20 Hemorrhagic Complications After Endovascular Treatment for Intracranial Dural Arteriovenous Fistulas

Kun Hou and Jinlu Yu

Abstract

Dural arteriovenous fistulas (DAVFs) are arteriovenous shunts within the dural leaflet. Endovascular treatment (EVT) has become the first-line treatment for DAVFs. However, during or after EVT, disastrous hemorrhagic complications can occur. Little is known about the potential for severe hemorrhagic complications. Currently, EVT-associated hemorrhage may be considered associated with the rupture of a glomus-like structure around the draining vein, which is often supplied by a pial artery. In addition, excessive Onyx occluding the ostium of cortical veins may result in venous hypertension, which carries a risk of venous hemorrhage. Therefore, the major pial arterial supply should be occluded first, and patency of the involved sinus and its tributaries should be preserved. To decrease EVT-associated hemorrhagic complications, staged EVT may be helpful after occlusion of the risky draining vein. EVT-associated hemorrhagic complications are often disastrous due to the nature of venous hypertension. If the hemorrhage can be evacuated after urgent craniotomy, especially in cases of supratentorial or epidural hemorrhage, a good outcome can be achieved.

Keywords

Dural arteriovenous fistula · Endovascular treatment · Hemorrhagic complication

20.1 Introduction

Dural arteriovenous fistula (DAVFs) are arteriovenous shunts between dural arteries (or with pial arteries) and venous sinuses or/and cortical veins, and in most cases of DAVF, the shunt is located within the dural leaflet [1]. One or multiple DAVFs can occur anywhere in the intracranial dura [2]. Although the outcome of microsurgery for DAVFs is acceptable, it could be feasible as a second-line treatment option for DAVFs [3].

During the past two decades, beyond microsurgery, endovascular treatment (EVT), including transarterial and transvenous access to fistulous connections, has become the first-line treatment for DAVFs [4]. EVT is safe for most DAVFs, with a good prognosis, but rarely, disastrous hemorrhagic complications can occur [5, 6]. Hemorrhagic complications after EVT for DAVFs have been reported in recent literature, with an incidence rate of 0–3.8% [5]. Currently, little is known about the potential for severe hemorrhagic complications.

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20.2 Classification of EVT-Associated Hemorrhage

EVT-associated hemorrhage can occur in various DAVFs, including those located in the tentorium, transverse-sigmoid sinus, cavernous sinus, superior sagittal sinus, petrosal region, etc. [7–10]. Hemorrhagic complications can often be associated with curative and complete EVT for DAVFs, and they can occur intraoperatively and early and late postoperatively [5, 11].

Immediate postoperative hemorrhages are usually due to rupture of the feeding artery, fistula point or draining vein due to the high-pressure casting of Onyx (Medtronic, Irvine, California, USA) [12]. In Jiang et al.'s report of EVT for tentorial DAVFs, one patient died as a result of venous rupture while undergoing Onyx injection [4]. Delayed postoperative hemorrhage often occurs during the first 24 h postoperatively due to unintended venous embolization followed by restricted venous outflow, which results in progressive venous hypertension [5, 13]. These delayed hemorrhagic complications may be similar to the mechanism of delayed hemorrhage after the procedure for cerebral arteriovenous malformations [14, 15].

In addition, according to the location of the hemorrhage, EVT-associated hemorrhages can include epidural, cerebral, cerebellar, and intraventricular hemorrhage [8, 9].

20.3 Angioarchitecture of EVT-Associated Hemorrhage

EVT-associated hemorrhage may originate from any structure with a DAVF, especially in cases of high Cognard and Borden grades [16–19]. However, the underlying causes are not thoroughly understood, and both a pial arterial supply and giant venous aneurysm may be risk factors [5].

20.3.1 Feeding Artery

Dural arteries are prominent feeders in DAVFs, while pial arterial involvement is less common. A pial arterial supply is defined as a supply from a pial artery to the DAVF [10, 11, 20]. The pial arterial supply may be the result of neovascularization in the setting of venous hypertension [20]. DAVFs associated with a pial arterial supply are more likely to be tentorial in location, especially galenic- and torcular-type DAVFs [20].

A pial arterial supply is present in 11.3–23.8% of all DAVFs [11]. The rate of a pial arterial supply has been reported in several large series. In a report by Osada et al., the rate on angiography was 10% [1]. In a report by Brinjikji et al., the rate on angiography was 13.4% [20]. In a report by Okamoto et al., the rate on microsurgery was 20% [11]. All intracranial arteries can send a pial arterial supply to a DAVF, the most common of which is the artery of Davidoff and Schechter, which is a dural branch arising from the posterior cerebral artery that supplies the region of the tentorial incisura (Fig. 20.1) [4, 20–23].

A pial arterial supply was divided into two types by Osada et al., including a dilated preexisting dural branch of the pial artery and a pure pial supply consisting of tortuous and fragile vessels [1, 20]. In EVT for DAVFs, a pial arterial supply increases the risk of hemorrhagic complications [11]. In a report by Wu et al. on EVT for tentorial DAVFs, the rate of hemorrhagic complications was 33%, and DAVF patients with post-EVT hemorrhage showed pial arterial supply involvement [8]. When the proximal draining vein of the DAVF is embolized, the restriction of venous outflow can lead to hemorrhage from residual pial arterial feeders [1]. In addition, flow-related aneurysm of the pial arterial supply can occur, which is dangerous (Fig. 20.1c).

