Chapter 14
Management of Dural Arteriovenous Fistulas

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14.1 Standard Management

Dural arteriovenous fistulas (DAVF) are the acquired abnormal connection between the dural artery and the dural vein. The pathogenesis includes venous/sinus thrombosis, trauma, craniotomy (surgery), but still remains unknown in the majority of cases. The incidence has been reported as 0.16–1.0 per 100,000 person-year [1–3].

Among several classifications of DAVF, Borden Classification [4] and Cognard Classification [5] are important. These classifications are based on the pattern of the venous drainage, which is an essential factor to affect the severity of the diseases and treatment indication and strategy.

The involved sites include the cavernous sinus (CS), superior sagittal sinus (SSS), transverse-sigmoid sinus (TSS), confluence of sinuses (torcular herophili), tentorial sinus, anterior condylar confluence, anterior cranial fossa, craniocervical junction, convexity, and spinal dura mater.

Treatment indication is recommended by the clinical presentations of the hemorrhagic or venous ischemic events, progressive neurologic deficits or symptoms (ocular hypertension, gait disturbance and incontinence), aggressive hemodynamic features (such as vigorous cortical venous reflux), and the symptoms such as intractable tinnitus disturbing the patient's ADL.

Treatment options include observation, endovascular and surgical treatment, and stereotactic radiosurgery. Since the venous hypertension plays an important role in the clinical course of this disease, the main purpose of the treatment is to cure the venous congestion or reflux by means of decreasing the venous pressure.

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14.1.1 Treatment Strategy

The lesions are divided into two types; the sinus type and the non-sinus type. The location of the sinus type includes the cavernous sinus (CS), superior sagittal sinus (SSS), transverse-sigmoid sinus (TSS), confluence (torcular herophili), tentorial sinus, and anterior condylar confluence. The location of the non-sinus type includes anterior cranial fossa, craniocervical junction, convexity, some of tentorial area, and spinal dura mater.

The principle of treatment of the sinus type is transvenous embolization (TVE), while that of the non-sinus type is transarterial embolization (TAE). In cases with difficulty of endovascular treatment, craniotomy and venous discontinuation will be an effective alternative treatment. The stereotactic radiosurgery will be the last choice of treatment in difficult cases, but it takes several months to obliterate the lesion. Because the difficult cases usually tend to need urgent treatment, we should not take an easy choice of the radiosurgery.

14.1.2 Transvenous Embolization (TVE)

Transvenous embolization includes two methods; selective TVE and whole sinus packing. The selective TVE is to occlude the localized inflow area of the blood flow (venous collector) in the involved sinus, keeping the physiological cerebral venous return to and from the sinus. This method is efficacious in the cases with localized AV shunt or localized venous collector, which can be seen frequently in the cavernous sinus. The whole sinus packing is to occlude the entire sinus. In case with diffuse AV shunt, the whole sinus packing is often required to cure the lesion.

When the brain still uses the involved sinus, the sinus blood flow should be maintained to keep the cerebral venous return, otherwise the treatment will cause the cerebral venous infarction. When the brain no longer uses the involved sinus, or the cortical venous reflux is apparent, the involved sinus can be occluded as a whole. In this case, the sinus occlusion will not affect at least the cerebral venous return.

The route of TVE is usually the trans-femoral trans-jugular vein. In case with the cavernous sinus DAVF, the first choice of the approach routes is the inferior petrosal sinus (IPS). The occluded IPS is sometimes seen but catheterization to the cavernous sinus via the occluded IPS is not difficult in majority of the cases. A microguidewire and a microcathter can proceed in the occluded IPS by rotating these devices with the sufficient backup of a guiding or distal access catheter. Other routes to the cavernous sinus include the inter-cavernous sinus (from the contralateral cavernous sinus), the superior petrosal sinus (from the ipsilateral/contralateral transverse sinus), and the superior ophthalmic vein (from the facial or superficial temporal vein). The distal access catheter will also be useful when the approach routes are very long.

The standard material of TVE is detachable coils. Onyx could be used in the involved sinus by cases, but it may cause the cranial nerve palsy in the cavernous sinus.

14.1.3 Transarterial Embolization (TAE)

Penetration of the liquid embolic materials from the arterial to the venous side can only cure the AV shunts. Proximal feeder occlusion using any materials will result in the recurrence of the shunts because the revascularization and recanalization of the fistula will occur soon after the feeder occlusion. Proximal occlusion can be effective when used as an adjunctive method of curative treatments. For example, the occipital artery can be occluded by coils before curative Onyx TAE from the middle meningeal artery or the middle meningeal artery can be occluded by coils before curative TVE of the cavernous sinus lesion.

