duo 156 cm microcatheter (Microvention/Terumo) was advanced over a Synchro Select guidewire into the left lateral condylar vein and then directed caudally toward the epidural venous plexus via the anastomotic vein. A 5Fr UCSF2 diagnostic catheter (Codman Neuro) was advanced via the transfemoral approach for intermittent arterial imaging and used for roadmapping, which was obtained from the left VA injection in the working projections (AP/Waters and Lateral Schuller's); the microcatheter was advanced over the microwire to the site of the arteriovenous fistula. Microcatheter navigation was generally straightforward and there was adequate support with the MPC guide catheter situated at the lateral condylar vein origin. Because of the angle of this connection and the abrupt change in vessel caliber, it was not feasible to use an intermediate catheter for additional support within the IVVP (biaxial system). As a consequence, the rete-like channels of the IVVP presented a challenge to navigate with an unsupported microcatheter and not all potential channels/pathways were believed to reach the fistula. These channels were navigated with careful rotation of the microwire, shaped with a sharp J-curve. Ultimately, a somewhat indirect route was taken (Figure 1) that involved passing from posterior to anterior IVVP; ultimately the shunt site was reached and microcatheter position was confirmed with gentle hand injection, showing brisk washout owing to arterial inflow at the C5–C6 level (the most caudal/distal site of the pouch on planning DSA). Coil embolization was performed using a total of 23 detachable ultrasoft coils deployed in caudal-cranial fashion (Target 360, Stryker, Kalamazoo, MI, size range 2–5 mmx4–15 cm for total of 207 cm). Because the pouch was relatively constrained by adjacent bone elements of the neural foramen, we did not encounter significant arterial pulsatility, which typically requires robust, oversized framing coils to prevent coil dislodgement. Instead, we were able to use exclusively shorter, soft coils in this case, deployed in "crescendo-decrescendo" sizes to prevent premature herniation of the microcatheter out of the targeted compartment. Care was taken not to overpack the shunt site, which encroached on the lateral recess and neural foramen and as such could cause compression of the C5 nerve root. At completion of the procedure, only trace, slow residual shunting and no reflux to intracranial veins occurred; heparin was reversed with protamine and the patient was instructed to avoid all blood thinners for 6 weeks to help facilitate continued thrombosis on the coil mass. After the procedure the patient's neck pain almost completely resolved, and the patient was discharged 1 day later with no complications. Follow-up angiography

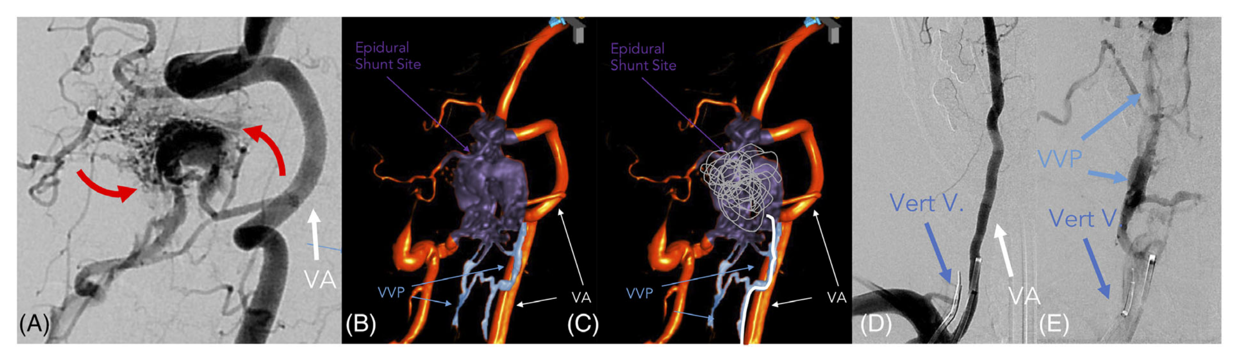

FIGURE 2. seAVF at the C2 level shown on DSA with injection of the VA, showing high-flow shunt (red arrows) (A). Three dimensional rotational DSA (**B**) from VA injection is used to select working projection and delineate path for treatment: light blue=IVVP channels, purple=epidural shunt recipient pouch). The intended microcatheter position is shown in (**C**) for transvenous coil embolization. Catheter position is shown in (**D**); a flexible Benchmark guide catheter is placed in the VA and a 6Fr Envoy catheter is positioned in the vertebral vein (Vert V.). Late-arterial phase (**E**) shows AV shunting and delineates the channels of IVVP for microcatheter navigation. DSA indicates digital subtraction angiography; IVVP, internal vertebral venous plexus; seAVF, spinal epidural arteriovenous fistulas; and VA, vertebral artery.

