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REVIEW

Arterial aneurysms associated with intracranial dural arteriovenous fistulas: epidemiology, natural history, and management. A systematic review

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Abstract
Arterial aneurysms are uncommon among patients with dural arteriovenous fistulae (DAVFs), and there is limited information available to guide treatment decisions in such cases. We performed a systematic review of the literature, including a case of a DAVF associated with a flow-related intraorbital ophthalmic artery (OA) aneurysm that we have recently managed. The purpose of our study was to clarify epidemiology, natural history, and management of these lesions. A total of 43 published cases of DAVF associated aneurysms were found in 26 studies on the topic. Anterior cranial fossa was the most common location (40%), and ethmoidal branches were the most common arterial feeders (55%). In about 63% of cases, the aneurysm was located on artery unrelated to DAVF supply. Approximately 10% of intracranial DAVFs were associated with aneurysms located in the intraorbital OA. Overall, 70% of lesions were Borden type III, and 50% of patients presented with hemorrhage. In approximately 17% of cases, the source of bleeding was a feeding artery aneurysm. All of the reported intraorbital OA aneurysms associated with DAVFs remained stable during follow-up. DAVF associated aneurysms are fairly rare. Anterior cranial fossa location and direct cortical venous drainage are common among these lesions. The aneurysms are less likely to be located on feeding arteries, and hemorrhagic presentation related to flow-related aneurysm rupture is uncommon.

Keywords Intracranial aneurysms · Dural arteriovenous fistula · Aneurysm rupture · Intraorbital aneurysm

Introduction

The association of brain arteriovenous malformations (bAVMs) with intracranial arterial aneurysms is well established. Several studies have suggested that bAVMs patients with associated arterial aneurysms have a higher rate of hemorrhage, which can be the result of either AVM or aneurysm rupture [3]. On the other hand, arterial aneurysms are fairly rare among patients with dural arteriovenous fistulae (DAVFs). Thus, there is limited information available to guide treatment decisions in such cases [9, 31]. We performed a review of all the published studies examining the association between arterial aneurysms and intracranial DAVFs. Beyond that, with the aim to illustrate the management of these lesions from a practical perspective, we report an uncommon case of a patient with a DAVF associated with a flow-related intraorbital OA aneurysm (Fig. 1, 2, 3). The purposes of our study were to clarify clinical, diagnostic, and therapeutic aspects of these lesions.

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Materials and methods

Literature search

A comprehensive literature search of three databases (PubMed, Ovid MEDLINE, and Ovid EMBASE) was conducted for any reports published from 1975 to March 2017 in combination with a thorough hand search. PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-analyses) [22] were followed (Supplemental Fig. 1).

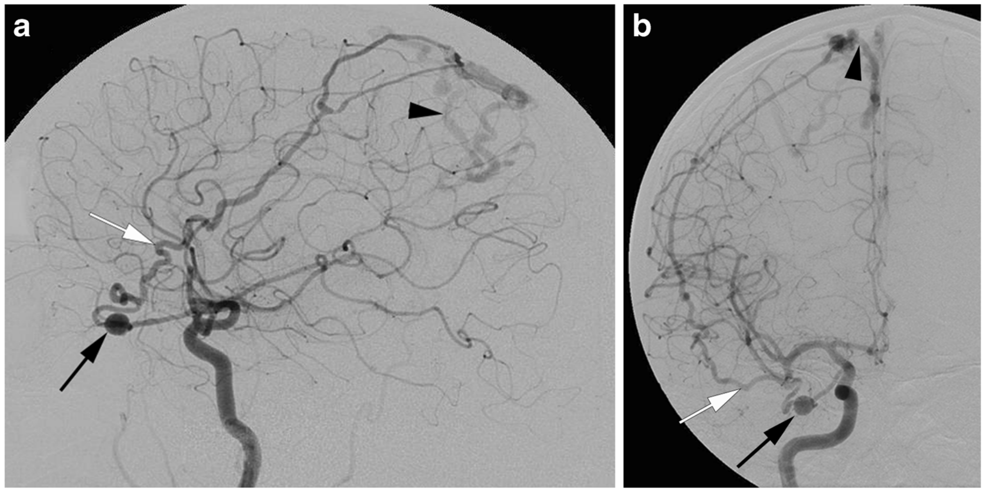

Fig. 1 **a**, **b** Digital subtraction angiography of the right ICA in a 59-year-old man presented with headache. The lateral and anteroposterior projections demonstrated an aneurysm on the intraorbital segment of the OA associated with a DAVF supplied by bilateral MMAs arising from the OAs. The venous drainage was via cortical vein toward the superior sagittal sinus