Onyx and NBCA (*n*-butyl cyanoacrylate) are the liquid materials to achieve the curative TAE. NBCA is an adhesive polymerizing material (glue) to be used as a mixture with lipiodol. The lower the concentration of NBCA, the higher the viscosity of the material and the higher the temperature of the material, the lower the viscosity. Usually 20–30% mixture of NBCA is used with heating to achieve the easy penetration without adhering to the catheter. Onyx is a new precipitating material containing ethylene vinyl alcohol polymer, DMSO (dimethyl sulfoxide), and tantalum powder (for visualization). Initially it has been developed for AVM embolization, but has been found to be very effective also to DAVFs. Because Onyx is not an adhesive material, prolonged injection (even for hours) can be done and clinical results have been improved dramatically [6]. Plug and push method is very effective to penetrate the lesion to the draining veins or sinuses. A tip of a catheter is sometimes trapped in the Onyx mass in case with excessive embolization. A balloon catheter acts like a plug and is useful to prevent Onyx from coming back to the catheter. Since Onyx can easily proceed not only to the venous side but also to the other feeding arteries, the lesion sometimes will be obliterated completely by a single pedicle injection. However, one must be careful not to cause cranial nerve palsy (embolization of vasa nervorum) and cerebral infarction through the dangerous anastomosis between external and internal carotid and vertebral arteries. A profound knowledge about the functional microvascular anatomy is very important to prevent these complications.

The site of a good indication of Onyx is transverse-sigmoid sinus, superior sagittal sinus, confluence, and tentorial area. Onyx TAE in the anterior cranial base is feasible but not easy because the feeding pedicles arising from the ophthalmic artery are distal, small, and tortuous. Use of Onyx for DAVF of the cavernous sinus and anterior condylar confluence is very dangerous, causing cranial nerve palsy and cerebral infarction. NBCA is a reliable and effective material for the spinal lesion. Effectiveness of Onyx for the spinal lesion remains unknown.

14.1.4 Complications of Treatment

In general, hemodynamic status will dramatically change after obliteration of the AVF, regardless of the treatment method. Venous stasis and/or embolic materials as the foreign bodies in the veins are the potential cause of venous thrombosis both after TAE and TVE. Heparin infusion will be an essential treatment in the postoperative course to prevent the venous thrombosis. Cerebral hyperperfusion syndrome may occur after abrupt occlusion of the AV shunt in cases with high flow AVF. Important is the prediction and recognition of the hyperperfusion syndrome as an unexpected complication before treatment. Single photon emission CT or transcranial Doppler ultrasound will be very useful to detect the hyperperfusion phenomenon.

14.1.4.1 Complications of TAE

Migration of the Embolic Materials via the Arterial Anastomosis

One of the most important and critical complications is cerebral ischemia resulted from the migration of embolic materials via the so-called dangerous anastomosis between dural and pial arteries. Usually the dural branches of the external carotid artery have rich anastomosis with the dural and pial branches of the internal and vertebral arteries. Liquid embolic materials like NBCA and Onyx as well as particulate materials smaller than 200 μm easily migrate to the pial arteries via the network. One must care about the dangerous behavior of the liquid materials; it tends to come back the parent feeding pedicle vie the arterial network arising from the feeding artery itself (Fig. 14.1).

Migration of the Embolic Materials to the Venous Side

Onyx, particularly, tends to penetrate the arteriovenous fistula very easily and go to the venous side. This penetration is the essential phenomenon needed to the radical treatment and is the most advantageous point of Onyx. However, excessive penetration (migration) could occasionally result in the occlusion of the functioning cerebral veins (Fig. 14.2) causing potential venous infarction.

NBCA tends to make fragmentation in the venous side when the arterial blood flow comes from the other feeding arteries. If a block of fragment occludes the distal side of the draining vein, venous bleeding may occur due to the remaining arterial inflow.

