**Review Article**

# Endovascular management of cavernous sinus dural arteriovenous fistulas: Overall review and considerations

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Cavernous sinus dural arteriovenous fistulas (CSDAVFs) are arteriovenous shunts between small dural branches arising from the external and/or internal carotid arteries and the cavernous sinus (CS). And now a days, endovascular treatment is the treatment of choice in CSDAVF. We review the anatomy and classifications of CSDAVFs, discussing and detailing these considerations in the treatment of CSDAVFs, theoretically and in the light of recent literatures.

**Keywords** Dural arteriovenous fistula, Carotid cavernous fistula, Cavernous sinus

## INTRODUCTION

Vascular anomalies involving the cavernous sinus (CS) and carotid artery have varying names. One such term is carotid cavernous fistulas (CCFs), which refers to vascular anomalies involving the CS and carotid artery. It is a very interesting entity for neurosurgeons, ophthalmologists, neuro-radiologists, and sometimes radio-surgeons. However, the term CCFs includes two very different entities—direct and indirect CCFs. Direct CCFs are direct connection between the internal carotid artery (ICA) and the cavernous sinus, usually due to trauma, or rupture of an intracavernous carotid aneurysm. Indirect CCFs are arteriovenous shunts between small dural branches arising from the external and/or internal carotid arteries and the CS.

Due to their characteristics, indirect CCFs have been referred to by various terms, such as dural CS arteriovenous malformation,[23] dural CCFs,[32] CS dural arteriovenous malformation,[44] cavernous sinus dural arteriovenous fistulas (CSDAVFs),[41][45] and dural CS fistulas.[39] The inconsistent terminology reflects that the etiology, pathophysiology, and natural history are not well-known and require further investigation.

In this review, "CSDAVF" has been used for all vascular anomalies involving the CS and dural arterial supply.

In the pre-endovascular era, treatment of CSDAVFs depended on direct surgical management. However, it was associated with high morbidity and mortality. Currently, while open surgery is considered useful in limited cases, endovascular treatment is the treatment of choice since Serbinenko[42] introduced a detachable balloon for the treatment of CCF. However, the treatment options, approaches, techniques, and agents continue to evolve. In this review, we focus on the endovascular treatment, which is the preferred treatment option in the modern era.

## HISTORY

The basic anatomical concept of CS in human was proposed by Claudius Galen; however, he never actually looked at the CS in humans. He merely transposed his findings in lower animals on to humans. The term "cavernous sinus" was coined by Jacobus Benignus Winslow (1669-1770). Due to the deep-seated and peculiar hypervascular anatomy, the CS was surgically inaccessible for a long time. Surgical treatment for CCF was first reported in 1809 when Travers successfully treated a patient with pulsating exophthalmos using proximal ligation of the common carotid artery.[48] Subsequently, various indirect surgical attempts for carotid cavernous fistula were attempted, such as ligation of the common carotid artery or internal carotid artery; however, the results were not promising and, sometimes, fatal. Surgical trapping in the form of ligation of the cervical and intracranial ICA demonstrated better results but not consistently.[20] In the 1960s, Parkinson reported first sequential surgical exposure of CS for CCF.[36)38] He performed direct surgical exposure of CS under hypothermia and cardiac arrest, and repaired carotid cavernous fistula. Another intravascular treatment concept was introduced by Brooks in the form of packing a long strip of skeletal muscle into the fistulous segment.[6]

Serbinenko et al. reported embolization of direct CCF

with a detachable balloon in 1974,[42] which was the first successful endovascular procedure for CCF. Detachable balloons were a valid solution in a majority of direct CCFs and were considered the treatment of choice in direct CCFs for the past three decades. Balloons can be flow-directed through the orifices of the fistula, inflated in the venous side to a size larger than the original communication to prevent herniation into the ICA, and then detached. With a detachable balloon, closure of the fistula with preservation of the ICA is possible in approximately 75–99% of the cases.[12)21)29] However, there are some limitations with detachable balloons in the treatment of CCFs, such as premature detachment and consequent risk of distal embolism, delayed balloon deflation with fistula recurrence, and rupture of the balloon due to sharp osseus fragments in the presence of traumatic fractures. In some cases, it can be difficult to navigate the balloon through a small communication. Furthermore, reconstruction of the parent vessel with this technique is not always perfect. An irregularity at the level of the ICA tear with protrusion into the CS can be seen in up to 50% of patients after successful treatment with detachable balloons.[12] Consequently, longterm follow-up of these wall irregularities is important as growth has been observed in up to 30% of patients.[29] Following detachable balloon treatment, up to a third of patients can experience worsening of the preexisting extraocular motility deficits or develop new ones. These often involve the sixth cranial nerve running between the ICA and the lateral wall of the CS. Postoperative deficits are usually transient but can become permanent in approximately 15% of the patients.[12] Ischemic complications have been reported in 7% of the patients (3% transient and 4% permanent).[29] Since 2003, detachable balloons have not been available in some countries, including the United States of America, because of problems with balloon valve leaks. However, in many other countries, the detachable balloon is still available for treating direct CCF.