6 months later showed complete resolution of epidural venous shunting. At the most recent clinical follow-up, 7 months after treatment, the patient's left-hand clumsiness and left leg dysesthesia had resolved; neck pain persisted but had improved substantially.

Technique 2: Caudal-Cranial Transvenous Approach

The more "direct" endovascular approach to the cervical epidural space is a *caudal-cranial* approach, which may be advantageous in select cases.[7] This method was used to treat an seAVF that presented with pulsatile tinnitus, retroauricular pain, and headache, identified on magnetic resonance imaging/magnetic resonance angiography, which showed enlarged vessels within the spinal canal adjacent to the C2/C3 vertebrae (Figure 2A). DSA revealed a large cervical epidural AV fistula centered at the level of C2 (Figure 2B). Comprehensive, 6-vessel diagnostic DSA (5Fr UCSF 2 Angled Catheter) identified dominant arterial supply from a C2 muscular branch of the right VA and lesser supply from branches from the right deep cervical artery and small contributions from a radiculomedullary artery supplying the anterior spinal artery (from right VA) at the C1 level and supply from a postero-lateral spinal artery at C2; there were no high-risk or intradural draining veins. Heparin bolus was administered to goal activated clotting time >250 seconds for the duration of the procedure. From a femoral arterial approach, a 071 Benchmark Guide catheter (Penumbra) was advanced over a 5 French Select catheter over a 035 Terumo Glidewire to a stable position in the extra-foraminal right VA. Three-dimensional (3D) rotational DSA of the right VA was performed using 2.5 mL/second for 18 seconds injection (Omnipaque 240). From the 3D-DSA reconstruction, working views (double 45° Waters) were selected. Ultrasound-guided common femoral vein access was obtained and a 6-French MPC Envoy guide catheter (Codman Neuro) was advanced over a 5Fr Select Angled-tip catheter over a Terumo Glidewire through the vena cava to the right vertebral vein (Vert. V) using late-phase roadmap in AP/lateral right VA injection. A 038 DAC intermediate catheter (Stryker) was prepared over a Prowler Plus (2.3 French) microcatheter (Codman Neuro) with Synchro 2 Soft microwire (Stryker) and advanced into IVVP via the vertebral vein. The relatively increased stiffness of this microcatheter was a favorable characteristic for "climbing" the vertebral plexus. This was easily navigated to the antero-medial pouch at the C2 level through distended IVVP channels. To improve stability, the intermediate catheter was advanced 1–2 cm past the ostium of the vertebral vein. To account for the irregular shape of the venous pouch (maximum size 12 mm) with many internal small, labyrinthine, channels, we used an approach similar to that which we employ for transvenous cavernous sinus embolization: for each subcompartment of the pouch: the initial coil is oversized with respect to secondary diameter by 25% to 50% and is followed by shorter, ultrasoft coils until the microcatheter is "pushed out" into a more proximal chamber and the process is repeated. After occlusion of the initial compartment by deposition of 5 small ultrasoft detachable coils (Target Ultrasoft 2—3 mmx6–9 cm), the microcatheter was exchanged for a 156 cm Headway Duo (2.1 French) microcatheter (Microvention/Terumo). The lower profile and increased softness of this catheter were favorable characteristics to facilitate catheterization of the most posterior and medial aspect of the pouch. In total, 63 detachable coils were used (size range 2–8 mm by 2–30 cm, total length=744cm), comprising a combination of Target 360 (Stryker) and Optima Complex coils (Balt, Montmorency, France) deployed in a similar oscillating manner (robust framing coils to appose the margins of the compartment followed by filling with shorter, softer coils). Following the procedure, the presenting symptoms of neck pain and pulsatile tinnitus completely resolved and there were no complications. At last clinical follow-up 10 months after treatment, the patient reported near complete resolution of pulsatile tinnitus (rare, intermittent, not debilitating) and no further headaches or scalp pain.