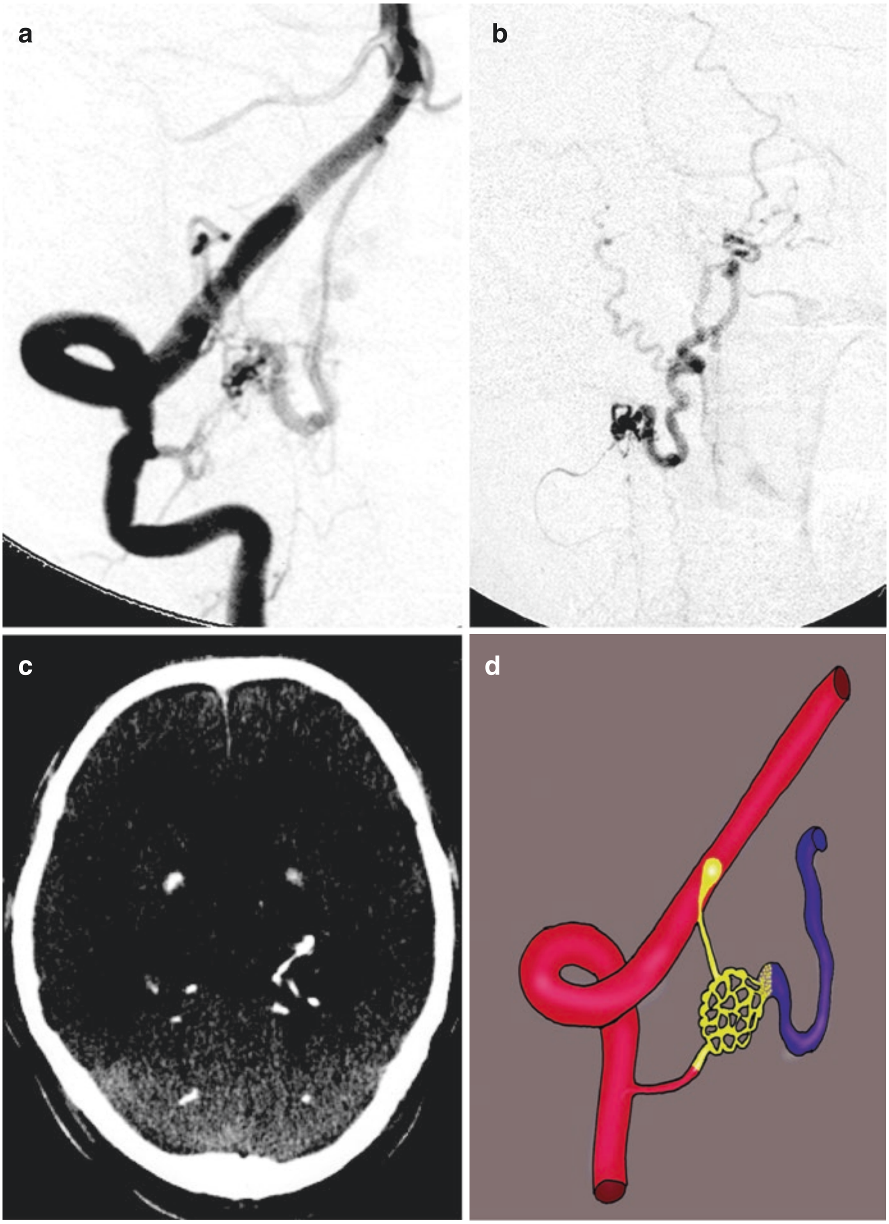

Fig. 14.1 A case with DAVF in the craniocervical junction showing NBCA migration. (**a**) Preoperative vertebral angiogram indicating DAVF fed by C2 segmental artery of the vertebral artery and drained into the cerebral vein in the brain stem. (**b**) Microangiogram from the feeding artery. (**c**) Postoperative CT scan indicating migration of the fragmented pieces of NBCA. (**d**) Schematic drawing of the mechanism of NBCA migration; injected NBCA came back to the distal parent vertebral artery via the network between the other feeding pedicle

