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Review

Current status of endovascular treatment for dural arteriovenous fistulae in the anterior cranial fossa: A systematic literature review

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Abstract

Anterior cranial fossa (ACF) dural arteriovenous fistulae (DAVFs) are rare, and a systematic review of the literature is lacking. Such a review is necessary, however, so a systematic PubMed search of related studies was performed. Twenty-four studies were identified, reporting on 48 patients, of whom 39 had definite age and sex information and 33 (84.6%, 33/39) were male. The afflicted patients were between 37 and 80 years old (mean 55.6). Among the 48 patients, 28 (58.3%, 28/48) primarily presented with intracranial hemorrhage, 47 (97.9%, 47/48) had feeding arteries from the anterior ethmoidal artery (AEA) of the ophthalmic artery (OA), and 40 (83.3%, 40/48) had bilateral feeding arteries. All of the cases had high-grade Cognard classifications (III-IV). Among the 48 patients, 43 (89.6%, 43/48) had drainage into the superior sagittal sinus (SSS). In addition, 36 (75%, 36/48) patients were treated via transarterial embolization (TAE). Of these patients, 28 (77.8%, 28/36) were managed via the AEA of the OA. Another 12 (25%, 12/48) patients were treated via transvenous embolization (TVE), 11 of whom (91.7%, 11/12) were treated with the trans-SSS approach. Complete angiographic cure was achieved in 44 (91.7%, 44/48) patients, with 4 (8.3%, 4/48) patients suffering from postprocedural complications. All 48 patients had clear descriptions of follow-up outcomes, with 45 (93.8%, 45/48) patients having a good outcome. Thus, when treating ACF DAVFs, endovascular treatment (EVT) can completely obliterate the fistula point and correct the venous shunting. EVT is therefore an effective treatment for ACF DAVF. Although many complications can occur, this approach achieves good outcomes in most cases.

Key words: endovascular treatment, dural arteriovenous fistula, anterior cranial fossa, systematic review

Introduction

A dural arteriovenous fistula (DAVF) is an arteriovenous shunt located in the dural wall of the venous sinus or the expanded layer of the dura mater [1-3]. Intracranial DAVFs account for only 10% to 15% of intracranial vascular malformations, and only 10% of all DAVFs are located in the anterior cranial fossa (ACF) [4-7]. Therefore, the rate of ACF DAVFs is 1% to 1.5% of intracranial vascular malformations, which is very rare.

ACF DAVFs are also termed ethmoidal DAVFs or cribriform plate DAVFs. These vascular events are notorious for their proclivity to drain directly into cortical veins, indicating a malignant natural history and a high bleeding risk in 91% of cases. Hence, ACF DAVFs are usually treated regardless of whether they are symptomatic [4, 8].

Currently, treatments for ACF DAVFs include surgical resection, endovascular treatment (EVT) and stereotactic radiosurgery [9]. Surgical resection is very effective because it has low postoperative morbidity and can achieve a complete cure [8, 10]. However, surgical resection is also associated with risks inherent to frontal craniotomy, including fontal sinus opening, cerebrospinal fluid leakage, intradural infection, and retraction damage to the frontal lobe and olfactory nerves [11]. Radiosurgery has been described as an efficient treatment, but an extended period of time is required to occlude the DAVF [9].

Recently, trends in the management of ACF DAVF have been significantly affected by technological advances in EVT related to the widespread use of new microcatheters, and morbidity and modality have apparently been reduced [8]. Since its introduction in 2000, the Onyx Liquid Embolic System (Irvine, CA, USA) has been widely used for embolization in DAVFs and is easier to control than previously available liquid agents [12, 13]. EVT, including transarterial embolization (TAE) and transvenous embolization (TVE), is currently considered the first therapeutic option for ACF DAVFs [14, 15].

Current data regarding EVT for ACF DAVFs are sporadic. No systematic review of EVT for ACF DAVFs has previously been published; hence, we reviewed the available literature on this subject. Literature searches identified 48 cases of EVT for ACF DAVFs, which are shown in Table 1. Meanwhile, general and angiographic data on the ACF DAVF series are summarized in Table 2. In this article, EVT for ACF DAVFs is the primary focus of the systematic literature review.

Material and methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [16]. Eligible English language articles (case reports, case series, and studies considering ACF DAVFs treated via EVT) were identified through searches of PubMed published (last search date was October 2018).