Takahashi et al. reported the first superselective CS venography in 1971,[46] and endovascular transvenous embolization of CCF was introduced by Mullan and

Hosobuchi in the late 1970s.[22)34)] Various surgical and endovascular treatment options for CCF have been introduced; however, endovascular occlusion of the venous fistula via transarterial or transvenous embolic agents, such as particles, coils, and liquid adhesives is considered the treatment of choice in symptomatic CCFs. Detachable platinum coils have been widely used in neurointerventions and, especially, in cerebral aneurysms. The first clinical case in which Guglielmi Detachable Coils (Boston Scientific Corporation, Boston, MA, USA) were used involved a patient with CCF due to ruptured intracavernous aneurysm.[17)] Now, detachable coils are the primary embolic devices in both direct and indirect CCFs due to their potential retrievability.[19)26)32)]

## ANATOMY

The concepts of arterial and venous anatomy of the CS are important in understanding CSDAVFs and their treatment. Anatomically, the CS is not a real dural sinus. The CS, or more appropriately the lateral sellar compartment, is an anatomical extradural space with direct continuity through the clivus and basiocciput with the epidural space surrounding the spine.[37)] The CS is an extradural space contained between the two layers of dura laterally and superiorly and the periosteum covering the lateral portion of the sphenoid sinus and the sphenoid bone inferiorly and medially. This extradural space contains the typical S-shaped ICA as well as nerves, fat, and a plexus of veins. Therefore, the CS is not a single venous space through which the ICA and cranial nerves course as has been classically described in older anatomical textbooks. The plexiform arrangement of the veins in the CS was apparent to Dwight Parkinson when he entered this space to directly obliterate a long-standing CCF.[37)] He remarked that "the engorged and thickened 'arterialized' veins were readily noted to be neither cavernous nor dural sinus but a plexus of veins." This observation explains "the compartmentalization" of the CS often noted during endovascular approaches in CSDAVFs.

### Arterial anatomy

The ICA gives rise to a number of small arterial branches during its course in the CS. The most consistent branch is the meningohypophyseal trunk that arises from the dorsal circumference of the C5 segment just immediately before the vertical part turns into the horizontal part. Luschka (1860) first described the arteria hypophysialis inferior. This vessel provides the arterial supply to the dura of the tentorium (tentorial artery or artery of Bernasconi-Cassinari), hypophysis (inferior hypophyseal artery), and the lateral clivus (lateral clival artery or dorsal meningeal artery). Other fairly constant branches are the infero-lateral trunk, which supplies the segment of the cranial nerves running into the lateral sellar compartment and the capsular artery of McDonnel. There are constant anastomoses between the branches of the ICA and external carotid artery (ECA). Although not always angiographically visible, these anastomoses are anatomically constant. Knowledge of these anastomotic channels is crucial in preventing complications during endovascular approaches in CS-DAVFs.[14)]

### Venous anatomy

Understanding the venous channels connected to the CS is key for the interpretation of the angiographic anatomy in CSDAVFs and plan their treatment. The superior and inferior ophthalmic veins provide normal venous drainage from the orbit to the anterior portion of CS. Furthermore, usually the superficial middle cerebral veins drain into the CS through the sphenoparietal sinus. The two separated CSs communicate through the anterior and posterior intercavernous sinus, thus, forming the circular sinus. Posterior drainage is through the basilar plexus, superior petrosal sinuses (SPS), and inferior petrosal sinuses (IPS) to the jugular bulb. Inferolaterally, connections exist through the dural veins draining into the pterigoid plexus. Intermittently, the CS can receive drainage from the inferomedial surface of the brain.