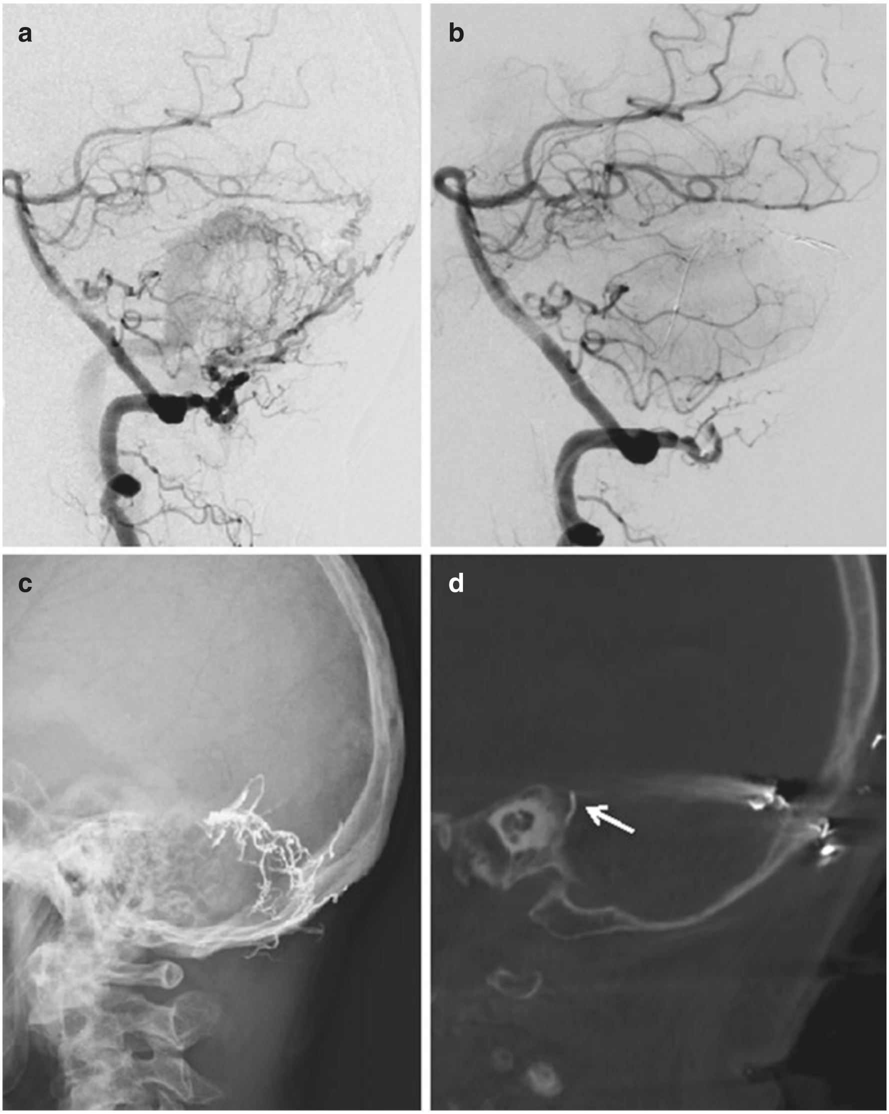

Fig. 14.2 A case with Borden type I DAVF involving the transverse-sigmoid sinus. The shunt was obliterated with Onyx injection from the distal occipital artery arising from the vertebral artery. A balloon catheter was inflated in the involved sinus to prevent Onyx migration to the sinus lumen. (**a**) Preoperative vertebral angiogram. (**b**) Postoperative vertebral angiogram indicating complete obliteration of the shunt. (**c**) Postoperative craniogram showing the Onyx cast. (**d**) Postoperative cone beam CT indicating Onyx migration to the tinny petrosal vein (*arrow*) from the superior petrosal sinus

Ischemia of the Vasa Nervorum

NBCA, Onyx, and small particulates (<200 μm) will cause cranial nerve palsy by migrating into the vasa nervorum. Many external carotid branches such as the middle meningeal, accessory meningeal, deep temporal arteries, and the artery of foramen rotundum give rise to branches which feed the cranial nerves around the middle fossa. The middle meningeal, ascending pharyngeal, occipital arteries, and posterior meningeal branch of the vertebral artery also feed the cranial nerves inside and outside of the posterior fossa. The inferolateral and meningohypophyseal trunks of the internal carotid artery feed many cranial nerves and have a rich collateral anastomosis between external carotid artery in the middle fossa.

14.1.4.2 Complications of TVE

Mass Effect to the Cranial Nerves

Excessive transvenous coil packing of the cavernous sinus causes III, IV, and V cranial nerve palsy and that of anterior condylar confluence causes XII nerve palsy. Sometimes, the delayed ocular palsy will occur and never recover [7]. This mechanism still remains unknown and one should remind.

Venous Infarction and Bleeding

Normal cerebral veins sometimes drain into the involved sinus in an antegrade fashion. Venous infarction will occur after the whole sinus packing by blocking the normal cerebral venous drainage (Fig. 14.3). Cortical venous drainage or retrograde

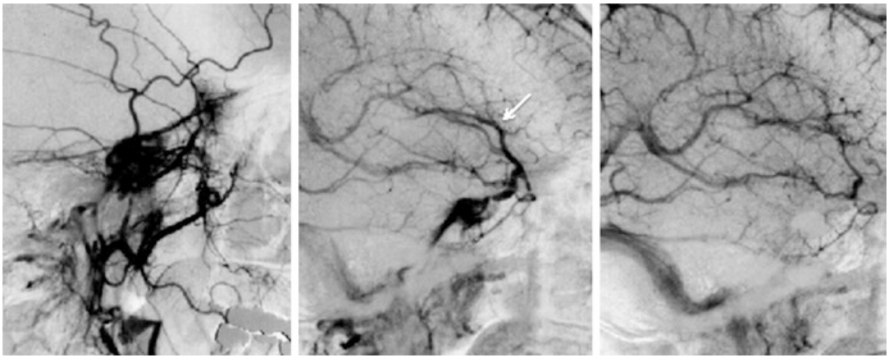

Fig. 14.3 A case with cavernous sinus DAVF treated with transvenous packing of the affected sinus. *Left*: Preoperative external carotid angiogram (*lateral view*) showing the shunt in the cavernous sinus. *Center*: Preoperative internal carotid angiogram (*lateral view*) showing the superficial middle cerebral veins are draining into the affected cavernous sinus in an antegrade fashion. *Right*: Venous phase of the postoperative common carotid angiogram (*lateral view*). Note one of the superficial middle cerebral veins (*arrow* in the *center figure*) was missing