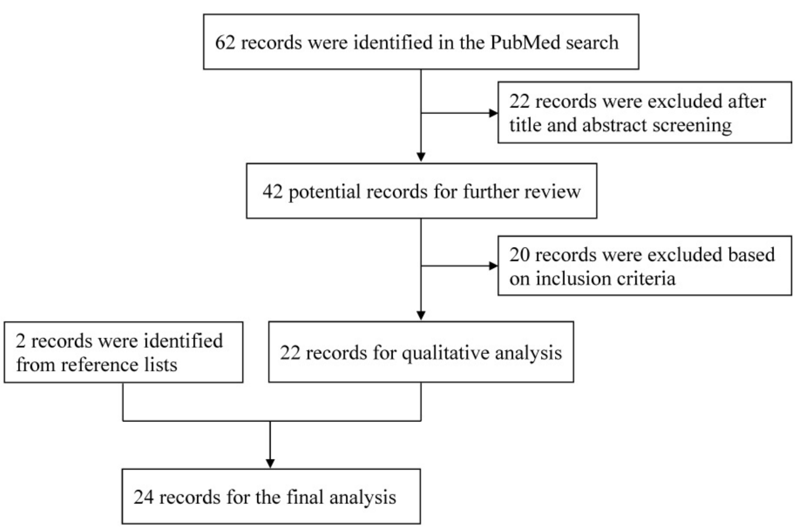

Figure 1. Flow chart of the search strategies.

The search algorithm used the terms "anterior cranial fossa dural arteriovenous fistula," "cribriform plate arteriovenous fistula," "ethmoidal dural arteriovenous fistula" and "embolization" as key words in relevant combinations. The reference lists of the identified articles were also manually searched for additional studies. The resulting flowchart is depicted in **Figure 1**.

The inclusion criteria were as follows: a) full text was available, b) clinical data were largely complete, and c) EVT was the only treatment used. Patients from EVT studies without sufficient descriptions of the individual demographic, clinical, and radiological data were excluded.

Results

General demographic, clinical, and radiological characteristics

Twenty-four studies [9, 11, 12, 14, 17-36] were identified in the literature search, reporting on a total of 48 patients who met the inclusion criteria. Of these patients, 39 had definite age and sex information, 33 (84.6%, 33/39) were male, and 6 (15.4%, 6/39) were female. The affected patients ranged in age from 37 to 80 years (mean 55.6). Of these 48 patients, 28 (58.3%, 28/48) primarily presented with intracranial hemorrhage (including intracerebral hematoma, subarachnoid hemorrhage, subdural hematoma and intraventricular hemorrhage).

Among the 48 patients, 47 (97.9%, 47/48) had feeding arteries from the anterior ethmoidal artery (AEA) of the ophthalmic artery (OA), 10 (20.8%, 10/48) patients had feeding arteries from the middle meningeal artery (MMA), 16 (33.3%, 16/48) patients had feeding arteries from the ethmoidal branches of internal maxillary artery (IMA), and one (2.1%, 1/48) had feeding arteries from the posterior ethmoidal artery (PEA) of the OA. Among the 48 patients, 40 (83.3%, 40/48) had bilateral feeding arteries, with the remaining 8 (16.7%, 8/48) having unilateral feeding arteries. All 48 cases were high-grade according to the Cognard classification (III-IV) system. Of the 48 patients, 43 (89.6%, 43/48) had drainage into the superior sagittal sinus (SSS), and 8 (16.7%, 8/48) patients had drainage via the Basal vein of Rosenthal.

Treatment process

Of the 48 patients, 36 (75%, 36/48) were treated via TAE. Of these 36 patients, 28 (77.8%, 28/36) were managed via the AEA of the OA, and 6 (16.7%, 6/36) were managed via the middle meningeal artery (MMA).

Of the 48 patients, 12 (25%, 12/48) patients were treated via TVE, and 11 (91.7%, 11/12) were treated via the trans-SSS approach. Of the 12 patients treated via TVE, 2 (16.7%, 2/12) had previously undergone TAE.

Outcome and follow-up

Of the 48 patients, all treated via TAE, complete angiographic cure was achieved in 44 (91.7%, 44/48), while 4 (8.3%, 4/48) patients experienced incomplete angiographic cure. Four (8.3%, 4/48) patients suffered complications, of whom 1 (2.1%, 1/48) exhibited edema of the thalamus and midbrain, 2 (4.2%, 2/47) exhibited excessive Onyx reflux, and 1 (2.1%, 1/48) experienced microcatheter retention. The clinical data are summarized in Table 1. All 48 patients had definite descriptions of follow-up outcomes. In total, 45 (93.8%, 45/48) patients had good outcomes, 2 (4.2%, 2/48) had improved neurological state, and 1 (2.1%, 1/48) was worse than before operation.