DISCUSSION

Transvenous embolization is an effective treatment option for cervical seAVF but demands meticulous planning and foreknowledge of cervical venous anatomy. It is therefore appropriate to present a brief review of the anatomy and physiology before discussing the details of treatment.

Anatomic Considerations

The epidural venous plexus is a cranio-caudally oriented, valveless network spanning the full length of the spinal canal (Figure 3A). Its function remains the subject of debate and various authors have speculated that the VVP serves principally as an alternate pathway to the jugular veins for cerebral venous drainage in the standing position[12,13] a cushion/support system to mitigate traumatic cord injury,[14] or a mechanism to modulate cerebrospinal fluid resorption and pressure.[15,16] The VVP has even been invoked as a “cooling” mechanism for the central nervous system.[17]

In the cervical spine, the epidural venous apparatus within the spinal canal is referred to as the IVVP, distinguished from the EVVP, which drapes the posterior and lateral elements of the vertebral bodies.[5] The capacitance and volume of the IVVP increase from C1 to L5 in a manner approximately proportional to the relative size of the corresponding bony vertebral body elements. The IVVP can be further subdivided into more constant *anterior* and more variable *posterior* divisions. Both anterior and posterior IVVP comprise 2 longitudinal venous trunks situated in the lateral aspect of the spinal canal. These channels form anastamoses between each intervertebral disc to join the basivertebral vein (Batson’s plexus) in the midline anteriorly. Recent microdissection work has shown that, contrary to prior belief, these longitudinal veins have a robust and muscular wall with extensive trabeculation, similar to the *chordae willisi* of the intracranial dural sinuses.[18] This has been posited to resist overdistension from intraabdominal pressure changes and to prevent spinal cortical reflux. In normal physiologic states, spinal cord venous blood is collected by anterior and posterior spinal veins that in turn feed radiculomedullary veins (which exit at neural foramina) and “bridging veins” (ie, veins exiting between foramina). These veins then empty into the epidural venous system.[19] The mechanism by which perimedullary blood escapes without reflux (and resultant congestive myelopathy) has been the subject of debate for decades.[5,18,20–-24] The contemporary consensus is that a nonvalvular but *valve-like* narrowing of the vessel as it pierces the dura generates an innate “antireflux mechanism.”[22,23] This protective mechanism accounts for the relative infrequency of intradural venous drainage and resulting venous hypertension/myelopathy in this condition.[4,25]

Pathways for Transvenous Embolization in the Cervical Epidural Space

Debrun first reported the concept of addressing polyarterial, epidural shunts using the strategy of venous pouch obliteration by means of a detachable balloon deployed transarterially across a vertebro-vertebral fistula in 1979[26] and the first true transvenous occlusion of such a fistula was performed shortly thereafter by Kendall and Hoare.[27] More recently, true transvenous approaches have been expanded to AVF of the foramen magnum region and craniocervical junction, which have been reported with good results.[28] Willinsky et al. reported the first transfemoral venous approach to the cervical epidural space, showing feasibility of catheterizing the vertebral vein and shutting down a cervical seAVF by occluding the epidural venous pouch.[7] Since this initial report in 1993, advances in microcatheter engineering have facilitated greater distal control and navigability, which are essential when maneuvering through the epidural space.