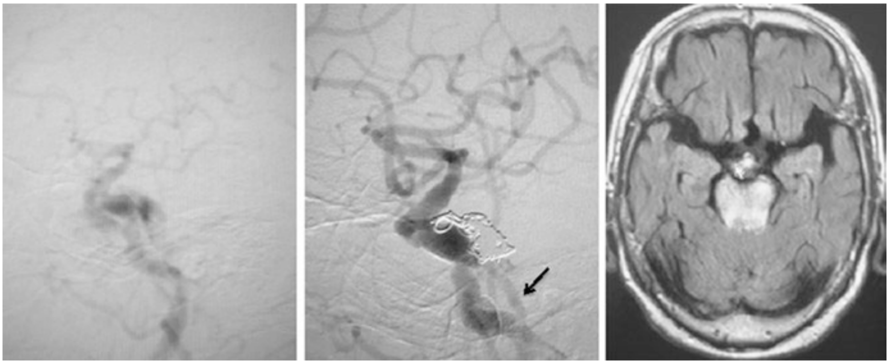

Fig. 14.4 A case with cavernous sinus DAVF treated by transvenous coil embolization. *Left*: Preoperative common carotid angiogram. *Center*: Postoperative common carotid angiogram showing incomplete obliteration of the affected cavernous sinus. Note the cavernous sinus was packed with coils but the inferior petrosal sinus was still opacified (*arrow*). *Right*: MRI (FLAIR) in the next day showing (venous) infarction of the entire brain stem, suggesting the postoperative change of the draining routes into the brain stem due to the incomplete transvenous occlusion of the cavernous sinus

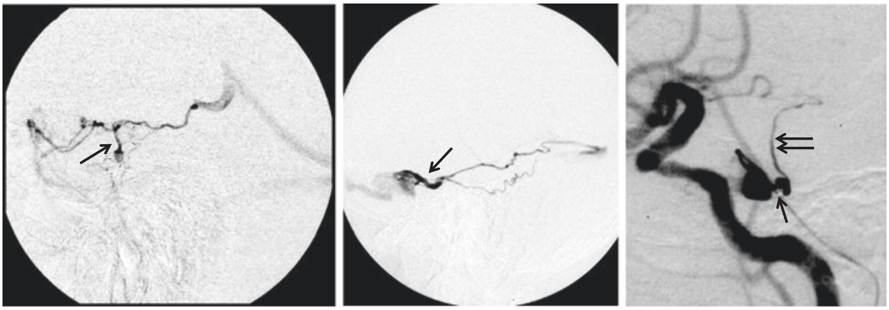

Fig. 14.5 Examples of the dangerous draining veins. *Left*: Cavernous sinus injection opaficied the uncal vein (*arrow*) connecting with deep cerebral veins (vein of Rosenthal and vein of Galen). *Center*: Cavernous sinus injection opaficied the petrosal vein (*arrow*). *Right*: Carotid angiogram showing the cavernous sinus DAVF draining only into the tinny vein of the brain stem (*double arrows*) via the bridging vein (*arrow*)

letpomeningeal venous drainage in sinus type is sometimes seen in Borden type II or III and Cognard type IIb. Transvenous sinus packing of these lesions have potent complication of venous bleeding from the residual cortical veins if the packing is incomplete (Fig. 14.4). One must obliterate, at first, the dangerous small draining veins like the uncal vein, petrosal vein, and bridging veins to the brain stem (Fig. 14.5).

14.2 Advances

Several topics at present will be shown with case presentation.

14.2.1 Selective TVE

Selective TVE is a recent trend. Advantage of this method is to spare the physiological cerebral venous return with a low cost, compared with the whole sinus packing. 3D-DSA can easily find the localized AV shunt (the shunting pouch or venous collector) in many cases with cavernous sinus DAVF (Fig. 14.6). Parallel sinus or small pouch is sometimes found in the case with transverse-sigmoid sinus DAVF (Fig. 14.7)

14.2.2 Onyx Embolization

Onyx has brought the paradigm shift in the treatment of DAVF of the transverse-sigmoid sinus, superior sagittal sinus, and confluence, especially in cases with Borden type I and II lesions. Curative treatment for these lesions was difficult before Onyx era because NBCA tended to result in a partial occlusion. Finally, sinus