Table 1: Clinical data for patients with EVT for ACF DAVF

No.	Author/Year	Age/Sex	Presentation	Feeding arteries	Venous drainage	Cognard type	EVT	Angiographic cure	Complication	Outcome
1	Matsumaru et al./1997[17]	62/M	IH	Bilateral AEA of the OA	Frontal vein to the SSS	III	TAE: via both AEAs of the OAs with NBCA	Complete	No	Good
2	Defreyne et al./2000[11]	40/M	SAH	Bilateral AEA of the OA; Ethmoidal branches of the IMA	Frontal vein to the SSS	III	TVE: trans-SSS approach with coils.	Complete	No	Good
3	Defreyne et al./2000[11]	39/M	Asymptomatic	Bilateral AEA of the OA	Frontal vein to the SSS; Basal vein of Rosenthal	IV	TVE: trans-SSS approach with coils.	Complete	No	Good
4	Abrahams et al./2002[18]	77/M	Dementia	Bilateral AEA of the OA; Ethmoidal branches of the IMA and MMA	Frontal vein to the SSS	IV	TAE: via ethmoidal branches of the IMA or MMA	Incomplete	No	Good
5	Flynn et al./2007[19]	39/F	IH	Unilateral AEA of the OA	Basal vein of Rosenthal	IV	TAE: via the AEA of the OA with NBCA	Complete	No	Good
6	Lv et al./2007[20]	52/M	IH	Bilateral AEA of the OA and ethmoidal branches of the IMA	Frontal vein to the SSS	IV	TAE: via both AEAs of the OA with Onyx, two stages.	Complete	No	Good
7	Katsaridis et al./2007[21]	76/M	IH	Bilateral AEAs of the OAs	Frontal vein to the SSS	IV	TAE: via both AEAs of the OAs with NBCA	Complete	No	Good
8	Lv et al./2008[22]	65/M	Dementia and seizure	Unilateral AEA of the OA and ethmoidal branches of the IMA	Frontal vein to the SSS	III	TAE: via the AEA of the OA with Onyx. TVE: trans-SSS approach with coils.	Complete	No	Good
9	Lv et al./2008[23]	48/M	Headache and blurred vision	Bilateral AEA of the OA, ethmoidal branches of the IMA and MMA	Frontal vein to the SSS	III	TVE: trans-SSS approach with coils.	Complete	No	Good
10	Lv et al./2008[23]	60/M	IH	Bilateral AEAs of the OAs	Frontal vein to cavernous sinus	IV	TAE: via the AEA of the OA with Onyx	Complete	No	Good
11	Tahon et al./2008[24]	50/M	Headache	Bilateral AEA of the OA and MMA, both pial branches of the ACA and MCA	Frontal vein to the SSS; Basal vein of Rosenthal	IV	TAE: via the MMA with Onyx	Complete	No	Good
12	Tsutsumi et al./2009[25]	59/M	IH	Bilateral AEA of the OA; Unilateral persistent primitive olfactory artery	Frontal vein to the SSS	III	TAE: via persistent primitive olfactory artery and AEA of the OA with NBCA	Incomplete	No	Good
13	Agid et al./2009[9]	55/M	IH	Bilateral AEA of the OA; Ethmoidal branches of the IMA	Frontal vein to the SSS	IV	TAE: via the AEA of the OA with NBCA	Complete	No	Good
14	Guedin et al./2010[26]	75/M	IH	Unilateral the PEA of the OA	Frontal vein to the SSS	IV	TAE: via the PEA of the OA with Onyx	Complete	No	Good
15	Ishihara et al./2010[27]	71/M	Blurred vision	Bilateral facial arteries; Unilateral AEA of the OA	Frontal vein to the SSS	III	TAE: via facial artery with NBCA	Complete	No	Good
16	Mack et al./2011[28]	57/M	SAH	Bilateral AEA of the OA and ethmoidal branches of the IMA	Frontal vein to the SSS	IV	TAE: via the AEA of the OA with Onyx	Complete	No	Good
17	Mack et al./2011[28]	54/F	Headache and vision impairment	Bilateral AEA and the PEA of the OA	Basal vein of Rosenthal	IV	TAE: via both AEAs of the OA with NBCA and Onyx	Complete	Edema of thalamus/ midbrain	IM
18	Zhao et al./2012[29]	58/M	SDH	Unilateral AEA of the OA	Frontal vein to the SSS	IV	TAE: via the AEA of the OA with Onyx.	Complete	No	Good
19	Li et al./2013[12]	37/M	SAH	Bilateral AEA of the OA; Branch of the	Frontal vein to the SSS	IV	TAE: via the AEA of the OA and branch of	Incomplete	Excessive reflux	Good