## CLASSIFICATION

After the first classification of this interesting disease by Aminoff et al. (1973) into anterior and posterior types depending on the venous drainage into the CS or lateral sinus, many other classifications have been introduced. Currently, the Barrow, Borden, and Cognard classifications are commonly used in the clinical field. While the Barrow classification mainly focuses on the type of arterial feeder, the Borden and Cognard classifications focus on the venous drainage in CSDAVF. Of them, the Cognard classification pays a little more attention to the characteristics of the cortical venous reflux.[10] The Borden and Cognard classifications are generally applicable to CSDAVF; however, CSDAVF has its own anatomical and angioarchitectural characteristics. Furthermore, even though the Cognard classification focuses on venous ectasia and cortical venous drainage as risk factors, those classifications have not been associated with clinical symptoms or treatment of CSDAVF.

In 2005, Suh et al. classified CSDAVF into three distinctive types: proliferative, restrictive, and late restrictive.[45] Suh's classification categorized CSDAVF according to the degree and pattern of the prominent arteriovenous shunt as well as the venous flow. The proliferative type includes numerous arterial feeders to the CS. The restrictive type includes multiple arterial feeders but not as many as the number of arterial feeders in the proliferative type. The late restrictive type includes a few arterial feeders with sluggish retrograde venous flow. This classification not only focuses on the venous drainage pattern of CSDAVF but also on its associated symptoms.

Thomas et al. classified CCF into five types using venous drainage in 2015. Except for type 5, which refers to direct shunt between the ICA and CS, types 1–4 are designed for CSDAVF.[47] Type 1 has posterior/inferior drainage (SPS, IPS, pterygoid, and parapharyngeal sinuses). Type 2 has posterior/inferior and anterior drainage (superior and inferior ophthalmic veins). Type 3 has anterior drainage only, and type 4 has retrograde drainage into the cortical veins with or without other routes of venous drainage. The classification by Thomas et al. differs from that by Suh et al. in that it is related not only to the symptoms but also the treatment approach and outcome.

In contrast, Wenderot et al. classified CSDAVF into three groups based on whether the IPS is patent.[51] Type 1 refers to both IPSs being patent. In type 2, both CSs are affected and unilateral IPS is occluded. Type 3 has no IPS outflow. This classification system is advantageous in that it more accurately reflects the morphology and hemodynamics of the lesion being described. Additionally, this classification can be incorporated into the existing Cognard system.

## ENDOVASCULAR TREATMENT

### Transvenous occlusion

Endovascular surgery is the primary treatment of choice for CSDAVF. With advancements in endovascular techniques, numerous routes of access and different occlusion methods are currently available.[15] Materials used in endovascular treatment include detachable balloons, platinum detachable coils, liquid embolic materials, and stents. These agents can be used alone or in combination with each other. Therefore, the approach to an individual CSDAVF is dictated by a variety of factors, such as the operator's preference for a specific embolic agent, angioarchitecture of the fistula, clinical symptoms, and available routes of access.

Traditionally, until Onyx (ev3 Inc., Irvine, CA, USA) became widely available, a transvenous approach to CSDAVF has been the standard primary route for endovascular obliteration of these lesions because of easier access, higher cure rates, and lower complication rates.[19,32] Various access routes to the CS are available and the preferred route also depends on the type of preferential drainage of the fistula, such as IPS, SPS, clival venous plexus,[9] cortical venous drainage,[4] pterygoid plexus,[24] inferior ophthalmic vein,[33] or superior ophthalmic vein (SOV) through the angular or retromandibular veins.[19,52] Choosing one of these alternate pathways

depends on the individual characteristics of the fistula's venous drainage and the anatomical position of the fistula itself in relation to the CS. When these routes are not available, more invasive percutaneous access through a surgical cutdown of the SOV is a well-established procedure. Direct percutaneous puncture of the CS is also feasible and avoids the need for surgical access to the CS.