The key words “intracranial aneurysms,” “subarachnoid hemorrhage,” “dural arteriovenous fistula,” “intraorbital aneurysms,” and “ophthalmic” were used in both “AND” and “OR” combinations. The search syntax is summarized in Supplemental Table 1. The inclusion criteria were the following: (1) studies reporting case reports or case series of patients with cerebral and intraorbital arterial aneurysms associated with intracranial DAVFs. Exclusion criteria were the following: (1) review articles, (2) studies published in languages other than English, (3) studies reporting aneurysms associated with arteriovenous malformations, and (4) studies reporting venous aneurysms associated with DAVFs. In cases of overlapping patient populations, only the series with the largest number of patients or most detailed data were included. Two reviewers independently selected the included studies, and a third author solved discrepancies.

Data collection

From each study, we extracted the following information: (1) patient’s demographics; (2) number of patients with DAVF associated aneurysms; (3) number, location, and size of the aneurysms; (4) location of the fistula and venous drainage pattern; (5) ruptured status of the lesions; (6) treatment modality; and (7) success of treatment.

DAVFs were classified according to Borden classification [2]. The location of DAVFs was classified into anterior cranial fossa, convexity/superior sagittal sinus, cavernous sinus, sigmoid/transverse sinus, and foramen magnum/jugular foramen. Location of DAVF associated aneurysms were classified as following: ophthalmic artery (carotid ophthalmic, distal to the origin, and intraorbital), ACA/AComA, MCA, ICA (including PcomA, AchorA, paraclinoid segment), VB, and meningeal branches (middle meningeal artery and posterior meningeal artery).

Outcomes

The primary objectives of this study were (1) to describe distribution of locations, size, and ruptured status of the aneurysms associated with intracranial DAVFs and (2) to determine distribution of locations, venous drainage pattern, and

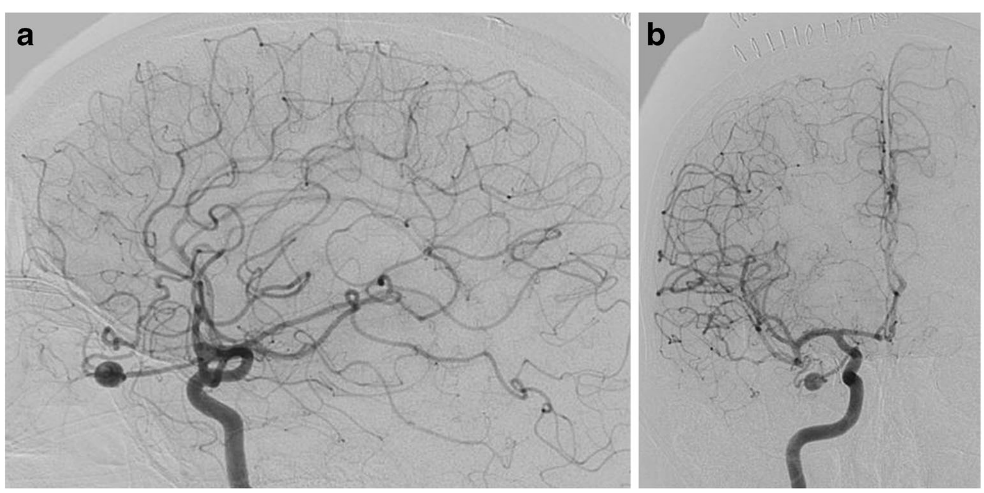

Fig. 2 **a**, **b** Digital subtraction angiography after surgical treatment of DAVF. Postoperative lateral and anteroposterior view, right ICA angiographic study demonstrating complete occlusion of the DAVF and persistence of the aneurysm

Fig. 3 Postoperative CTA obtained 18 months after surgical obliteration of the DAVF disclosed that the aneurysm was unchanged in shape and size

hemorrhagic presentation of the DAVFs associated with arterial aneurysms. The secondary objective was to examine the treatment management of these lesions. Intraorbital OA aneurysms associated with DAVFs were analyzed separately, due to the uncommon aneurysm location, and with the aim to compare radiological, clinical presentation, and treatment management with the reported case.