				facial artery; MMA			the facial artery with Onyx, twice stages.			
20	Li et al./2013[12]	52/M	Blurred vision	Bilateral AEA of the OA; Pial branch of the ACA	Frontal vein to the SSS	III	TAE: via AEA of the OA with Onyx.	Complete	No	Good
21	Li et al./2013[12]	68/M	IH, IVH	Bilateral AEA of the OA; Ethmoidal branches of the IMA	Frontal vein to the SSS	IV	TAE: via the AEA of the OA with Onyx.	Complete	No	Worse
22	Li et al./2013[12]	60/M	IH, SDH	Bilateral AEA of the OA; Ethmoidal branches of the IMA	Frontal vein to the SSS	IV	TAE: via the AEA of the OA with Onyx.	Complete	No	Good
23	Li et al./2013[12]	54/M	SAH	Bilateral AEA of the OA; Pial branch of the ACA	Frontal vein to the SSS	IV	TAE: via the AEA of the OA with Onyx.	Complete	No	Good
24	Li et al./2013[12]	43/M	IH, IVH	Bilateral AEA of the OA; MMA	Frontal vein to the SSS	IV	TAE: via AEA of the OA with Onyx.	Complete	No	Good
25	Li et al./2013[12]	55/M	IH, IVH	Bilateral AEA of the OA	Frontal vein to the SSS	III	TAE: via the AEA of the OA with Onyx.	Complete	Excessive reflux	Good
26	Li et al./2013[12]	57/F	SAH	Bilateral AEA of the OA; Ethmoidal branches of the IMA	Frontal vein to the SSS	IV	TAE: via the AEA of the OA with Onyx.	Complete	No	Good
27	Li et al./2013[12]	40/M	Headache	Bilateral AEA of the OA; Branches of the facial artery	Frontal vein to the SSS	IV	TAE: via AEA of the OA with Onyx.	Complete	No	Good
28	Li et al./2013[12]	37/M	IH, SDH	Bilateral AEA of the OA; Branches of the facial artery; MMA	Frontal vein to the SSS	III	TAE: via the AEA of the OA with Onyx.	Complete	No	Good
29	Li et al./2013[12]	42/M	IH, IVH	Bilateral AEA of the OA	Frontal vein to the SSS	IV	TAE: via the AEA of the OA with Onyx.	Complete	No	Good
30	Li et al./2014[30]	NM (range: 38-68)	IH	Unilateral AEA of the OA, ethmoidal branches of the IMA and MMA	Frontal vein to the SSS	III or IV	TAE: via AEA of the OA with Onyx.	Incomplete	No	Good
31	Li et al./2014[30]	NM (range: 38-68)	IH	Unilateral AEA of the OA and ethmoidal branch of the IMA; Bilateral pial branches of the ACAs	Frontal vein to the SSS	III or IV	TAE: via the MMA and pial branches of the ACAs with Onyx.	Complete	Microcatheter entrapment	Good
32	Li et al./2014[30]	NM (range: 38-68)	IH, IVH	Bilateral AEA of the OA	Frontal vein to the SSS; inferior frontal vein into the sylvian veins	IV	TAE: via both AEAs of the OAs with Onyx.	Complete	No	Good
33	Li et al./2014[30]	NM (range: 38-68)	IH	Bilateral AEA of the OA, unilateral ethmoidal branch of the IMA	Frontal vein to the SSS; Ophthalmic vein	III or IV	TAE: via both AEAs of the OAs with Onyx.	Complete	No	Good
34	Li et al./2014[30]	NM (range: 38-68)	Asymptomatic	Bilateral AEA of the OA	Frontal vein to the SSS; Basal vein of Rosenthal	IV	TAE: via the AEA of the OA with Onyx.	Complete	No	Good
35	Li et al./2014[30]	NM (range: 38-68)	IH	Bilateral AEA of the OA	Inferior frontal cortical vein into the sylvian veins	III or IV	TAE: via the AEA of the OA with Onyx.	Complete	No	Good
36	Spiotta et al./2014[31]	41/M	Headache and blurred vision	Bilateral AEA of the OA	Frontal vein to the SSS	III	TAE: via the AEA of the OA with Onyx. TVE: Trans-SSS approach with Onyx	Complete	No	Good
37	Spiotta et al./2014[31]	72/M	Headache	Bilateral AEA of the OA	Frontal vein to the SSS	III	TVE: Trans-SSS approach with Onyx	Complete	No	Good
38	Spiotta et al./2014[31]	55/F	Headache	Bilateral AEA of the OA	Frontal vein to the SSS, Basal vein of Rosenthal	III	TVE: Trans-SSS approach with Onyx	Complete	No	Good
39	Albuquerque et al./2014[32]	NM	Asymptomatic	Unilateral AEA of the OA	Frontal vein to the SSS	III	TVE: Trans-SSS approach with coils.	Complete	No	Good
40	Deng et al./2014[14]	NM	Headache	Bilateral AEA of the OA, Unilateral MMA and ethmoidal branches of the IMA	Frontal vein to the SSS, Basal vein of Rosenthal	IV	TAE: via the MMA to embolize the DAVF with Onyx.	Complete	No	IM
41	Deng et al./2014[14]	NM	SAH	Bilateral AEA of the OA, Unilateral MMA	Frontal vein to the SSS	IV	TAE: via the MMA to embolize the DAVF with Onyx.	Complete	No	Good
42	Inoue et al./2014[33]	58/M	Exophthalmos, chemosis and diplopia	Bilateral AEA of the OA	Superior and inferior ophthalmic veins	III	TAE: via both AEAs of the OAs with NBCA	Complete	No	Good
43	Cannizzaro et al./2018[34]	80/M	Headache	Unilateral AEA of the OA, ethmoidal branches of the IMA and MMA	Frontal vein to the SSS	IV	TAE: via the MMA to embolize the DAVF with Onyx.	Complete	No	Good
44	Limbucci et al./2018[35]	59/F	Headache	Bilateral AEA of the OA	Frontal vein to the SSS	III	TVE: Trans-SSS approach with coils.	Complete	No	Good
45	Limbucci et al./2018[35]	63/F	Asymptomatic	Bilateral AEA of the OA	Frontal vein to the SSS	III	TVE: Trans-SSS approach with Onyx	Complete	No	Good