There are 2 major routes for obtaining endovascular access to the cervical epidural space (Figure 3B,C). The first takes advantage of numerous interconnections between the internal jugular vein bulb and VVP at the skull base,[11,24,29] including direct communications with the sigmoid and inferior petrosal sinus, the suboccipital venous plexus, and smaller channel-like communication with the marginal sinus. Tubbs defined communications between the cranial dural sinuses and the IVVP using human cadavers, observing that the posterior IVVP connected to the marginal sinus in 80% of cases; such connections between the marginal sinus and anterior IVVP were less consistent. Connections linking the posterior EVVP to the intracranium were scarce but nearly always drained the suboccipital venous plexus.[29] As shown in Case 1, a cranio-caudal approach is feasible by positioning a guide catheter in the jugular bulb and using a

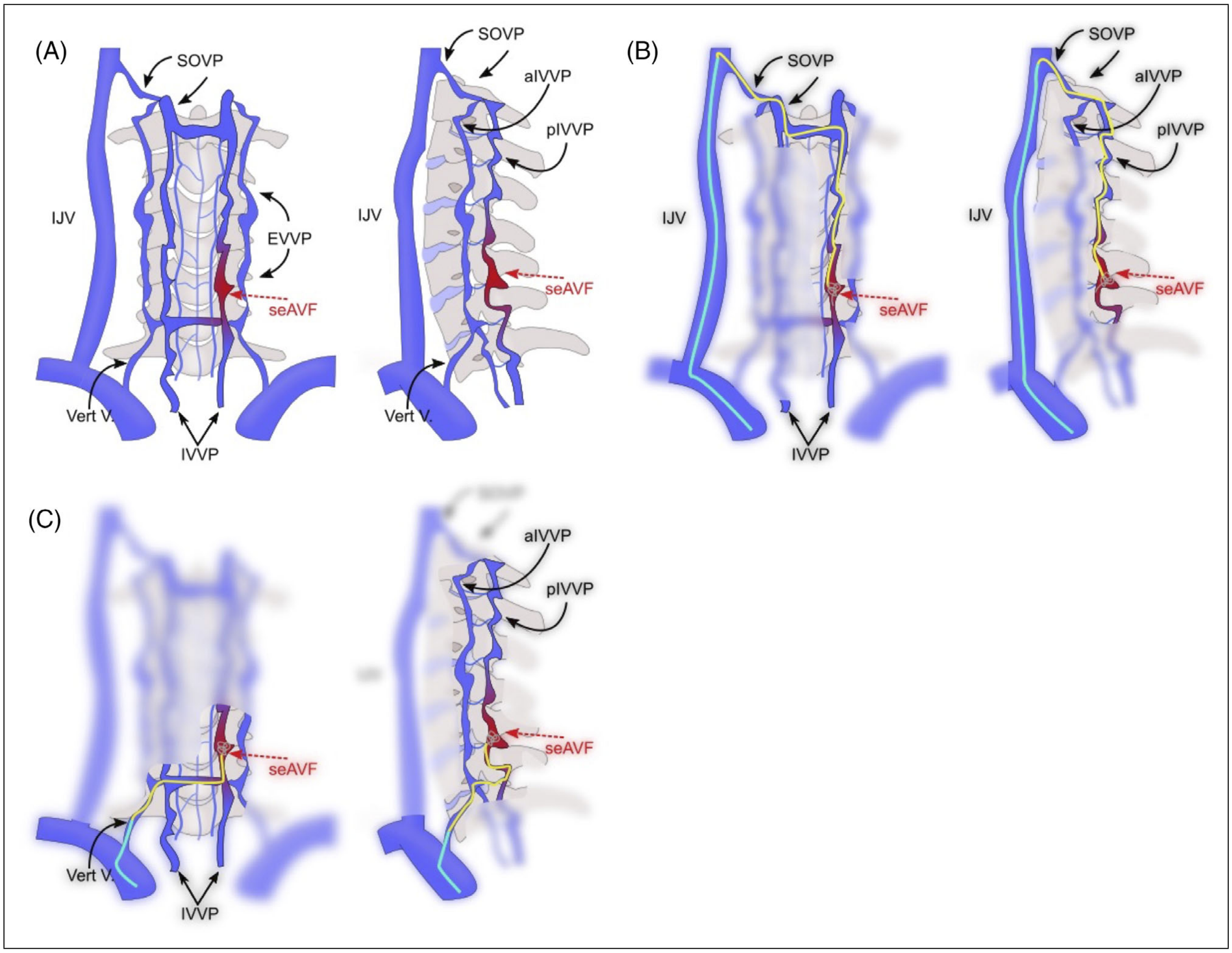

FIGURE 3. Anatomy of the cervical epidural venous spaces is shown in (A): the IJV communicates with the IVVP and EVVP via the SOVP at the skull base. The IVVP is within the spinal canal and contains anterior (aIVVP) and posterior (pIVVP) channels; the EVVP drapes the outer aspect of vertebral bodies. The vertebral vein (Vert V.) arises from the brachiocephalic vein and communicates directly with IVVP. seAVF is shown at C5–C6 level. The cranio-caudal approach to seAVF embolization is shown in (**B**). A guide catheter is advanced through IJV and microcatheter is tracked through SOVP into IVVP to access the shunt site. The complementary approach (caudo-cranial) is shown in (**C**). A guide catheter is positioned in the Vert V. and the microcatheter is navigated across the IVVP to seAVF site for coil embolization. EVVP indicates external vertebral-venous plexus; IJV, internal jugular vein; IVVP, internal vertebral venous plexus; seAVF, spinal epidural arteriovenous fistulas; and SOVP, suboccipital venous plexus.

microwire to navigate the condylar confluence, and suboccipital plexus to reach the IVVP. This approach has been described previously,[8,30] but the anatomic access and trajectory are not elaborated in detail. Once the epidural space is accessed, navigating along the cranio-caudal axis is relatively straightforward but transverse/horizontal maneuvers can be challenging owing to the highly variable presence of horizontal channels. Groen et al. showed that these so-called bridging channels tend to be most prominent at the suboccuput (C1) and C6–C7 levels, thus transversal navigation may be most feasible at these levels.[5]