Results

Literature review

Studies included in our review are summarized in Table 1. The search flow diagram is shown in Supplemental Fig. 1. A total of 26 studies and 43 published cases of DAVF associated aneurysms were found and were included in the review. All but three of the included studies were case reports.

Demographic data and characteristics of the DAVFs associated with aneurysms

The mean age of patients was 52 years (range 0–77), and 80% were male (Table 1).

The characteristics of the lesions are summarized in Table 2 and Table 3. The most common DAVF location was anterior cranial fossa (40%), followed by posterior cranial fossa/tentorium location (23%), and convexity/superior sagittal sinus (21%). The main arterial feeders were ethmoidal branches (55%), and nearly 70% of DAVFs were Borden type III. The mean number of aneurysms associated with the fistula was 1.5, and the mean size was 7 mm (range 2–16). Overall, nearly 63% of associated aneurysms were unrelated to the DAVF supply. The most common aneurysm location was ICA (24.5%), followed by ACA/AComA (23%), and ophthalmic artery (15%). Approximately 10% of intracranial DAVFs were associated with aneurysms located in the intraorbital segment of the OA (Table 4) .

Hemorrhagic presentation

The hemorrhagic presentation of the lesions is summarized in Table 5. Roughly 50% of intracranial DAVF patients with an aneurysm presented with hemorrhage. Overall, 57% of hemorrhagic cases presented a Borden Type III fistula, whereas 8.6 and 17% were Borden type II and I, respectively. A ruptured aneurysm was the source of bleeding in 60% of the hemorrhagic cases. However, in only 17% of patients, the ruptured aneurysm was located on the feeding artery of the fistula.

Treatment management

Treatment management of DAVFs and aneurysms associated is summarized in Supplemental Table 2. Overall, 93% of lesions were treated. Clipping was the most common aneurysm treatment (62%), followed by coiling (21%). Complete aneurysm occlusion was reported in 100 and 83% of surgical and endovascular cases, respectively. Similarly, surgery was the most common treatment of DAVFs (63%), followed by endovascular treatment (22%). Angiographic cure of fistulas was achieved in 83 and 30% of the surgical and endovascular cases, respectively .

Discussion

While arterial aneurysms associated with cerebral arteriovenous malformations are fairly common, aneurysms associated with DAVFs are quite rare. Because of this, the epidemiology, natural history, and management of these lesions are not completely understood. Very few studies have reported the prevalence of DAVF associated aneurysms. In a series of 46 DAVFs, Suzuki et al. [31] reported a prevalence of 13%, whereas in a series of 70 DAVFs, Gross et al. [9] reported a prevalence of 21%. In a recent study of 14 anterior cranial fossa DAVFs, Meneghelli et al. [21] described one case (7%) of ethmoidal DAVF with associated a flow-related ophthalmic artery aneurysm.

In reviewing the literature on DAVF associated aneurysms, there are a number of interesting associations (Table 1). It is worth noting that the most common location for DAVFs associated with aneurysms was the anterior cranial fossa (40%), and the most common arterial feeders were ethmoidal branches of ophthalmic artery (55%). Accordingly, most of aneurysms were located in the anterior circulation. Based on our review, 70% of DAVFs associated with aneurysms presented an aggressive angioarchitecture with drainage directly into subarachnoid veins (Borden III) [2] (Table 2).