46	Limbucci et al./2018[35]	50/M	Asymptomatic	Bilateral AEA of the OA	Frontal vein to the SSS	III	TVE: Trans-SSS approach with Onyx	Complete	No	Good
47	Limbucci et al./2018[35]	70/M	IH	Bilateral AEA of the OA, ethmoidal branches of the IMA	Basal vein of Rosenthal	IV	TVE: Trans-Basal vein of Rosenthal approach with Onyx	Complete	No	Good
48	Sirakov et al./2018[36]	40/M	SDH	Bilateral AEA of the OA	Frontal vein to the SSS	IV	TAE: via the AEA of the OA with Onyx.	Complete	No	Good

Abbreviations: EVT: endovascular treatment; ACF: anterior cranial fossa; DAVF: dural arteriovenous fistula; M: male; IH: Intracerebral hematoma; AEA: anterior ethmoidal artery; OA: ophthalmic artery; SSS: superior sagittal sinus; TAE: transarterial embolization; NBCA: N-butyl-2-cyanoacrylate; SAH: subarachnoid hemorrhage; IMA: Internal maxillary artery; TVE: transvenous embolization; MMA: middle meningeal artery; ACA: anterior cerebral artery; MCA: middle cerebral artery; PEA: posterior ethmoidal artery; F: female; IM: improved; SDH: subdural hematoma; IVH: intraventricular hemorrhage; NM: not mentioned