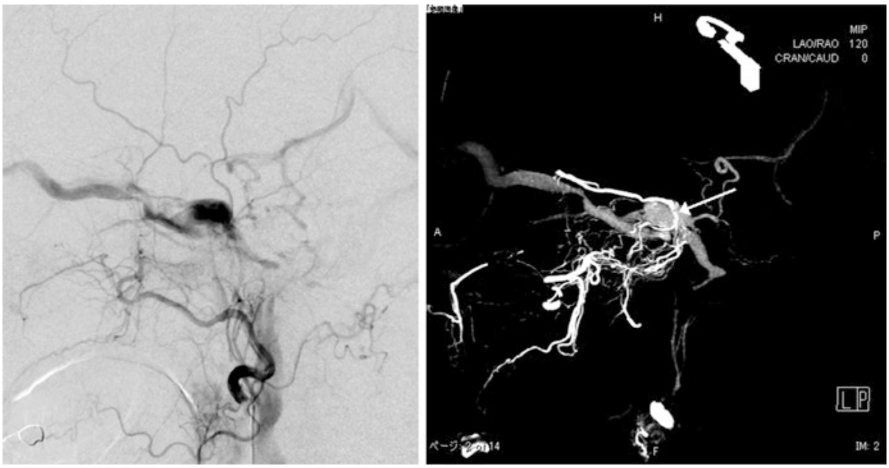

Fig. 14.6 A case with cavernous sinus DAVF. *Left*: external carotid angiogram showing the lesion fed by the dural branches of the external carotid artery, draining to the superior ophthalmic vein, inferior petrosal sinus, and the bridging vein connecting with the lateral mesencephalic vein. *Right*: a MIP image of 3D-DSA. Note the localized AV shunt point (venous collector) is clearly indicated (*arrow*)

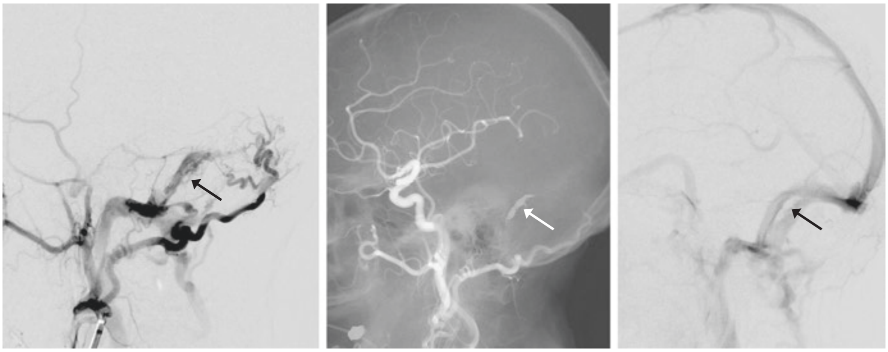

Fig. 14.7 A case of the sigmoid sinus DAVF with a shunting pouch in the parallel sinus. *Left*: lateral view of the external carotid angiogram showing the DAVF (*black arrow*) draining into the sigmoid sinus in an antegrade fashion. *Center*: arterial phase of the common carotid angiogram after selective transvenous embolization with coils (*white arrow*). *Right*: its venous phase. Note the patent sigmoid sinus after packing of the involved parallel sinus (*black arrow*)

packing was performed if necessary. Onyx has dramatically improved the obliteration rate of the shunts even in Borden type I lesion (Fig. 14.8). It also enables transarterial sinus packing instead of TVE (Fig. 14.9).

14.2.3 Spinal Dural and Epidural AV Shunts

Clinical entity of spinal "epidural" AVF has been newly proposed [8]. Recently, the concept of the angioarchitecture of the spinal dural and epidural AVF has changed and well been elucidated by the nation-wide survey in Japan [9]. The feeding arteries are usually the bilateral dorsal somatic arteries and the AV shunt is located in the dural lake on the ventral surface of the dura and drained into the radiculomedullary to the perimedullary veins and/or the paravertebral veins (Fig. 14.10). While, in the case with spinal "dural" AVF, the radiculomeningeal and/or prelaminar arteries connect with the bridging vein of the spinal dura and drained into the perimedullary vein. Previously it was said that the AV shunt located in the dural sleeve in the textbook. However, in the majority of cases with dural AVF, the AV shunt was located away from the dural sleeve in this report.

This nation-wide survey in Japan proved that dominant location of the spinal dural AVF was the thoracic level, while that of the spinal epidural AVF was lumbosacral level. Because the angioarchitecture of the feeding vessels of the epidural AVF is simpler, in general, than that of dural AVF, catheterization is usually easier in the epidural AVF. Successful rate of the surgery, tansarterial NBCA injection, or combination of these treatments was high. Effectiveness of Onyx for the spinal lesion remains unknown. When the endovascular treatment is failed or incomplete, surgical treatment should be followed.