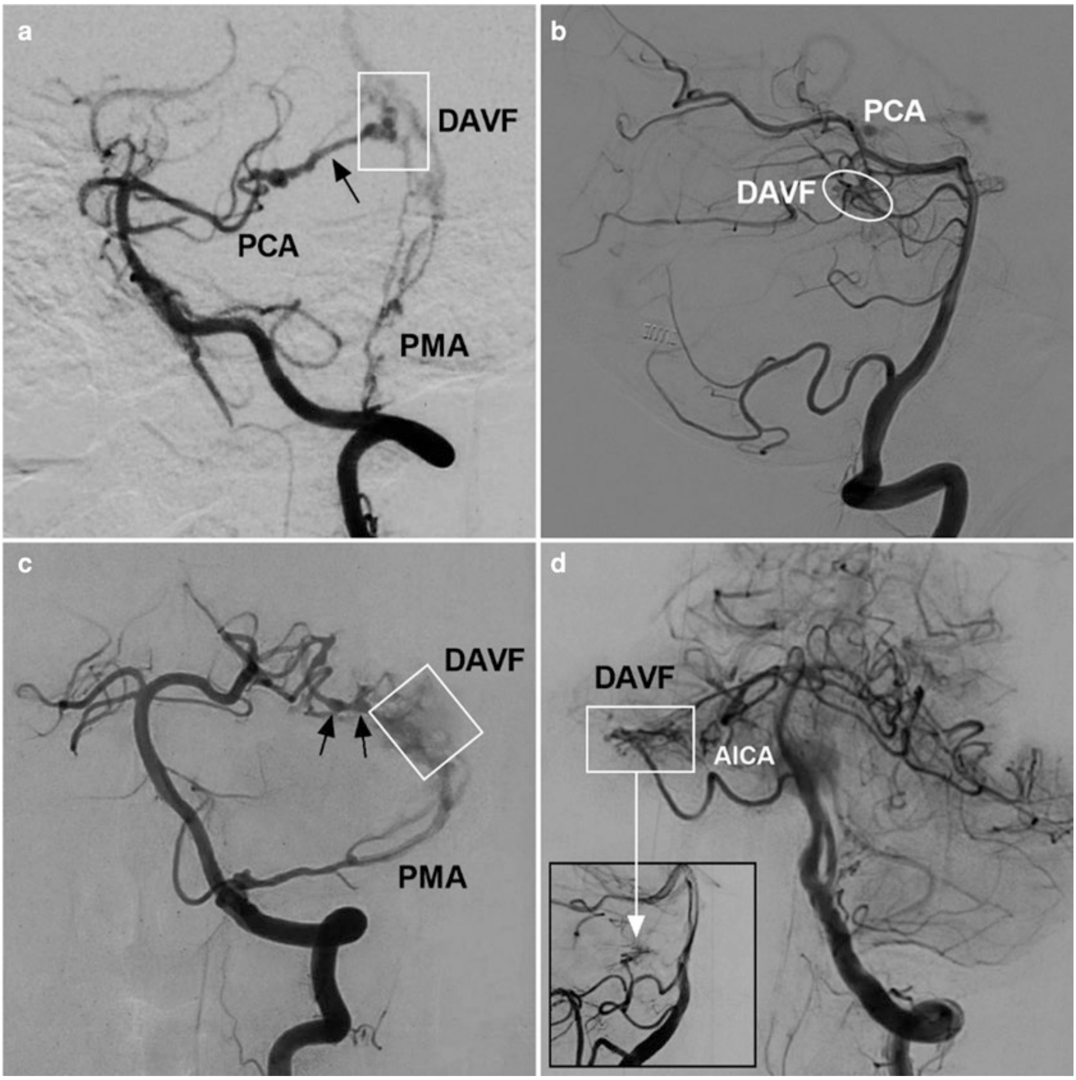

Fig. 20.1 Pial arterial supply in DAVF. (**a**) DSA of the VA showing that the DAVF (frame) was supplied by the meningeal branch of the PCA, which was dilated (arrow), as well as the PMA. (**b**) DSA of the VA showing that the PCA sent a pure pial supply to the DAVF (circle). (**c**) DSA of the VA showing that the PCA sent a dilated pial supply to the DAVF (frame), with flow-related aneurysms (arrows) in the pial supply; the PMA also supplied the DAVF. (**d**) DSA of the VA showing that the AICA sent a pure pial supply to the DAVF (frame). The inset shows the lateral view of the VA, and the arrow indicates the DAVF. *Abbreviations*: *AICA* anterior inferior cerebellar artery, *DAVF* dural arteriovenous fistula, *DSA* digital subtracted angiography, *PCA* posterior cerebral artery, *PMA* posterior meningeal artery, *VA* vertebral artery

20.3.2 Fistula Structure

Commonly, DAVFs are located in the dural leaflet, and they can be divided into sinus and nonsinus types according to the presence of communication with the sinus [1, 24]. DAVFs can result in venous hypertension; in turn, venous hypertension may promote DAVF growth [25]. Rarely, DAVFs may extend to the subdural space along the drainage route, presenting with a glomus-like structure around the drainage vein, which is often supplied by a pial artery [12]. The presence of a glomus-like structure increases the risk of EVT, so its identification is necessary. Due to the hypervascularized and complex angio-architecture of DAVFs, such glomus-like structures may not be visible on angiography [12, 26]. In Okamoto et al.'s report on microsurgery for DAVFs, the detection rate of an angiographically occult pial arterial supply was estimated to be 6.7% [11]. In theory, the location and classification (sinus or nonsinus type) of DAVFs may be associated with the occurrence of hemorrhagic complications (Fig. 20.2). However, in report by Liu et al., no difference in EVT-associated hemorrhages was found between sinus and nonsinus DAVFs or by the location of DAVFs [5].

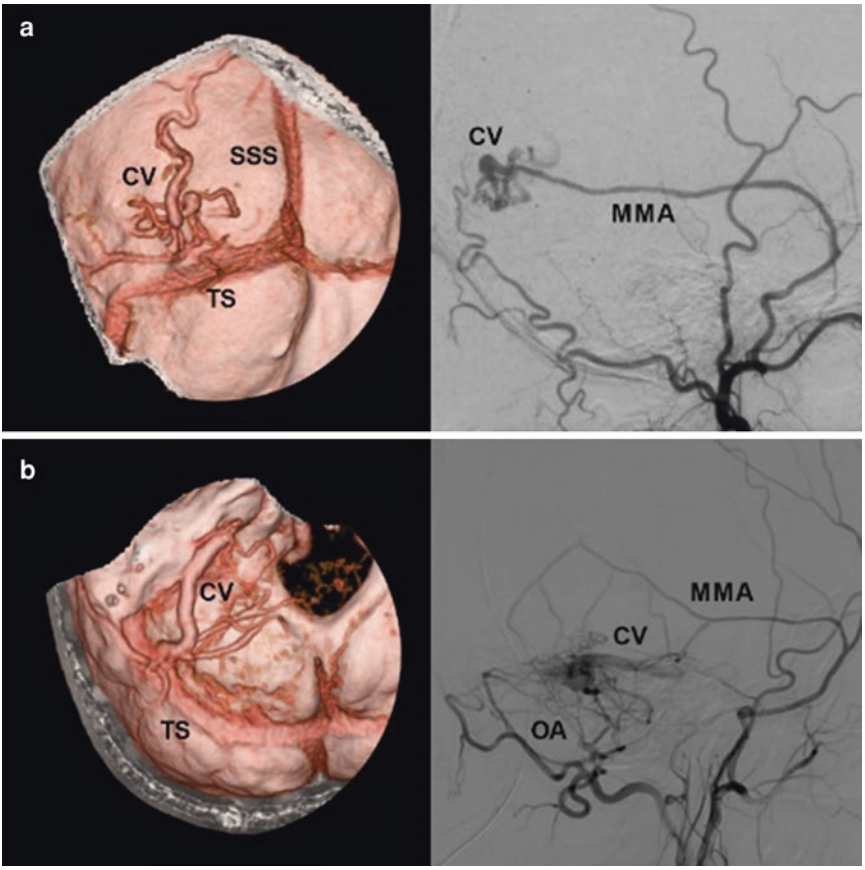

Fig. 20.2 Venous draining patterns in DAVFs. (**a**) Left, CTA showing a nonsinus-type DAVF located in the TS, with a tortuous draining vein; right, DSA showing the Cognard grade IV DAVF. In this DAVF, although the grade was high, the draining vein was not extensive, and EVT could be performed via the MMA safely, and complete EVT may not result in excessive venous occlusion. (**b**) Left, CTA showing a nonsinus-type DAVF located in the TS, with a dilated draining vein extended into the cerebellum; right, DSA showing the Cognard grade IV DAVF. In this DAVF, the draining vein was extensive, and EVT via the MMA would be dangerous, as it would result in excessive venous occlusion. (**c**) Left, CTA showing a sinus-type DAVF located in the TS, with a dilated draining vein; right, DSA showing the Cognard grade IIa + b DAVF and indicating that EVT may impact the TS. (**d**) Left, CTA showing a sinus-type DAVF located in the TS, with a dilated draining vein; right, DSA showing the Cognard grade IIb DAVF and indicating that EVT via the MMA may impact the TS. *Abbreviations*: *CTA* computed tomography angiography, *CV* cortical vein, *DAVF* dural arteriovenous malformation, *DSA* digital subtracted angiography, *EVT* endovascular treatment, *MMA* middle meningeal artery, *OA* occipital artery, *SSS* superior sagittal sinus, *TS* transverse sinus