Table 1 Summary of studies included in review

Study name	No of Pts w DAVF and AA	Mean age in years	Sex	DAVF Borden type	AA location	DAVF location	Main arterial feeders	Hemorrhagic presentation	Source of bleeding	DAVF treatment	Complete occlusion of treated DAVF	AA treatment	Complete occlusion of treated AA
Sanchis et al. 1975[29]	1	59	F	NA	MMA	Parietal	NA	Yes	NA	NA	NA	NA	NA
Gàcs et al. 1983[6]	1	64	M	NA	PICA	Tentorium	NA	Yes	AA	No treatment	_	Clipping	NA
Kaech et al. 1987[11]	1	44	M	III	ICA+AICA	Tentorium	MMA+ AphA	Yes	AA	Endovascular	No (small residual)	Clipping	Yes
Martin et al. 1990[20]	1	55	M	III	MMA	Ethmoidal	Ethmoidal	No	NA	NA	NA	Clipping	NA
Preul et al. 1992[26]	1	72	M	III	AcomA+ ACA	Parietal	MMA	No	NA	No treatment	_	Clipping	Yes
Kikuchi et al. 1994[14]	2	53.5	2 M	2III	IO+3ACA	2 Ethmoidal	2OphtA/ Ethmoidal	2Yes	2DAVF	2Surgery	No (small residual)	1No treatment+ 2clipping+ 1wrapping	2Complete (clipping) 1growth (wrapped)
Ishikawa et al. 1997[10]	1	70	M	III	2ICA	Ethmoidal	Ethmoidal	No	NA	Surgery	Yes	1Clipping+ 1wrapping	Yes
Murai et al. 1999[23]	1	27	M	III	ACA	Ethmoidal	Ethmoidal	Yes	AA	Radiosurgery	NA	Clipping	Yes
Suzuki et al. 2000[31]	6	58.3	6 M	NA	NA	3 Ethmoidal +3convexity	3Ethmoidal + 3MMA	1Yes	AA	3Surgery	NA	6Clipping	NA
Kawaguchi et al. 2001[13]	1	51	M	III	IO	ACF	OphtA	No	NA	Surgery	NA	No treatment	_
Rumboldt et al. 2002[28]	1	34	F	NA	PCA+3ICA+ 2 MCA+ AcomA	SS	PCA	Yes	NA	No treatment	_	_	_
Kleinschmidt et al. 2004[16]	1	47	M	III	IO	ACF	Ethmoidal	No	NA	No treatment	_	No treatment	_
Andersson et al. 2004[1]	1	77	F	III	OphtA(I segment)	Ethmoidal	Ethmoidal	No	NA	Endovascular	Yes	No treatment	(AA regression)
Chen et al. 2006[4]	1	65	M	III	ICA	ACF	OphtA	Yes	AA	Radiosurgery	NA	Coiling	Yes
Kan et al. 2007[12]	1	27	M	I	AICA	PCF	OA+MMA	No	NA	Multimodality	Yes	No treatment	(AA regression)
Ko et al. 2010[17]	1	New born	M	I	PCA	PCF	PMA	Yes	NA	Endovascular	No	Coiling	No
	1	29	F	I	PMA	TSS	OA+MMA	No	NA	Endovascular	No		Yes

Table 1 (continued)

Study name	No of Pts w DAVF and AA	Mean age in years	Sex	DAVF Borden type	AA location	DAVF location	Main arterial feeders	Hemorrhagic presentation	Source of bleeding	DAVF treatment	Complete occlusion of treated DAVF	AA treatment	Complete occlusion of treated AA
Muro et al. 2010[24]												Excision of artery	
Sato et al. 2011[30]	1	77	M	III	AcomA	Ethmoidal	Ethmoidal	Yes	AA	Surgery	Yes	Clipping	Yes
Kirsh et al. 2011[15]	1	62	M	III	IO	Ethmoidal	Ethmoidal	Yes	AA	Endovascular	Yes	Coiling (parent artery occlusion)	Yes
Gross et al. 2012[9]	12	50	8 M+ 4F	4I + 8III	PMA+MMA +2AICA+ SCA+ BA+ MCA+ 2AcomA+ 6ICA	JF+ 3tentorial+ 2SSS+CS+ ACF+ 3PCF+ petrosal+TS	NA	7Yes	4AA + 3DAVF	9Surgery + 2radiosurgery + 1no treatment	NA	8Clipping + 2coiling + 5no treatment	NA
Li et al. 2012[19]	1	45	M	I	ICA+2Carotid OphtA+ACA	Convexity	MMA	Yes	AA	Endovascular	No	Coiling	Yes
Gilard et al. 2013[7]	1	59	F	III	ASA	Forame magnum	PMA	Yes	DAVF	Surgery	Yes	No treatment	AA regression
Onu et al. 2013[25]	1	60	M	II	MMA	Convexity	MMA	Yes	DAVF	Surgery	Yes	Clipping	Yes
Reinard et al. 2014[27]	1	52	M	III	Carotid OphtA	Ethmoidal	Ethmoidal	No	NA	Surgery	Yes	Coiling	No
Kohyama et al. 2015[18]	1	72	M	II	SCA	Occipital sinus	PMA	Yes	DAVF	Endovascular	No	Parent artery occlusion	Yes (parent artery occlusion)
Meneghelli et al. 2017[21]	1	61	M	III	Carotid OphtA	Ethmoidal	Ethmoidal	Yes	DAVF	Surgery	Yes	Clipping	Yes