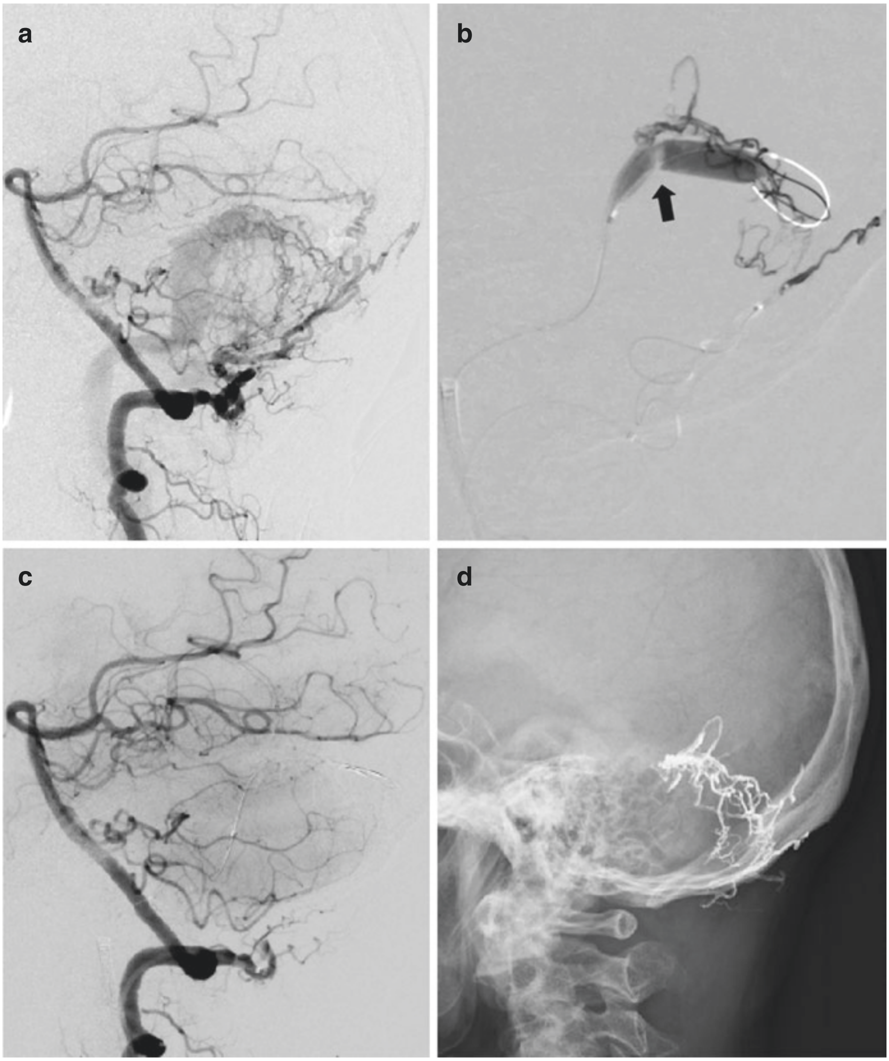

Fig. 14.8 The same case with Fig. 14.2 (Borden type I DAVF involving the transverse-sigmoid sinus). The shunt was obliterated with Onyx injection from the distal occipital artery. (**a**) Preoperative vertebral angiogram showing the transverse-sigmoid sinus DAVF fed by the occipital artery arising from the vertebral artery. (**b**) A sinus balloon (*arrow*) is inflated in the involved sinus during the Onyx injection from the occipital artery to avoid Onyx migration to the sinus lumen. (**c**) Postoperative vertebral angiogram. Note the DAVF was completely obliterated. (**d**) Postoperative craniogram showing the Onyx cast

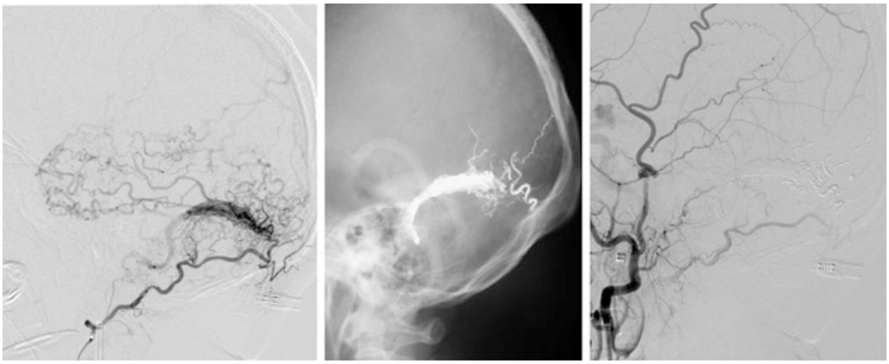

Fig. 14.9 A case of the transverse-sigmoid sinus DAVF with the so-called isolated sinus. *Left*: The occipital angiogram showing the DAVF (Borden type III, Cognard type IIa + b) with the vigorous cortical venous reflux. *Center*: Postoperative craniogram showing the Onyx cast which packed the entire sinus. *Right*: The left external carotid angiogram after the Onyx TAE showing the complete obliteration of the DAVF