Table 2: General and angiographic data in ACF DAVF series

No.	Author/Year	Cases	Mean Age (years)	Male Sex	Hemorrhagic presentation	Arterial feeders	Venous drainage
1	Başkaya et al./1994[6]	50 cases	56	81%	77%	AEA of the OA: 100%.	Frontal vein into the SSS: 75%.
2	Lawton et al./1999[38]	16 cases	62	68%	50%	AEA of the OA: 100% (50% were bilateral). Ethmoidal branch of the IMA: 31%.	Frontal vein into the SSS: 62.5%. Cavernous sinus: 44.8%. Basal vein of Rosenthal: 2.5%. Labbé vein: 2.5%. Venous ectasia: 69%.
3	Agid et al./2009[9]	24 cases	57	92%	46%	AEA of the OA: 100% (all were bilateral). Ethmoidal branch of the IMA and MMA: 62%.	Frontal vein into the SSS: 75%. Superficial sylvian veins: 21%. Basal vein of Rosenthal: 4%. Venous ectasia: 46%.
4	Li et al./2013[12]	11 cases	50	91%	82%	AEA of the OA: 100% (all bilateral). Ethmoidal branch of the IMA: 36%. MMA: 27%. Pial branch of the ACA: 18%. Branches of the facial artery: 18%. Flow-related aneurysms: 18%.	Frontal vein into the SSS: 100%. Venous ectasia: 73%. Cavernous sinus and Basal vein of Rosenthal: 18%.
5	Gross et al./2016[4]	27 cases	62	67%	37%	AEA of the OA: 93% (all bilateral). Ethmoidal branch of the IMA: 66% (bilateral in 48%). MMA: 22%. Dural branch of ICA: 7%. Pial branch of the ACA: 7%. Flow-related aneurysms: 7%.	Frontal vein into the SSS: 70%. Basal vein of Rosenthal: 19%. Superficial sylvian veins and Trolard or Labbé veins: 11%. Venous ectasia: 59%.
6	Robert et al./2016[37]	10 cases	59	67%	20%	AEA of the OA: 100% (80% were bilateral). Ethmoidal branch of the IMA: 20%. MMA: 30%.	Frontal vein into the SSS: 60%. Cavernous sinus: 20%. Superficial sylvian veins: 20%. Venous ectasia: 70%.

Abbreviations: ACF: anterior cranial fossa; DAVF: dural arteriovenous fistula; AEA: anterior ethmoidal artery; OA: ophthalmic artery; SSS: superior sagittal sinus; IMA: internal maxillary artery; MMA: Middle meningeal artery; ACA: anterior cerebral artery; ICA internal carotid artery

Discussion

Angioarchitecture and grade

In ACF DAVFs, the sources of the main feeding arteries are the AEA of the OA and are primarily bilateral[4, 5, 8, 9, 11, 24, 31, 37]. In the considered ACF DAVF studies (Table 2), the involvement of the AEA of the OA was 93-100%, and 50-100% of ACF DAVFs had bilateral feeding arteries [4, 6, 9, 12, 37, 38]. In the identified 48 cases, 97.9% of patients had feeding arteries from the AEA of the OA, and 83.3% of patients had bilateral feeding arteries.

The MMA can be involved in ACF DAVFs and, when involved, is typically unilateral [14, 15, 37]. In the considered ACF DAVF studies (Table 2), the rate of MMA involvement was 20-30% [4, 6, 9, 12, 37, 38]. In the 48 analyzed cases, the overall rate was 20.8%. The ethmoidal branch (sphenopalatine artery) of the internal maxillary artery (IMA) was also involved in ACF DAVFs. In the studies considered in this series (Table 2), the rate of involvement of the ethmoidal branch of the IMA was 20-66% [4, 6, 9, 12, 37, 38]. In the 48 cases, the overall rate was 33.3% [8, 11, 12, 23, 28, 30].

In addition, the pial branches of the ACA and MCA, the angular branch of the facial artery and even the persistent primitive olfactory artery can be involved in ACF DAVFs in rare cases [4, 9, 12, 25, 27, 39, 40]. Flow-related aneurysms can occur in the feeding artery in 18% of cases [12].

The fistula point of an ACF DAVF is usually located at the level of the cribriform plate in the lateral epidural space, which includes the lamina cribrosa and the orbital roofs. The fistula point of an ACF DAVF is most often single and located on one side of the cribriform plate [11]. Rarely, an ACF DAVF can occur bilaterally [41, 42].

The venous drainage routes of ACF DAVFs include drainage to the frontal veins and then secondarily into the SSS, via the olfactory vein to the cavernous sinus or the basal vein of Rosenthal, or to the sylvian veins and then ultimately into the vein of

Trolard or Labbé [8, 11, 12, 15, 24, 28, 38, 43, 44]. These venous drainage routes are usually unilateral but can be bilateral in rare cases [40].

Of all such venous drainage routes, the frontal cortical veins to the SSS are the most frequently affected [8, 9, 12]. In the considered ACF DAVF studies (Table 2), the rate of drainage into the SSS was 60-100% [4, 6, 9, 12, 37, 38]. In the 48 cases, the overall rate was 89.6%.

In addition, Gross et al. reported that in 19% of all cases, ACF DAVFs had venous drainage that was routed posteriorly into the basal vein of Rosenthal and then into the deep venous circulation, sometimes including the lateral mesencephalic vein [4, 11]. In the 48 analyzed cases, 16.7% of patients had drainage via Basal vein of Rosenthal. This drainage pattern could be related to hemorrhages that occur at a position remote from the DAVF site [10, 28, 30].