### Inferior Petrosal Sinus

Access to the CS through the ipsilateral IPS is usually the preferred route because of the direct connection of the IPS with the internal jugular vein (IJV) through the petrooccipital fissure. Thrombosis of the IPS can be a major impediment to direct catheterization of the CS. Based on the complex drainage pattern of CSDAVF, alternative venous pathways for accessing the ipsilateral CS have included the contralateral IPS through the intercavernous sinus.[52] However, catheterization of the IPS is possible even when this sinus is not angiographically visible as well as in the presence of thrombosis.[25] Using the loop technique, catheterization into the CS through the IPS can be safely performed. Rhim et al. advocated that reopening of an occluded IPS is reasonable as an initial attempt for access. In case of "aberrant IPS," which describes the unusual variant of low termination of the IPS, late venous phases of arteriogram or repeated phlebogram from a lower portion of the IJV can clarify the true anatomical details.[5]

After placing a microcatheter into the posterior part of the CS safely, it is usually possible to navigate the microcatheter into the anterior part of the CS to approach the junction between SOV and CS. Assuming a complete comprehension of the fistulous portion, surgeons should consider the following in transvenous occlusion of CSDAVF. 1) If cortical drainage is present, the fistulous portion should be blocked at the beginning of the procedure. 2) In cases with drainage toward the contralateral fistula, it should be blocked before blocking the ipsilateral fistula. To do this, the catheter should be navigated through the intercavernous sinus. 3) The coils should be packed from the anterior to posterior direction, considering that complete blocking should be made between SOV and CS. 4) Embolization of IPS itself should be avoided whenever possible. The entire transvenous embolization of CSDAVF through IPS is illustrated in Fig. 1.

### Superior Ophthalmic Vein

In case of failure of the ipsilateral or contralateral IPS approach, attempts to approach through SOV can be considered. The treatment of CSDAVF is difficult and abstruse; therefore, SOV is an alternative route that can be considered in the treatment plan. Generally, there are two approaches to the CS via the SOV: one is the transfemoral SOV approach via the facial vein, and the other is percutaneous SOV approach with direct access. Fig. 2 illustrates our experience in treating CSDAVF through SOV. In the case of transfemoral SOV approach, many interventionists often face difficulty in navigating the microcatheter over the angular vein because of its acute angle. In such a situation, a slightly stiffer microcatheter can be helpful; however, excessive manipulation can jeopardize the patient. Therefore, in such cases, percutaneous SOV approach can be considered. Although SOV is a useful route, the presence of fragile or clotted veins can preclude successful cannulation. Interventionists should be aware of the higher risk of uncontrolled bleeding and this approach should be avoided, especially, in older patients with fragile veins.[28]