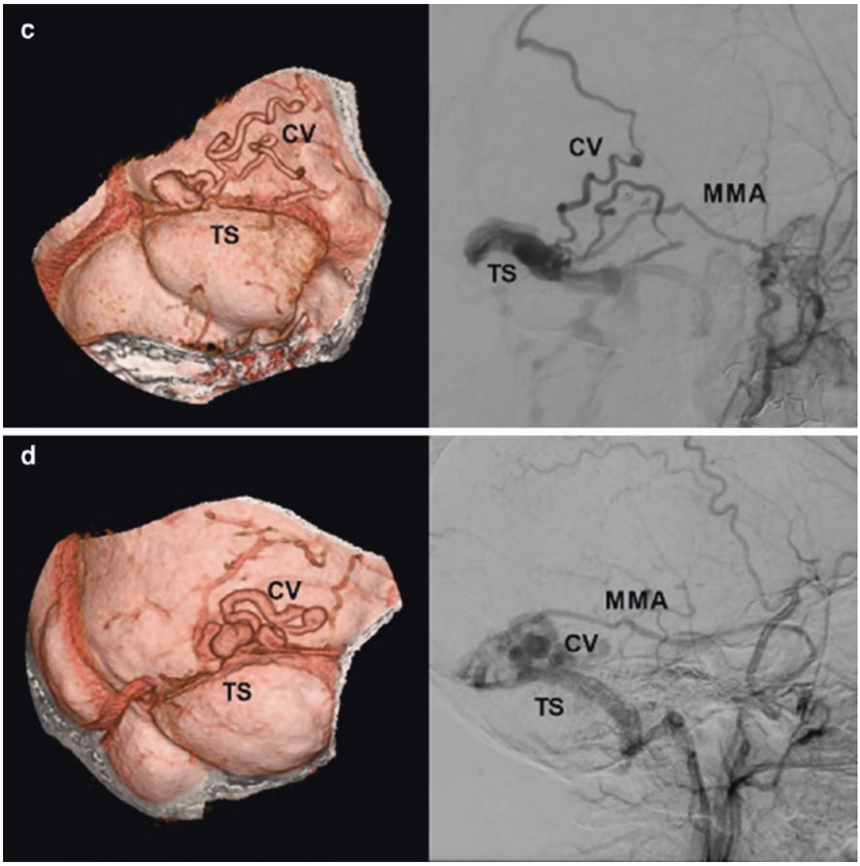

Fig. 20.2 (continued)

20.3.3 Draining Vein

In normal veins in the brain, many tributaries often share one trunk and flow into a sinus (Fig. 20.3) [27]. In cases of DAVF, venous hypertension results in draining vein arterialization, presenting with dilatation, varix formation, aneurysm formation and congestion [4, 20, 28]. Venous dilatation is defined as an increase in the normal vessel diameter, a varix is defined a vessel dilatation to more than twice that the diameter of veins proximal and distal to the varix, and venous congestion is defined as veins exhibiting a pseudophlebitic pattern (Fig. 20.4) [29]. DAVFs with a pial arterial supply are more likely to have these venous pathologies [20]. Venous hypertension in cases of DAVFs can result in dural sinus stenosis or occlusion and lead to an isolated venous sinus, which can be associated with EVT-associated hemorrhage [30].

During EVT, an excessive amount of Onyx may enter and penetrate these fragile venous structures. In addition, occlusion of the ostium of cortical veins may result in venous hypertension, and these veins tend to rupture [18, 31, 32]. After EVT, venous blood stagnation may occur, which is a very powerful trigger of the coagulation cascade and may also cause venous rupture [31]. Large or giant venous aneurysms may be more prone to lead to thrombosis after EVT, and they carry a risk for delayed rupture (Fig. 20.5) [5, 33, 34].

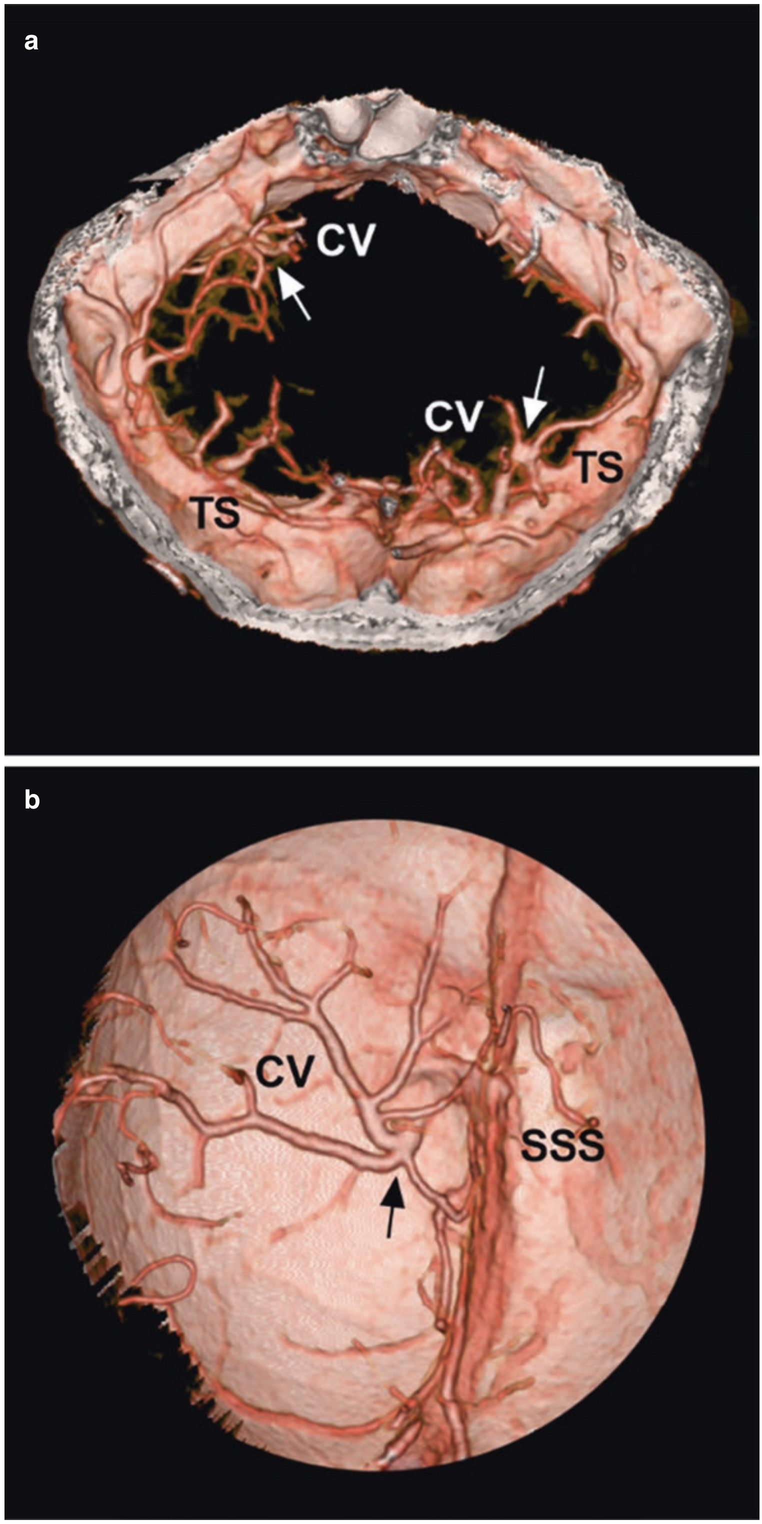

Fig. 20.3 Normal venous draining pattern in the brain. (**a**) CTA showing the venous draining pattern in the tentorium, with the veins flowing into one trunk (arrows). (**b**) CTA showing the venous draining pattern in the superior sagittal sinus, with the veins flowing into one trunk (arrow). *Abbreviations*: *CTA* computed tomography angiography, *CV* cortical vein, *SSS* superior sagittal sinus, *TS* transverse sinus