When approaching the shunt from a caudo-cranial approach, the operator may encounter difficulty in entering the vertebral vein as it arises from the brachiocephalic vein, and these vessels typically contain a bicuspid valve at the origin.[31] Once this initial challenge is overcome, selection of venous channels to the IVVP can be relatively straightforward because the epidural venous spaces in the cervical spine have considerable capacitance and is typically enlarged in pathologic, high-flow states.[15,16] This characteristic can be advantageous to the endovascular operator as the high-flow characteristics of seAVF would be expected to distend otherwise narrow venous channels, rendering them more accessible to catheterization. Willinksy reported this "caudo-cranial" approach for treatment of both seAVF and paraspinal arteriovenous malformations.[7,32] In our experience, this approach is highly feasible and enables greater catheter support than the cranial-caudal approach described previously.

Although the transvenous approach to cervical seAVF offers numerous advantages, there are limitations and hazards that must be considered. Overpacking of the epidural space poses a theoretical risk of compressive radiculopathy[33] although this has not been a reported complication and was not encountered in our cases. Perforation of the epidural veins could result in extradural hematoma which may be difficult to recognize angiographically and require emergent decompression.[34,35] The considerable technical complexity of this approach can necessitate long procedure times (approximately 6 and 10 hours in cases 1 and 2, respectively). Proper preprocedure planning including comprehensive image review, anticipated resource allocation, and support staff availability is essential for undertaking these procedures to mitigate fluoroscopic dose, contrast, and overall complication risks. Lastly, although the venous channels described herein are relatively constant, it is possible that the shunt site cannot be adequately occluded by transvenous coiling despite best efforts. In such situations, direct percutaneous embolization using flat-panel computed tomography navigation has been reported as an alternative option that offers similar advantages to our method.[36]

In summary, the authors describe the technical and anatomic considerations of transvenous access to the cervical epidural space for treatment of seAVF through 2 distinct strategies. It is not clear from the authors' experience or limited existing case depictions[7,8,30,32] whether 1 route is superior and doubtless individual anatomy will reveal the optimal strategy on a patient-by-patient basis. With this in mind, it is important for neurointerventionalists to be familiar with the structure and function of the epidural veins of the cervical spine before undertaking transvenous embolization.

ARTICLE INFORMATION

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Author Contributions

MTC, MI, and MRA: conception and design of the work; initial drafting of the work. KHN, AB, JM, SWH, DLC, CFD, RTH, and VVH: substantial contributions to the conception or design of the work; or the acquisition and interpretation of data for the work; revising the work critically for important intellectual content. All authors: final approval of the version submitted. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Conflicts of Interest

All authors declare no conflicts of interest.

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