### Other transvenous approaches

If all the approaches mentioned above are impossible, other accesses can also be considered. Some authors have reported direct cannulation of the facial vein, superficial temporal vein, and frontal vein.[31)49] Infrequently, direct cannulation of the superficial middle cerebral vein by combining open craniotomy surgery and endovascular surgery have been reported.[1)8)13)27] Generally, CSDAVFs present with ocular symptoms; however, they may rarely present with intracranial hemorrhage.[1)3)27] In such cases, direct cannulation of superficial middle cerebral vein is advantageous in that hematoma evacuation and CSDAVF embolization can be performed in a single procedure.
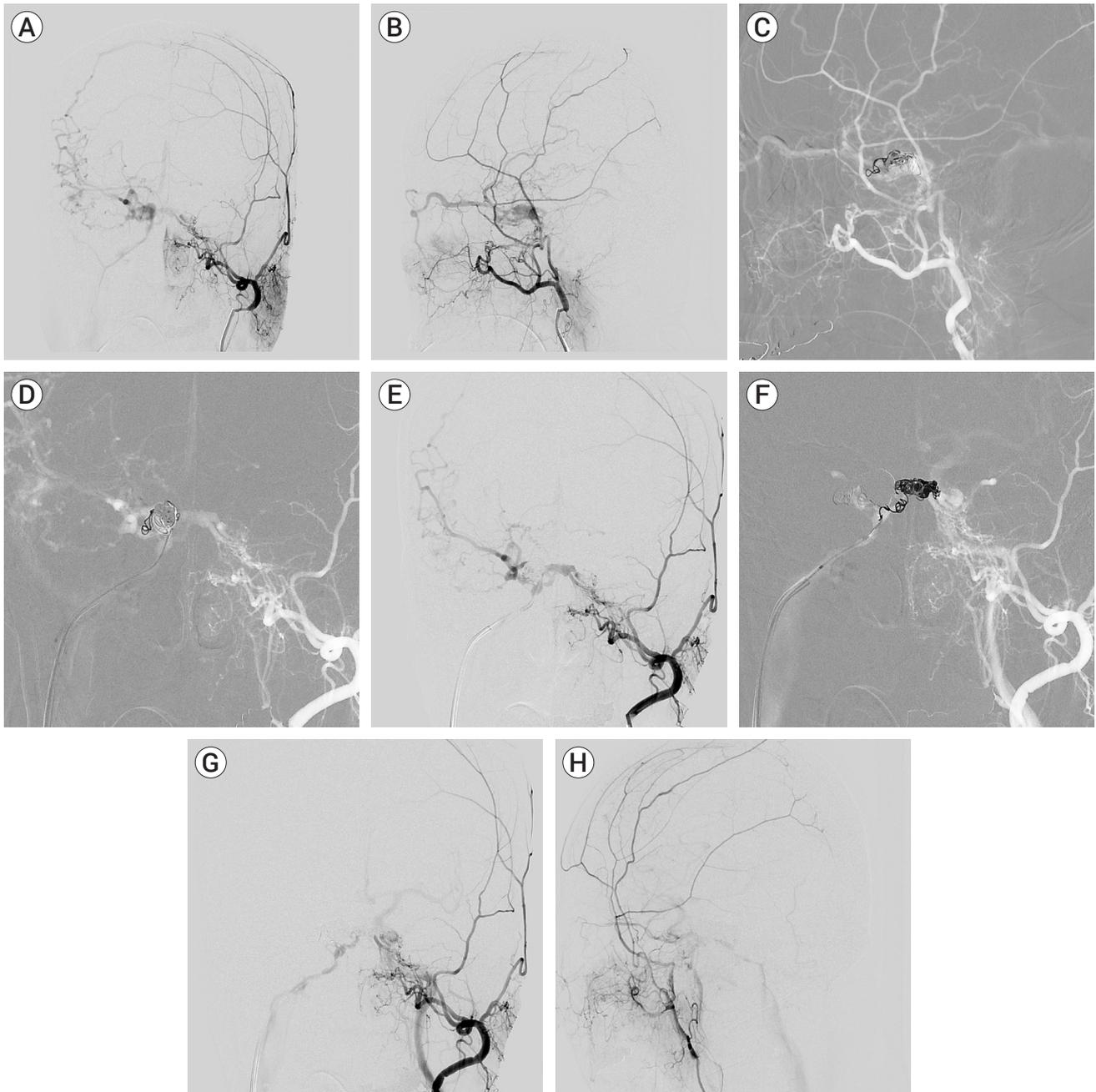
**Fig. 1.** The patient experienced right exophthalmos and ocular pain. Left ECA angiogram AP (A) and Lat (B) revealed CSDAVF supplied by dural arteries of ECA and venous reflux to the right SOV through the intercavernous sinus. The microcatheter was advanced into the CS via right IPS. Subsequently, the coils were packed at the junction of SOV and CS (C, D). On follow-up angiogram, venous reflux was noted again (E). Therefore, additional packing coils were inserted in the intercavernous sinus (F). On follow-up angiogram, venous reflux into SOV disappeared (G, H). The patient's symptoms were relived after the surgery. ECA, external carotid artery; AP, anteroposterior; Lat, lateral; CSDAVF, cavernous sinus dural arteriovenous fistula; SOV, superior ophthalmic vein; CS, cavernous sinus; IPS, inferior petrous sinus.