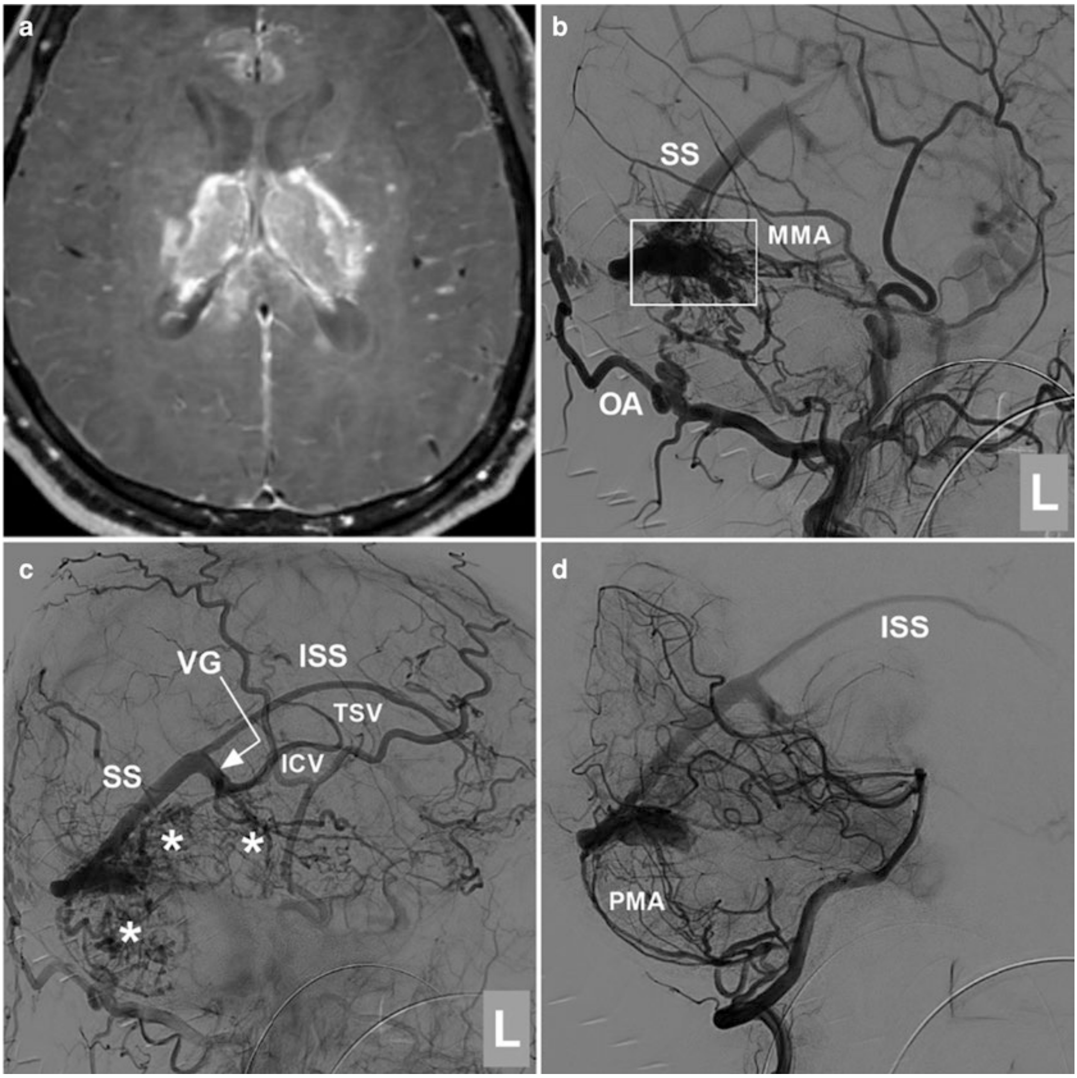

Fig. 20.4 Venous pseudophlebitic pattern in a case of DAVF. (**a**) MRI with a T1WI VISTA sequence showing the bilateral thalamus with a high signal indicating edema. (**b**, **c**) DSA of the left ECA showing the DAVF (frame in **b**) in the transverse sinus, with the MMA and OA as feeders and brain deep vein system congestion; the asterisks in (**c**) indicate the pseudophlebitic pattern. (**b**) Arterial phase. (**c**) Venous phrase. (**d**) DSA of the VA showing that the PMA was also feeding the DAVF. *Abbreviations*: *DAVF* dural arteriovenous fistula, *DSA* digital subtracted angiography, *ECA* external carotid artery, *ICV* internal cerebral vein, *ISS* inferior sagittal sinus, *L* left, *MMA* middle meningeal artery, *MRI* magnetic resonance imaging, *OA* occipital artery, *PMA* posterior meningeal artery, *SS* straight sinus, *TSV* thalamostriate vein, *VA* vertebral artery, *VG* vein of Galen