AA aneurysm, *MMA* middle meningeal artery, *PMA* posterior meningeal artery, *PICA* posterior inferior cerebellar artery, *SCA* superior cerebellar artery, *AICA* anterior inferior cerebellar artery, *ICA* internal carotid artery (including posterior communicating artery, paraclinoid/cavernous segment, ICAbif, AChA), intraorbital ophthalmic, *AcomA* anterior communicating artery, *ACA* anterior cerebral artery, *ASA* anterior spinal artery, *OA* occipital artery, *JF* jugular foramen, *CS* cavernous sinus, *SSS* superior sagittal sinus, *SS* sigmoid sinus, *TS* transverse sinus, *ACF* anterior cranial fossa, *PCF* posterior cranial fossa

Table 2 Characteristics of intracranial DAVFs associated with arterial aneurysms

Location of DAVF (25 articles)	
Anterior cranial fossa	17 (39.5%)
Convexity/superior sagittal sinus	9 (21%)
Cavernous sinus	1 (2.3%)
Posterior cranial fossa/tentorium	10 (23.2%)
Sigmoid/transverse sinus	4 (9.3%)
Foramen magnum/jugular foramen	2 (4.6%)
Main arterial feeders (23 articles)	
Ophthalmic/ethmoidal branches	17 (54.8%)
Middle meningeal artery	6 (19.3%)
Other external carotid artery feeders (OA, PMA)	6 (19.3%)
Posterior circulation (PICA, PCA)	2 (6.4%)
Venous drainage pattern (Borden classification) (20 articles)	
Borden I	8 (24.2%)
Borden II	2 (6%)
Borden III	23 (69.6%)

OA occipital artery, *PMA* posterior meningeal artery, *PICA* posterior inferior cerebellar artery, *PCA* posterior cerebral artery

Most of aneurysms associated with DAVFs were small, and nearly 63% were located on an artery unrelated to DAVF supply. Conversely, nearly 70% of aneurysms associated with

Table 3 Characteristics of DAVF associated aneurysms

Variables	Number
N of associated aneurysms (related and unrelated)	62
Related aneurysms*	23 (37%)
Unrelated aneurysms**	39 (62.9%)
Mean number of aneurysms associated with DAVF	1.5
Mean size of aneurysms	7 mm (2–16)
Aneurysm location (24 articles)	
Ophthalmic artery	9 (15%)
Distal opht (I opht A segment)	1 (1.6%)
Distal intraorbital (III opht A segment)	4 (6.5%)
Carotid opht	4 (6.5%)
ACA/AComA***	14 (23%)
ICA****	15 (24.5%)
Basilar A (AICA-SCA-PCA)	9 (14.7%)
MCA	5 (8%)
Meningeal branches (MMA or PMA)	6 (9.8%)
Vertebral A (PICA-ASA)	3 (5%)

*Related aneurysm: saccular arterial aneurysm located on the arteries supplying the DAVF

**Unrelated aneurysm: saccular arterial aneurysms located on vessels that are not DAVF feeders

***Including pericallosal, frontopolar, orbitofrontal arteries

****Including posterior communicating artery and paraclinoid/cavernous segment, ICA bif, AChA

Table 4 Management of intraorbital ophthalmic aneurysms associated with DAVF

Author, year	Borden type DAVF	Aneurysm	Treatment of aneurysms/radiological outcome	Treatment of DAVF/radiological outcome	Mean radiological follow-up	Neurological outcome
Kikuchi K 1994	III	5 mm/unruptured	No/unchanged	Surgery/small residual	3 months	Anosmia
Kawaguchi S 2001	III	NA/unruptured	No/unruptured	Surgery/NA	18 months	No neurological symptoms
Kleinschmidt 2004	III	4 mm/unruptured	No/NA	No	NA	No neurological symptoms
Kirsh M 2011	III	9 mm/ruptured	Coiling/complete occlusion of aneurysm and parent artery	Transarterial and transvenous embolization/complete occlusion	1 month	No improvement of complete visual loss
Present Case 2016	III	5 mm/unruptured	No/unchanged	Surgery/complete occlusion	18 months	No neurological symptoms