Some authors have also reported an approach through the foramen ovale.[11)16)] Complications with approaching the foramen ovale into the Meckel's cave are infrequent but include subarachnoid hemorrhage, carotid cavernous fistula, meningitis, and death.[7)] Therefore, surgeons and interventionists should consider this approach carefully in cases with no other possible routes of intravenous embolization.
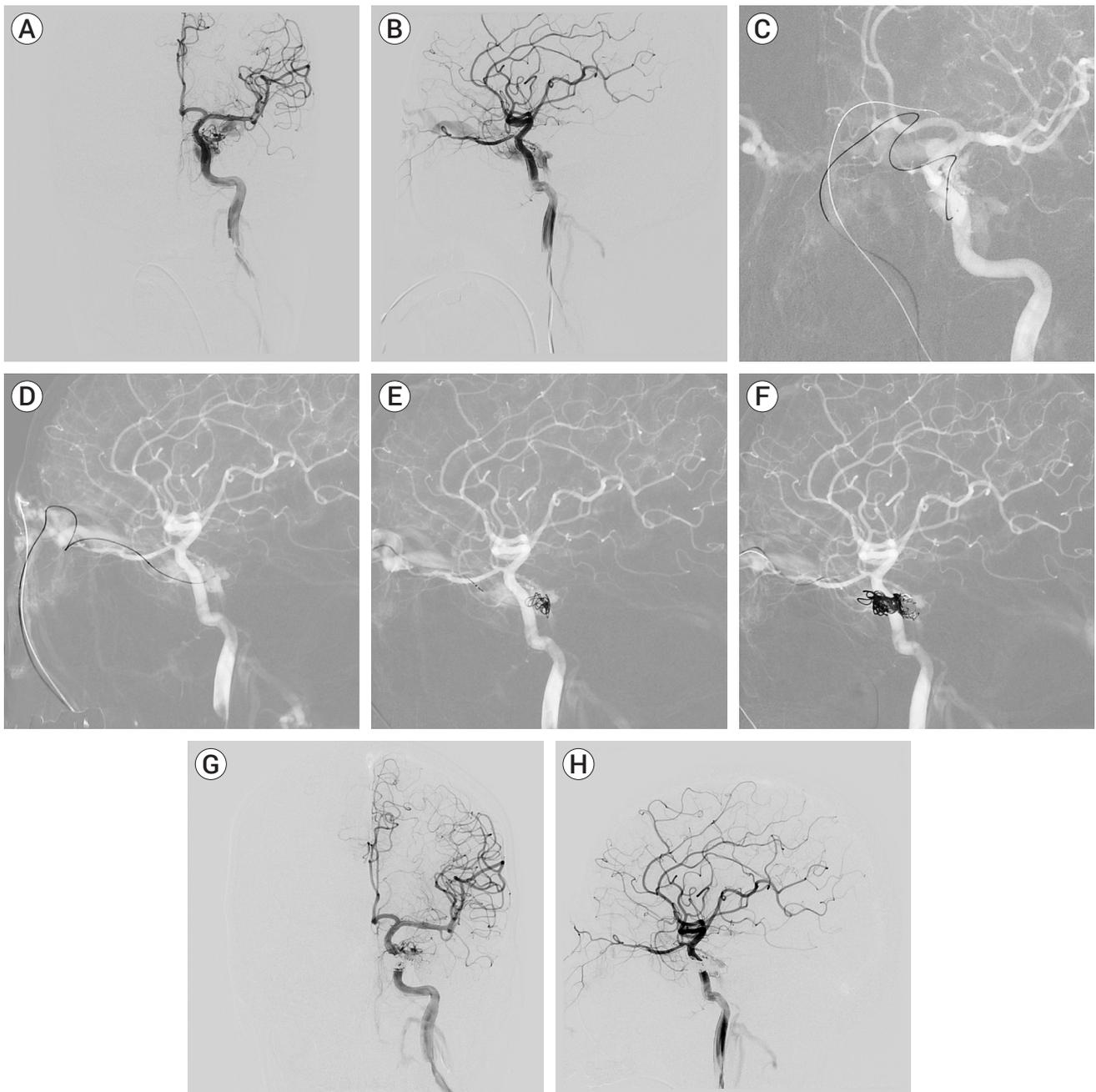
**Fig. 2.** The patient complained of left exophthalmos and chemosis. On left ICA angiogram AP (A) and Lat (B), CSDAVF supplied by dural arteries of cavernous ICA was noted. The microcatheter was advanced into the CS via SOV (C, D). Note that coil packing was performed from the posterior portion of the CS anteriorly (E, F). On follow-up angiogram, venous reflux to SOV disappeared (G, H). ICA, internal carotid artery; AP, anteroposterior; Lat, lateral; CSDAVF, cavernous sinus dural arteriovenous fistula; CS, cavernous sinus; SOV, superior ophthalmic vein.