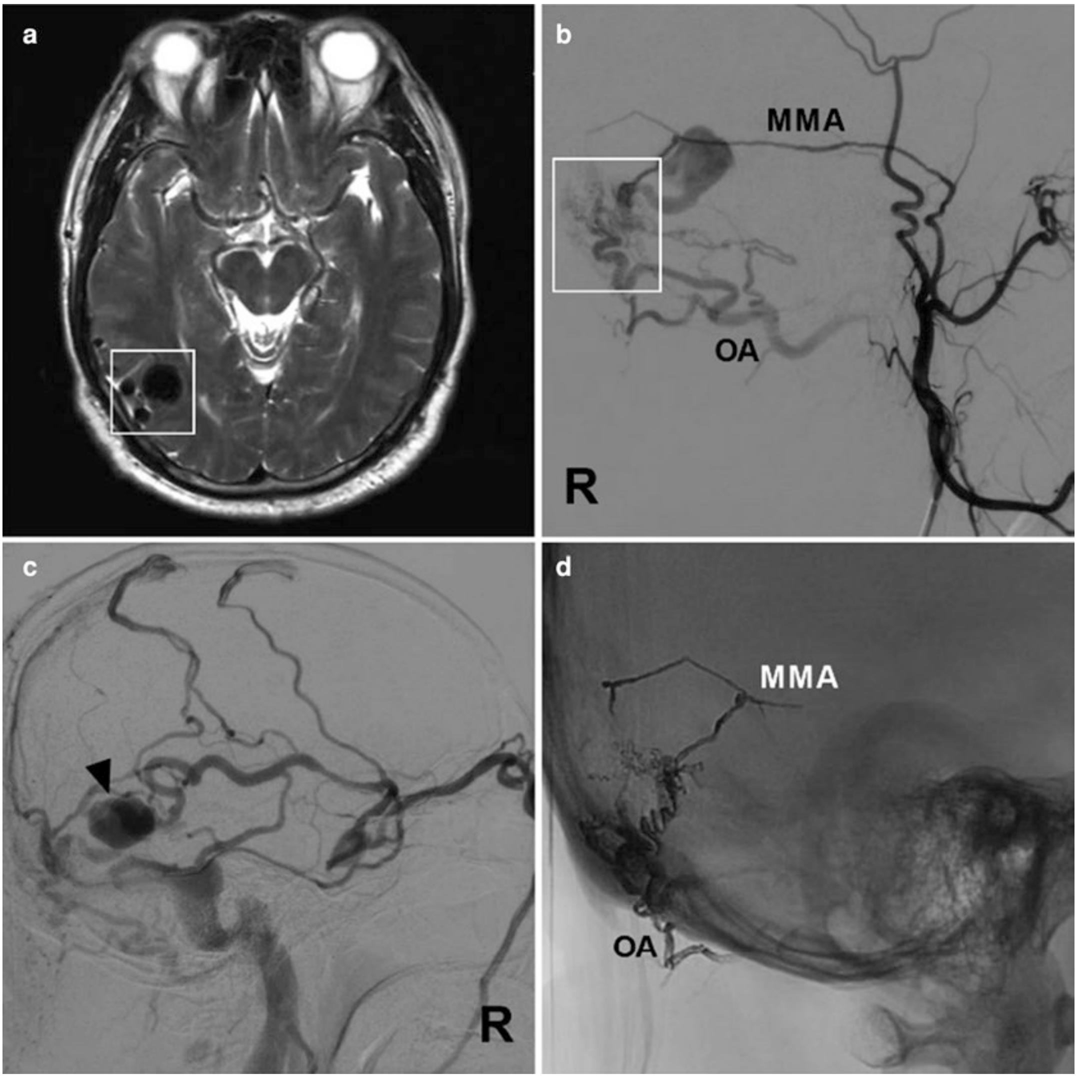

Fig. 20.5 Delayed hemorrhagic complication after TAE for a DAVF. (**a**) MRI with a T2WI sequence showing the venous lesion (frame) at right posterior temporal lobe. (**b**) Arterial-phase DSA of the right ECA showing the DAVF (frame) in the transverse sinus, with the MMA and OA as feeding arteries. (**c**) Venous-phase DSA of the right ECA showing that the draining veins were extensive and many superficial veins of the hemisphere were involved; the triangle indicates a venous aneurysm. (**d**) X-ray examination showing Onyx casted via the MMA and OA. (**e**) DSA of the right OA showing no visible DAVF with capillary-like termination of the OA (frame). (**f**) CT 2 h postoperatively showing hemorrhage in the posterior temporal lobe around the venous aneurysm (asterisk). *Abbreviations*: *CT* computed tomography, *DAVF* dural arteriovenous fistula, *DSA* digital subtracted angiography, *ECA* external carotid artery, *MRI* magnetic resonance imaging, *MMA* middle meningeal artery, *OA* occipital artery, *R* right, *TAE* trans-arterial embolization

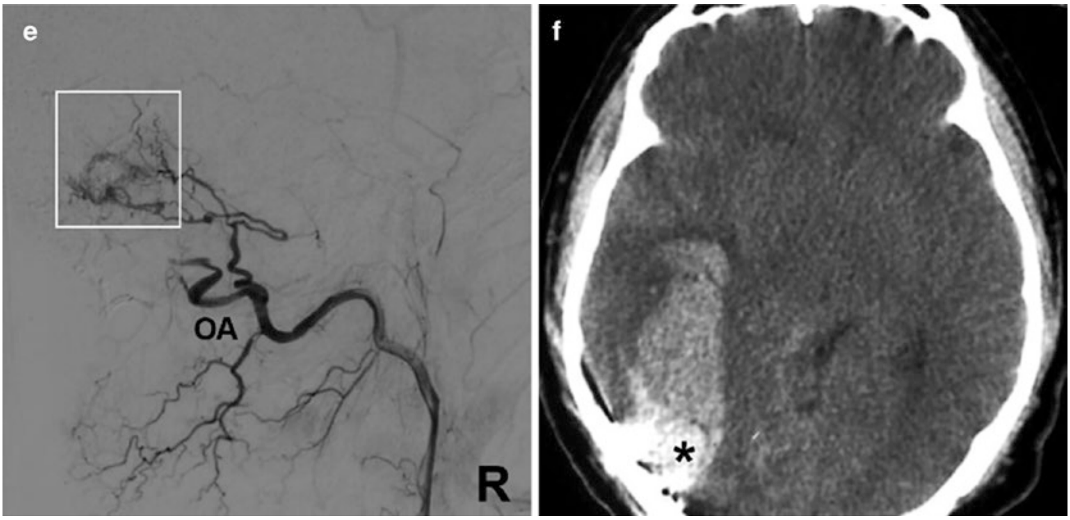

Fig. 20.5 (continued)

20.4 EVT Techniques, Risks, and Preventive Measures

Various EVT techniques can be used in the treatment of DAVFs, including transarterial embolization (TAE), transvenous embolization (TVE), or both in combination [35]. All of these methods are associated with hemorrhagic complications [7, 35, 36]. For instance, EVT-associated hemorrhages can occur in 7.7–33.3% of TAE procedures for DAVFs [11, 37].

20.4.1 General Considerations

EVT-associated hemorrhages are usually due to complete fistula occlusion [13]. If the Cognard grade is downgraded after EVT reduces the shunt volume or the size of the DAVF, staged EVT can become safer. Nontarget embolization has a high risk of post-EVT hemorrhage because it risks the occlusion of functional drainage veins, potentially leading to venous hemorrhage [38]. It is feasible to leave a small remaining fistula rather than risk severe secondary complications due to complete single-stage embolization [4].

In TVE, a sinus occlusion approach is crucial for obtaining an angiographic cure; however, normal drainage function can be affected, which is associated with post-EVT hemorrhage. Therefore, a sinus-preserving approach is attractive because it enables the physiological venous drainage of brain tissue. In addition, in DAVFs with sinus stenosis or occlusion, the restoration of sinus flow with cortical venous reflux was feasible [39].

EVT should not transfer blood flow into the veins of the cortex or brainstem or into the deep vein system, as this can result in post-EVT hemorrhagic complications. In a report by Mochizuki et al., after TVE for a cavernous sinus DAVF, delayed brainstem hemorrhage occurred because of partial obliteration of the drainage pathways exacerbated reflux of the prepontine bridging vein into the brainstem [7].