Because the ACF contains no dural sinuses, ACF DAVFs always drain via the cortical venous drainage system. In approximately one-half of ACF DAVFs, hemodynamic stress causes fragile draining veins to undergo progressive structural modifications, including dilation and the formation of a venous aneurysm [8-12, 40, 45-49]. Hence, when using the Cognard classification system, ACF DAVFs are often graded as Cognard Type III/IV [10, 12, 24, 37, 50-52]. The 48 cases we considered all had high-grade (III-IV) Cognard classifications.

Cognard et al. noted that intracranial hemorrhage was observed in 10% of patients with type II, 40% with type III and 65% with type IV DAVFs [51]. In the assessed ACF DAVF studies (Table 2), the rate of intracranial hemorrhage was 22-82% [4, 6, 9, 12, 37, 38]. In the 48 cases, the overall rate of intracranial hemorrhage was 58.3%.

Outline of EVT

The therapeutic goal of EVT is for the embolic agents to penetrate through the transosseous shunt to obliterate the fistula point [4, 12]. Performing TAE through the OA is considered technically challenging because the surgeon must avoid occluding the central retinal artery (CRA) [17, 30]. TVE can achieve complete obliteration, but the route from the puncture point to the DAVF is long and difficult to navigate, especially when passing the venous varix, and TVE is more time consuming and therefore requires more patience [10].

In ACF DAVFs, EVT should be considered only in patients with favorable angiographic anatomy. However, in appropriate patients, EVT is effective and associated with a high obliteration rate [14]. TAE is the first option in cases with good transarterial access to the fistulous point (e.g., via a large and easily navigable OA with limited proximal vessel tortuosity) that allows distal microcatheterization to be performed in close proximity to the fistulous point and a tolerable degree of reflux [14, 17, 30]. Additionally, due to safety issues, TVE is preferred if the ACF DAVF has an easily navigable draining vein and covers a short cortical distance [10, 37].

Transarterial embolization

When performing TAE for ACF DAVFs, almost all feeding arteries can be used as the TAE path [24, 30]. However, TAE is rarely performed when the feeding arteries are too thin, such as when the ethmoidal branch of the IMA is involved [11, 38]. Currently, TAE is primarily performed via the OA and MMA, although in rare cases, the facial artery can be used [27].

(i) AEA of OA

In ACF DAVFs, the AEA of the OA is the most frequently reported feeding artery, and in these cases, TAE must be performed via these arteries [12, 53]. In the 48 studied cases, 36 patients were treated via TAE. Of these 36 patients, 28 (77.8%, 28/36) were managed via the AEA of the OA. When using TAE to treat an ACF DAVF via the OA, the CRA must be given sufficient consideration during Onyx injection to reduce the risk of retinal ischemia and acute vision loss. Because the space available for Onyx reflux is limited in these patients, excessive reflux should be strictly controlled [9, 30].

The origin of the CRA is at the same level of the ciliary arteries and originates from the second segment of the OA [54]. Therefore, the surgeon should ensure that the ciliary arteries are recognized. Moreover, it is essential that there is no evidence of retinal choroidal blush on superselective angiography before the Onyx injection is performed [30]. Therefore, the optimal position of the microcatheter is as close as possible to the fistula, and the microcatheter should be placed in the third segment of the OA immediately proximal to the origin of the AEA. Finally, when injecting Onyx, the origin of the CRV should also be noted and kept under consideration [37, 55].

(ii) MMA

In ACF DAVFs, the MMA is usually not the main feeding artery, and its route to the DAVF is very long and occasionally tortuous. For this reason, the MMA is not often used for TAE [14, 15]. However, the MMA is actually an excellent path to take when performing TAE because it is strongly resistant to rupturing when the microcatheter is pulled back. Moreover, this vessel contains sufficient space for Onyx reflux, increasing the forward penetration of the Onyx into vascular networks, including nearby drainage veins or feeders

[15, 56, 57]. Occasionally, a dual lumen balloon and the pressure-cooker technique can help to increase the penetration of the Onyx [37]. In our summarized 48 cases, 36 were treated via TAE. Of these 36 patients, 6 (16.7%, 6/36) were managed via the MMA.

However, most ACF DAVFs are primarily supplied by the ethmoidal artery, and in these cases, the OA must be used [12].