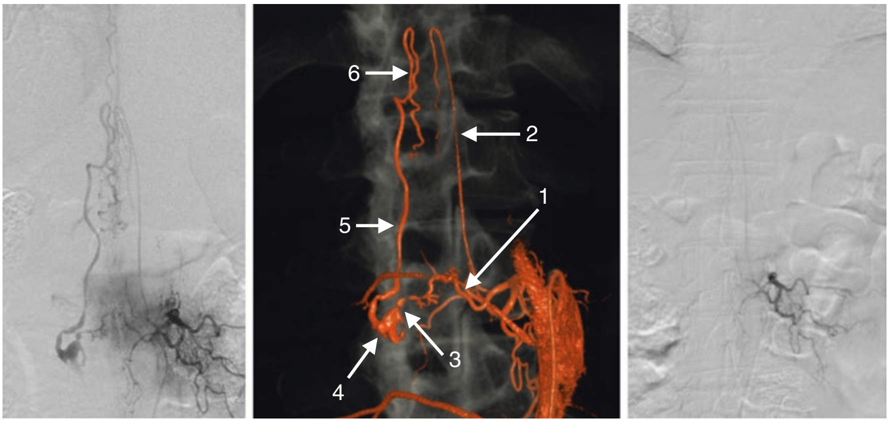

Fig. 14.10 A case with spinal epidural AVF. *Left*: No. 2 lumbar angiogram showing the epidural AVF fed by the dorsal somatic artery and draining into the venous lake on the dural surface. *Center*: 3D-DSA. (*1*) Dorsal somatic artery, (*2*) posterior spinal artery, (*3*) shunting point, (*4*) epidural venous lake (pouch), (*5*) radiculomedullary vein, (*6*) perimedullary vein. *Right*: postoperative angiogram. Note the shunt was completely obliterated with NBCA injection

14.3 Controversies

14.3.1 Timing of Treatment

Urgent treatment is mandatory in cases with the hemorrhagic onset, because re-bleeding rate is high [10]. Cortical venous reflux in cases with hemorrhagic onset is a potential risk of re-bleeding and is a strong reason of treatment. However, the bleeding risk of asymptomatic cases with cortical venous reflux is not high [11] and the necessity of the urgent treatment is controversial.

Treatment should not be delayed in cases with progressive (neurologic) symptoms such as diplopia and ocular hypertension in the cavernous sinus DAVF and congestive myelopathy in the spinal dural and epidural AVF.

Other symptoms such as headache, pulsatile tinnitus should be followed up conservatively because those symptoms do not harm the patients. In rare cases, intractable tinnitus in Borden type I fistulas may need to treat in order to improve the patients' mental status and activities of daily life.

14.3.2 Shunt Location and Treatment Modality

In the cavernous sinus DAVF, the priority of treatment is TVE. Recent trend is a selective TVE (targeted embolization). Multiplanar reconstruction (MPR) images of 3D-DSA help to find out the localization of the AV shunts (venous collector) and enable the selective TVE.

In the DAVF of transverse-sigmoid, superior sagittal sinuses and confluence, variety of treatment will be indicated according to its hemodynamic status. Recent topic is Onyx embolization for the Borden type I and II lesions. The sinus packing for the Borden type III lesions can be done both by TVE and transarterial Onyx injection.

Surgical treatment will be the first choice in the lesions of anterior cranial base and craniocervical junction. Also surgery with or without the endovascular treatment plays an important role in the treatment of tentorial DAVF and spinal dural and epidural AVF.

14.3.3 Surgical Treatment

Surgical treatment will be safer and the first choice in the region of anterior cranial fossa. Endovascular treatment (Onyx TAE) could be feasible but less safe. Craniotomy and clipping of the draining vein is a simple treatment. However, one must pay attention to the olfactory veins as draining routes running on the frontal base, not in the interhemispheric space.

Atypical angioarchitecture is a characteristic feature in the lesion of craniocervical junction. Feeding arteries include dural and pial branches and it is very difficult to differentiate these arteries. Even the anterior spinal artery often joins the fistula. Detection of the precise location of AV shunt (epidural, dural, or perimedullary) would be difficult by means of any diagnostic modality. Surgical exploration of the complex angioarchitecture is very effective and safe.

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