20.4.2 TAE, Risks and Preventive Measures

TAE can be considered in the treatment of all types of DAVFs; it requires distal catheterization of the feeding artery as much as possible, and then Onyx is used to penetrate the fistulous connection and proximal aspect of the venous receptacle [21]. During navigation, the feeding artery can rupture by microguidewire penetration [40]. Additionally, when the microcatheter tip is too far away from the fistula, complete EVT is difficult, and high-pressure Onyx casting could result in rupture of the path artery, resulting in epidural hemorrhage (Fig. 20.6). Therefore, the micro-

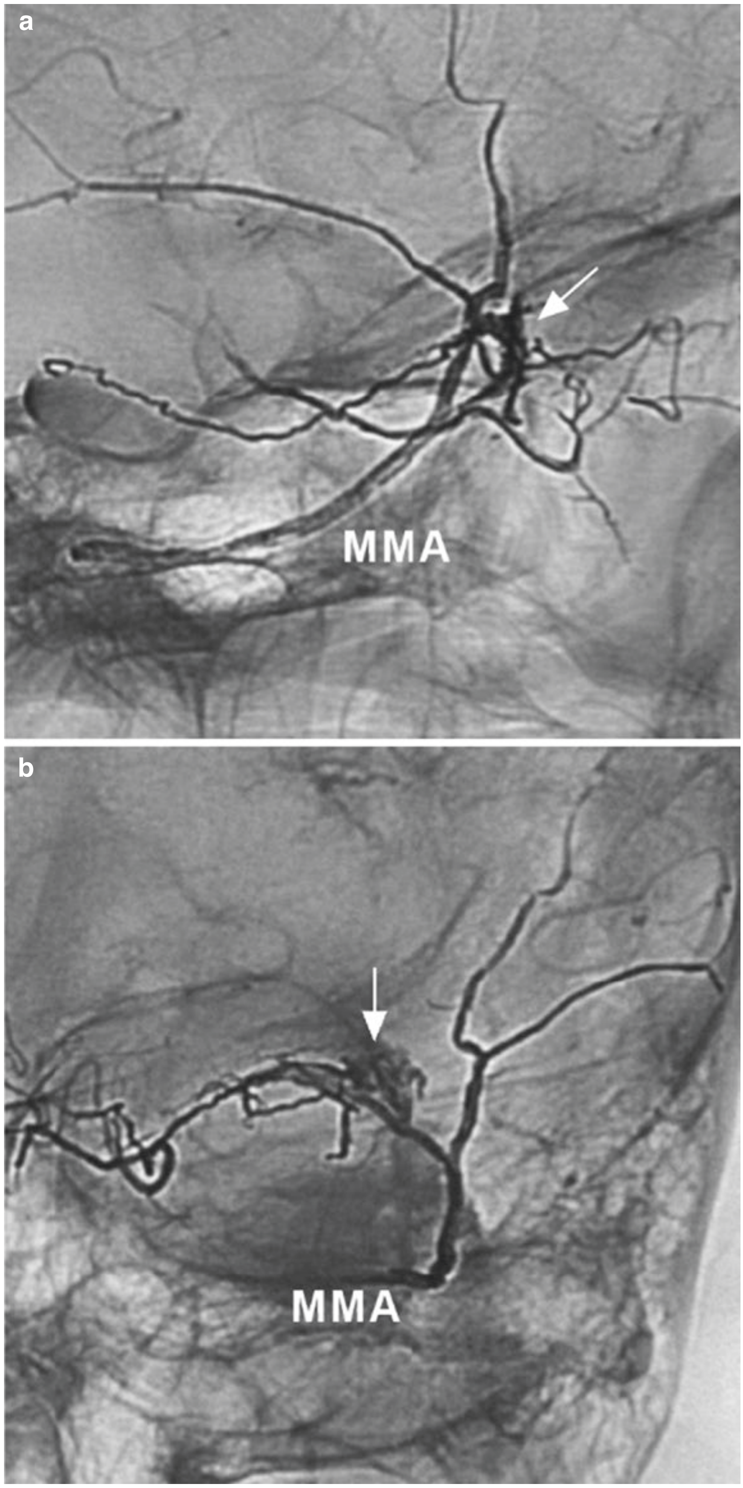

Fig. 20.6 MMA rupture during Onyx casting for DAVF. (**a**, **b**) X-ray examination showing Onyx casting in the MMA and its branches. During Onyx casting, the MMA ruptured; the arrows show the point of rupture. (**a**) Lateral view. (**b**) Anteroposterior view. *Abbreviations*: *DAVF* dural arteriovenous fistula, *MMA* middle meningeal artery

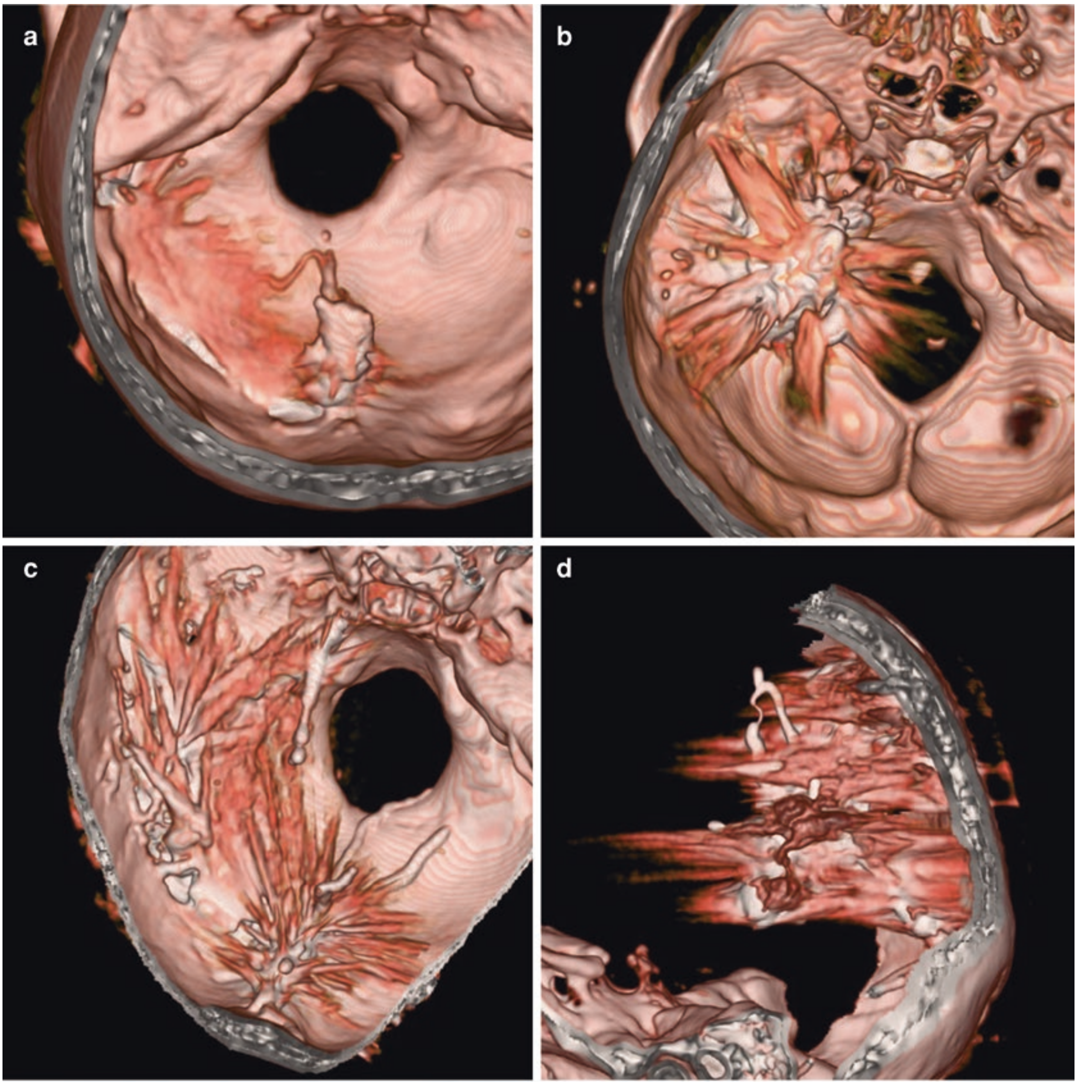

Fig. 20.7 Onyx casting for DAVFs on CTA. (**a–d**) CTA showing Onyx casting in DAVFs, with occlusion of the fistula and the origin of the draining vein. (**a**) A DAVF of a sinus confluence. (**b**) A DAVF in the tentorium. (**c**) Multiple DAVFs. (**d**) A DAVF in the cerebral falx. *Abbreviations*: *CTA* computed tomography angiography, *DAVF* dural arteriovenous fistula

catheter tip should be "wedged" into the feeding artery to access the DAVF.