Transvenous embolization

In ACF DAVFs, the main advantage of TVE over TAE is that TVE is not associated with a risk of occluding the CRA because the Onyx is deployed directly into the vein [4, 10]. In TVE, the trans-SSS approach is widely used. In the 48 cases considered herein, 12 (25%, 12/48) patients were treated via TVE, and 11 (91.7%, 11/12) were treated with the trans-SSS approach. The TVE approach via deep veins is considered to be dangerous.

However, when TVE is used in ACF DAVFs, venous retrograde catheterization becomes difficult because the transvenous routes are tortuous [11, 58]. To overcome this difficulty, it is recommended that TVE be performed via a puncture of the internal jugular vein [10, 11]. In addition, it can be helpful to use a flexible intracranial guiding catheter or an intermediate catheter that is advanced to the ostium of the cortical draining vein [10, 31].

When TVE is performed in an ACF DAVF, after the microcatheter tip is positioned in the fistula point, arteriography of the OA and superselective venography of the microcatheter are necessary to confirm the placement of the microcatheter tip [11, 31]. When performing TVE, Onyx is a good choice because it can penetrate the fistula through the cribriform plate and can pass retrogradely into the tiny transosseous arterial feeders [59]. In the 48 cases we considered, we found that Onyx has become popular in EVT for ACF DAVFs since 2005.

Complications

In EVT for ACF DAVFs, the overall complication rate is 6.25% [4]. In the 48 cases considered in this review, the rate of postprocedure complications was 8.3%. Of all complications, CRA ischemia is the most dangerous and damaging complication associated with TAE and is caused by Onyx excessive reflux into the OA [37]. In our paper, 2 (4.2%, 2/47) patients experienced excessive Onyx reflux. Thus, when retrograde Onyx approaches the origin of the CRA, low molecular-weight heparin should be postoperatively administered every 12 h for the first 72 h, and 100 mg aspirin should be administered per day for the first month to prevent ischemic events in the CRA [12].

Microcatheter retention can occur when using an undetachable microcatheter. In addition, while injecting Onyx via a feeding artery in TAE, the Onyx may reflux into the contralateral ethmoidal branches and then into the OA. Therefore, the inappropriate migration of Onyx to the contralateral side must be closely monitored during injection [60].

When performing TVE in a patient with tortuous vein anatomy, vein navigation may cause venous perforation, resulting in intracranial hemorrhage. Alternatively, the microcatheter can become embedded in the veins. Hence, excessively tortuous vein anatomy is a contraindication for TVE [30]. Rarely, if the EVT disturbs the drainage of the deep vein system, congestion in the BVR is likely to result in transient thalamic and brainstem edema.

Prognosis

After appropriate patients are selected, EVT, including TAE and TVE, achieve good therapeutic outcomes [10, 12, 15, 28, 30]. From a statistical standpoint, TAE has an occlusion rate ranging from 12.5% to 63.6% in ACF DAVFs [4, 9], whereas TVE has achieved a complete occlusion rate of 63.3-91% in a larger series [8]. Completely occluding the ACF DAVF is associated with good outcomes. In the 48 cases considered herein, 91.7% of patients experienced complete angiographic cure, and 93.8% of patients had a good outcome.

Summary

The fistula point of an ACF DAVF is usually located at the level of the cribriform plate, and the AEA of the OA was the most commonly observed feeding artery. The frontal cortical veins to the SSS are the most frequently involved. Because of their cortical vein drainage pattern, ACF DAVFs often have a malignant natural history with high-grade Cognard classifications (III-IV). EVT, including TAE and TVE, is currently considered an effective therapeutic option in ACF DAVFs. The therapeutic goal of EVT is for the embolic agents to penetrate through the transosseous shunt to obliterate the fistula point.

When performing TAE through the AEA of the OA, it is important to ensure that the CRA is not occluded. TVE can also achieve complete obliteration, but the path from the puncture point to the DAVF is longer and difficult to navigate, meaning that TVE is more time consuming and requires more patience. EVT is associated with both technique- and treatment-related complications. However, although complications may occur, AVF DAVFs have an acceptable prognosis when the patients are appropriately selected.

Limitations

ACF DAVFs are rare intracranial lesions, most of which are sporadically presented as case reports. As a result of the small sample size in this review, the statistical analysis is inappropriate. Because of the selection criteria in this study, cases without adequate description of the patients' medical histories were excluded. Cases mixed in with larger case series with DAVFs of other intracranial locations were also occasionally omitted due to the difficulty of data extraction. Furthermore, only articles written in English were included in this study. Hence, the findings of this review may not reflect actual circumstances in the clinic, and readers should interpret the presented results with the appropriate level of caution.

Competing Interests

The authors have declared that no competing interest exists.

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