## Transarterial embolization

A transarterial approach can be performed when adequate supply from the external carotid branches are present. Transarterial approach with polyvinyl alcohol (PVA) particles is easy and safe. It is usually utilized as a palliative maneuver to decrease the symptoms in patients with fistulas without dangerous features as well as an adjunct to radiosurgery.[40] However, transarterial

embolization with particles has been abandoned as a primary therapeutic approach because of very high rates of recanalization.[35] Good results in CSDAVF have been reported with the use of n-butyl cyanoacrylate (NBCA).[30] For embolization with NBCA, the microcatheter should be navigated and wedged in the far distal feeder to the fistula to allow for distal glue penetration. The main problems with NBCA embolization are related to the quick polymerization of the glue, which warrants very short periods of injections. Furthermore, NBCA is not cohesive with the consequent risk of microemboli. Due to these limitations, NBCA is highly operator-dependent and requires high degree of skill and experience with the material for safe and effective transarterial treatment of CSDAVF.

With the availability of Onyx as a new embolic agent,

there has been a resurgence of interest in the transarterial approaches in CSDAVF. The primary advantage of Onyx in the management of CSDAVF is that it can be used irrespective of the size and anatomical variability of the CS due to its penetrability without adhesiveness. In Fig. 3, we illustrate a case in which a patient was treated with transarterial Onyx embolization. In selective cases, including the one in Fig. 3, transarterial embolization alone may be sufficient. Additionally, creative approaches using combinations of different endovascular devices have been reported. For example, placement of a covered stent to occlude ICA supply followed by transarterial Onyx injection to occlude ECA supply has been reported to be successful in obliterating CSDAVF with leptomeningeal drainage and venous varices compressing the brainstem.[43]
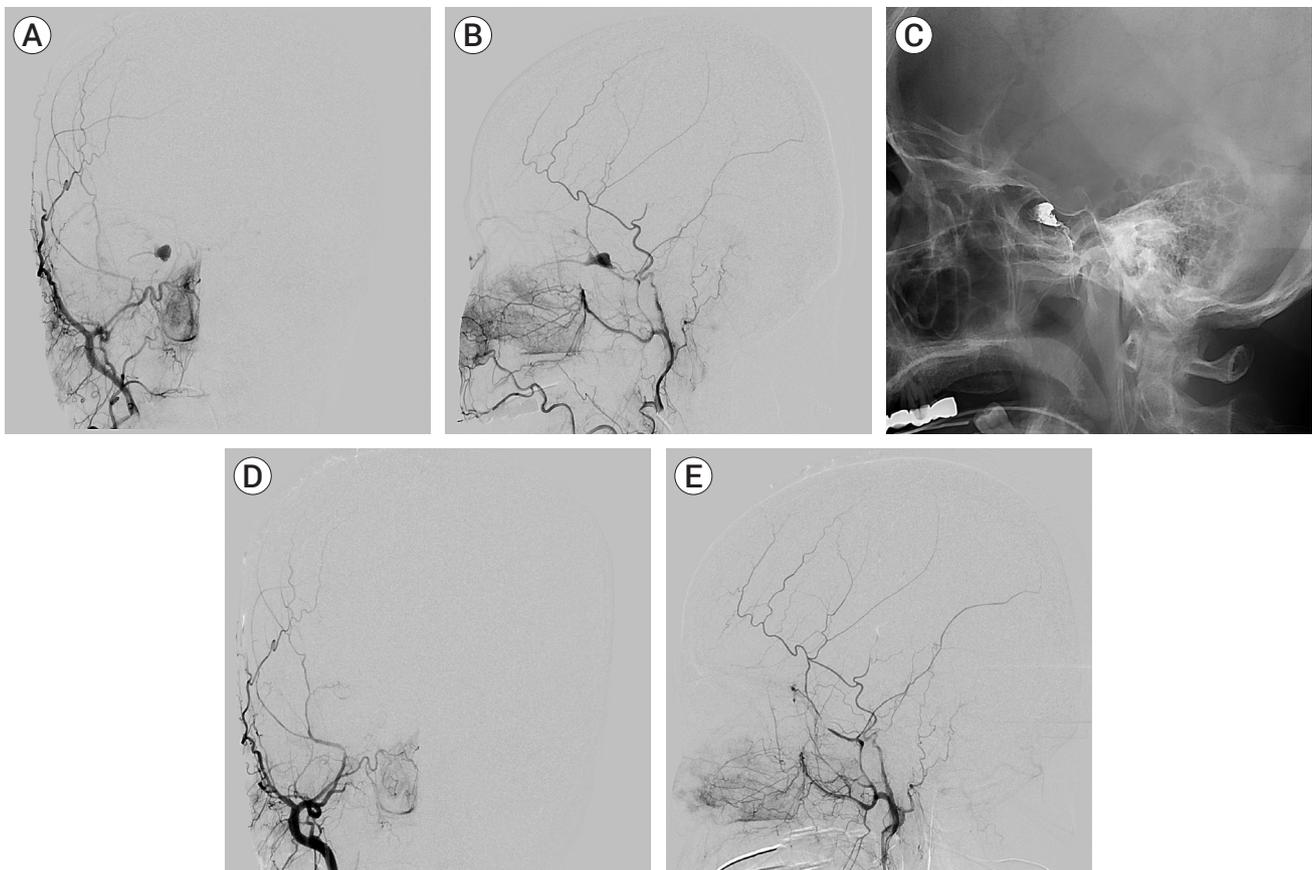
**Fig. 3.** On right ECA angiogram AP (A) and Lat (B), CSDAVF supplied by accessory meningeal arterial feeder and venous reflux to SOV were noted. This single arterial feeder was occluded using transarterial Onyx embolization (C). On follow-up angiogram, CSDAVF had disappeared (D, E). The patient had presented with ocular pain and exophthalmos. After the procedure, the symptoms were relieved immediately. ECA, external carotid artery; AP, anteroposterior; Lat, lateral; CSDAVF, cavernous sinus dural arteriovenous fistula; SOV, superior ophthalmic vein.