When pursuing complete EVT via TAE, the ostium of cortical veins may be occluded by Onyx casting (Fig. 20.7). The angiographic view after Onyx casting should be superimposed at the end of the procedure on the initial angiographic view of the venous phase to verify that the Onyx did not contaminate the ostium of the veins. The patency of all involved sinuses and their tributaries should be preserved to avoid delayed hemorrhage. In addition, the volume of Onyx used in one session should be minimized. In a report by Liu et al. on EVT for DAVFs, an Onyx casting volume of more than 6 mL was a risk factor for EVT-associated hemorrhage [5].

A pial arterial supply is also a risk factor for hemorrhagic complications in EVT for DAVFs (Fig. 20.1). The stagnation of the pial feeding artery from EVT via other dural arteries may be insufficient to avoid EVT-associated hemorrhage. Therefore, at least major pial feeding arteries, and if possible, the entire pial network, should be obliterated before performing curative EVT. However, in general, gaining catheter access to the pial artery is difficult and sometimes dangerous due to its distal location and tortuous structure [11, 12].

Although the risk of a pial arterial supply is acceptable, whether it should be occluded remains controversial. In the Osada et al. study, postoperative bleeding did not occur even when the pial arterial supply was not obliterated, while the venous outflow was occluded [1]. In a report by Brinjikji et al., more than 10% of DAVFs had a pial supply, but this was not a contraindication to EVT; post-EVT hemorrhage related to pial arterial supply rupture was not found [20].

20.4.3 TVE, Its Risks, and Preventive Measures

TVE can be considered mainly in the treatment of sinus-type DAVFs, and either dural sinus occlusion or preservation can be used. However, whenever it is possible, sinus preservation should be preferred [39], especially when a specific sinus segment is essential for intracranial venous drainage [41].

20.4.3.1 Sinus Trapping

It is easy to perform dural sinus occlusion by trapping the sinus together with fistula points at the dural sinus wall. Coiling combined with Onyx casting is helpful, and after coiling to form the frame, the dural sinus can be completely occluded by casting Onyx. Trapping the dural sinus with TAE via arterial feeders is supposed to offer a higher rate of definite angiographic cure of DAVFs. However, occlusion of the dural sinus carries a risk of venous hemorrhage (Fig. 20.8). Iatrogenic sinus occlusion is never recommended because the complete obliteration of a dural sinus might impair normal venous drainage.

20.4.3.2 Sinus Preservation by Retrograde Catheterization

There are two approaches in TVE: one is catheterization to shunt the pouch through the dural sinus; the other is retrograde catheterization of the cortical vein.

A shunted pouch is a tubular or elliptic vascular structure that is separated from the main sinus lumen into which multiple feeding arteries converge and continue to the sinus. For DAVFs located within the dural sinus wall, TVE by coil deposition and/or Onyx casting has been reported to provide a higher likelihood of cure than TAE [42]. During TVE aimed at a shunted pouch, balloon-assisted sinus protection is helpful. By keeping a temporary balloon in the diseased sinus segment during EVT, the balloon can preserve the natural dural venous sinus drainage and allow better penetration of the fistula network by the Onyx [43].

Retrograde cortical vein catheterization is also an option for TVE. First, the DAVF can be embolized via TAE to reduce blood flow, and then the microguidewire can be carefully introduced and advanced to the fistular portion via the cortical draining vein, followed by the microcatheter [4]. However, navigation to reach the arteriovenous shunting point of a leptomeningeal vein is usually technically demanding and therefore riskier, and should be the last resort, as the draining vein may be perforated by the microguidewire [44].