Various embolic agents alone or in combination have been utilized for transvenous obliteration of CSDAVF. Detachable or fibered coils are usually preferred although liquid embolic agents, often in combination with coils, have also been reported.[50] Excellent immediate and long-term angiographic and clinical results have been reported with the transvenous approach.[25)26)] Symptoms related to increased intraocular pressure are often the first to improve following successful fistula obliteration. Cranial neuropathies improve in most patients but may fail to improve in up to 11% of the patients. Paradoxical aggravation of the ocular symptoms and signs is uncommon (3%) and is probably related to the effects of CS thrombosis or mass effect from the embolizing material. These postoperative new deficits are often transient and improve over a period of 1–2 months following the procedure.[52] Overall, transvenous embolization of CSDAVF is safe when performed by experienced surgeons, with extremely low rates of severe permanent morbidity and virtually no mortality.

### Role of radiosurgery

Stereotactic radiosurgery also has a role in the management of CSDAVF. The reported total occlusion rate after radiosurgery alone in CSDAVF is 80–90.9%.[2)18)] However, the major drawback of radiosurgery is the latency time during which the patient continues to be exposed to the symptoms and the potential risk for intracranial hemorrhage in patients with retrograde cortical venous drainage. To overcome this limitation of radiosurgery, Pollock et al. have advocated a staged approach with radiosurgery followed by planned transarterial embolization with reportedly good results.[40] The rationale for performing embolization after radiosurgery is to allow for complete radiosurgery coverage of the involved dural sinus nidus without having it obscured by the embolization. Following radiosurgery, transarterial particle embolization can be performed to provide rapid symptomatic relief and eliminate cortical venous drainage. Since CSDAVFs often involve the inferior or posterior portions of the CS, the radiation dose to the optic apparatus can be limited to less than 10 Gy. Using this combined radiosurgery-embolization strategy, chemosis and proptosis were reported to improve in 94% of patients. Of those presenting with decreased visual acuity or visual field defects, 88% experienced resolution of their symptoms, and 77% of those presenting with diplopia noticed improvement or resolution.

## CONCLUSIONS

Endovascular treatment is the treatment of choice in CSDAVF. The transvenous approach to CSDAVF has been the primary route for endovascular embolization because of easier access, higher cure rates, and lower complication rates. Various access routes to the CS are available and the choice of access route depends on the characteristic angioarchitecture. With the development of embolic agents, transarterial approach is another good alternative in selected patients. In case of incomplete obliteration, radiosurgery can be considered. Therefore, CSDAVF with complex angioarchitectural features can be managed effectively using endovascular treatment.

### Disclosure

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

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