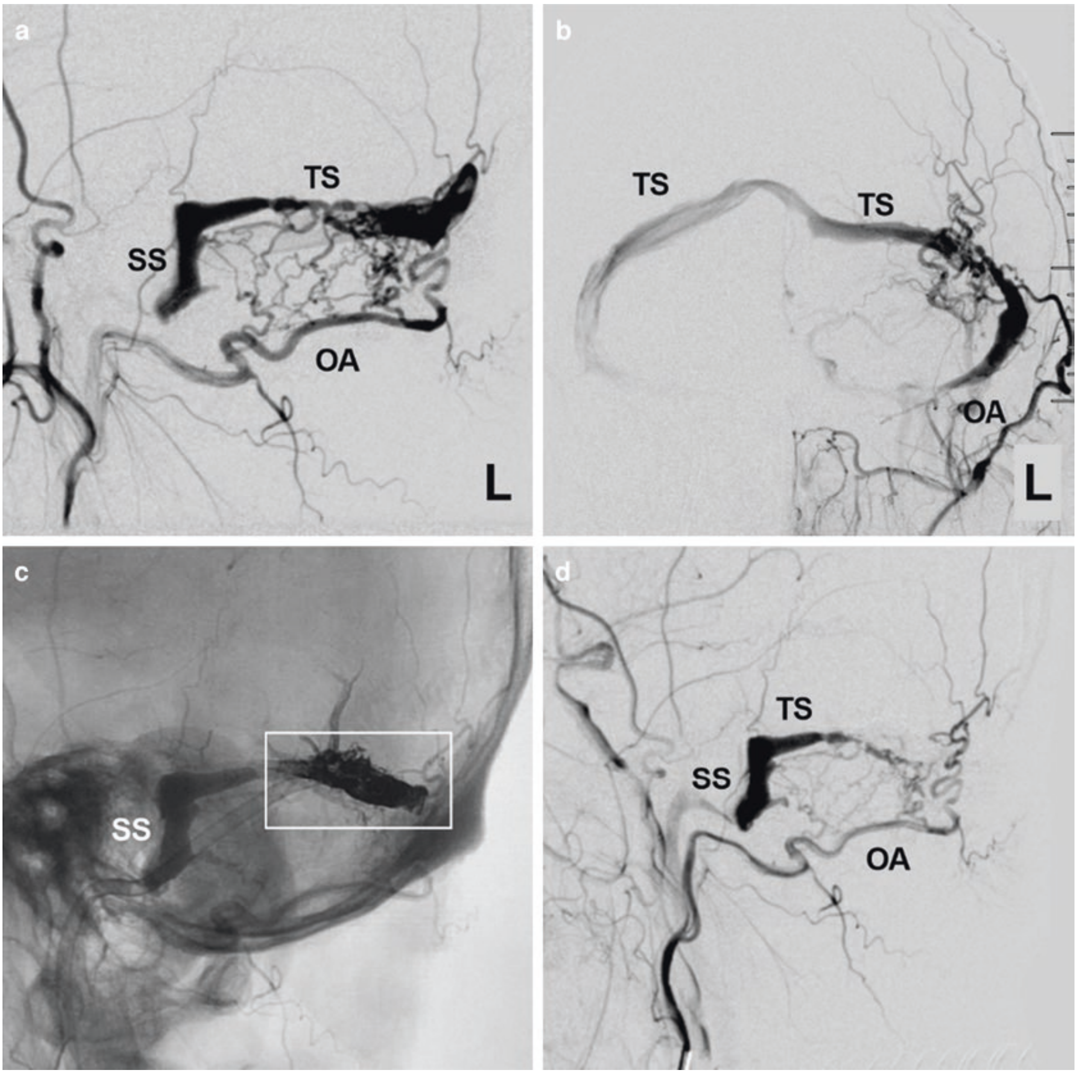

Fig. 20.8 Postoperative hemorrhage after TVE for a TS DAVF. (**a**, **b**) DSA of the left ECA showing the DAVF in the TS, occlusion of the SS, and draining toward the contralateral TS; the Cognard grade was IIa. (**a**) Lateral view. (**b**) Anteroposterior view. (**c**) X-ray examination showing occlusion of the DAVF via TVE with coiling and Onyx assistance (frame). (**d**) DSA of the ECA showing downgrading of the DAVF from grade IIa to grade I after TVE. (**e**) CT at 4 h postoperatively showing multiple cerebellar hemorrhages (asterisks). (**f**) CT reconstruction showing the casted Onyx in the cerebellar veins (frame). *Abbreviations*: *CT* computed tomography, *ECA* external carotid artery, *DAVF* dural arteriovenous fistula, *DSA* digital subtracted angiography, *L* left, *MMA* middle meningeal artery, *OA* occipital artery, *SS* sigmoid sinus, *TS* transverse sinus, *TVE* transvenous embolization

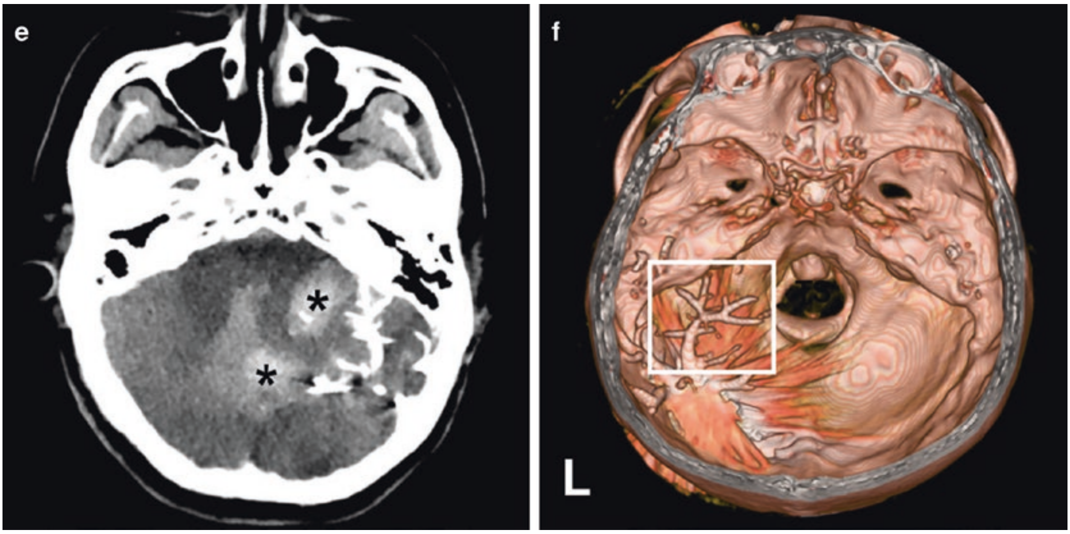

Fig. 20.8 (continued)

20.4.4 Combination of TAE and TVE with Balloon Protection

TAE under intrasinus balloon protection is an efficient treatment strategy for DAVFs, and the use of supercompliant balloons is important [45]. With this technique, Onyx casted via TAE can diffuse into arteriovenous shunts up to the area in communication with the normal sinus, and the balloon can preserve the natural dural venous sinus drainage and allow better penetration of the fistula network by the Onyx [43]. In addition, balloon-assisted sinus protection can prevent the unwanted embolization of nontarget veins.

However, balloon assistance has been a source of hemorrhagic complications due to the occlusion of normal veins by Onyx diffusing between the balloon and the sinus wall. In addition, even the stasis of a small vein can result in disastrous postoperative hemorrhage [46]. In a report by Guo et al. of EVT for 14 DAVFs, hemorrhagic complications, including epidural hematoma and cerebellar hematoma, occurred after the treatment of 14.3% of DAVFs due to temporary balloon obstruction [9].

Due to the drawbacks of balloon-assisted sinus protection, the balloon can be replaced with a stent. Guedon et al. reported that TAE for sinus-type DAVFs with Carotid WALLSTENT (Boston Scientific, Natick, MA, USA)-assisted sinus protection may be prioritized over that with balloon assistance. Before TAE, a Carotid WALLSTENT is semireleased in the sinus lumen to obstruct Onyx diffusion into the sinus; after EVT, the Carotid WALLSTENT is recaptured with some Onyx. Such stent-assisted sinus protection is effective in protecting the sinus without causing stasis or venous congestion that could lead to hemorrhagic complications [47].

The combination of TAE and TVE with balloon protection is controversial. In a report by Zamponi et al., TAE for DAVFs without transvenous balloon protection did not show an advantage over that with transvenous balloon protection, and TAE both with and without transvenous balloon protection was effective [48].

20.5 Treatment and Prognosis of Hemorrhagic Complications

Hemorrhagic complications are often disastrous due to the nature of venous hypertension. In the report by Liu et al. of post-EVT hemorrhagic complications in 12 patients, 2 patients died of severe intracranial hemorrhage, 2 patients suffered severe disability, and the other 8 patients recovered well

[5]. In Wu et al.'s report of EVT for tentorial DAVFs, intraoperative hemorrhage occurred in 2 of 6 patients with a pial arterial supply, and one patient died as a result of hemorrhage [8]. If the hemorrhage can be evacuated after urgent craniotomy, especially in cases of supratentorial or epidural hemorrhage, a good outcome can be achieved. In general, extensive cerebellar and brainstem hemorrhages may have poor outcomes.

20.6 Summary

Hemorrhagic complications of EVT for DAVFs are disastrous. These complications can be considered to be associated with the rupture of a glomus-like structure around the draining vein. Excessive Onyx occlusion of the ostium of cortical veins may also carry a risk of venous hemorrhage; thus, it is necessary to identify glomus-like structures before EVT. The major pial arterial supply should be occluded first, and patency of the involved sinus and its tributaries should be preserved. If hemorrhage can be evacuated after urgent craniotomy, especially in cases of supratentorial or epidural hemorrhage, a good outcome can be achieved.

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Conflicts of Interest The authors declare that they have no conflicts of interest.

Ethics Approval Ethics approval is not needed for review articles at our institution.

Informed Consent Informed consent was obtained from all individual participants included in the study or their legal guardians.

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