Table 5 Hemorrhagic presentation

Variables	Number
N of hemorrhagic presentation	23 (53%)
Borden type and hemorrhage	
N of Borden I/Tot of hemorrhage DAVF	4 (17%)
N of Borden II/Tot of hemorrhage DAVF	2 (8.6%)
N of Borden III/Tot of hemorrhage DAVF	13 (57%)
Unknown	4 (17%)
Source of bleeding*	
Aneurysm rupture	12 (60%)**
Bleeding from DAVF	8 (40%)

*Available for 20 patients

**In two patients the source of hemorrhage was a ruptured feeding arterial aneurysm

bAVMs are flow-related (distal and proximal flow-related), underlining a prominent contribution of hemodynamic stress in the development of these lesions [3]. Interestingly, some authors reported regression of aneurysms located on the feeding artery, after complete exclusion of the fistula [1, 12, 27], demonstrating that hemodynamic factors, in some cases, can play a role in the development of aneurysms located on the arteries that feed DAVFs [9]. However, unlike bAVM associated aneurysms which are typically located along the feeding artery, only 37% of DAVF associated aneurysms positioned along the feeding artery. In addition, our review demonstrated that approximately 50% of intracranial DAVFs associated with an aneurysm presented with hemorrhage, and a majority of these cases demonstrated retrograde cortical venous [2, 8]. However, roughly 20% of DAVF associated hemorrhages among lesions with aneurysms are due to feeding arterial aneurysm rupture (Table 5). These findings suggest a minor role of hemodynamic factors in the development and rupture of arterial aneurysms associated with DAVFs. Accordingly, it is likely that most of the arterial aneurysms and intracranial DAVFs are concomitant lesions, without hemodynamic relation.

In general, the majority of DAVF associated aneurysms are treated with clipping or coiling. Regarding DAVFs, the most common modality was surgical obliteration (60%), followed by endovascular (embolic agents), and radiosurgery. Complete occlusion rates for treated aneurysms are approximately 80% for coiled lesions and 100% for clipped lesions.

The etiopathogenesis and the factors leading to aneurysm formation in patients with DAVFs are unknown. Since most of aneurysms associated with DAVFs are located on an artery unrelated to DAVF supply, the mechanism suggested for the formation of feeding pedicle aneurysms in patients with parenchymal AVMs (i.e., increased hemodynamic stress on vessels normally not submitted to such a high flow load eventually leading to formation of aneurysms in unusual sites and not necessarily at bifurcation points) can be hypothesized only in selected cases of DAVFs.

Intraorbital ophthalmic artery aneurysms associated with DAVFs

Saccular arterial aneurysms rarely arise from the intraorbital ophthalmic segment and, to our knowledge, only 21 cases were reported in the literature [5]. Many authors supposed that congenital defects during vascular embryogenesis are implicated in the development of these aneurysms. However, it is difficult to deny the role that hemodynamic stress may play in the development of these lesions. In a recent review, Della Pepa et al. [5] reported that roughly 20% of intraorbital OA aneurysms were diagnosed associated with dural fistulas or bAVMs. Accordingly, in our review, approximately 10% (four cases) of intracranial DAVFs were associated with aneurysms located in the intraorbital segment of the OA (Table 4) [13–16]. Intraorbital OA aneurysms associated with DAVFs are generally on the order of 5–10 mm and are associated with aggressive DAVFs with direct cortical venous drainage (Borden type III). While these aneurysms may seem worrisome, rupture rates are low [14, 15].

Limitations of the study

There are several limitations to this study. All of the included reports were case reports or small case series, with no higher level data available. In addition, many of the series included in our analysis described cases collected over several years, and diagnostic and treatment techniques are changed in this long time period. Due to the lack of large series, the exact prevalence of aneurysms associated with DAVFs cannot be estimated. Finally, our analysis is unable to comment on the natural history of these lesions.

Conclusions

DAVF associated aneurysms are less common than bAVM associated aneurysms. Anterior cranial fossa location and direct cortical venous drainage are frequently among these lesions. Intraorbital OA segment is involved in 10% of cases, and aneurysm rupture was uncommon in this location. In general, the aneurysms are uncommonly located on feeding arteries, and most of the ruptured aneurysms are unrelated to the flow. In conclusion, it is likely that most of the arterial aneurysms and DAVFs are concomitant lesions, whereas hemodynamic factors can influence the development of aneurysms located along the feeding artery.

Compliance with ethical standards This work was performed ethically and complies with the ethical standards of our Institutional Review Board.

Conflict of interest Dr.Cagnazzo, Dr. Peluso, Dr. Vannozzi, Dr. Brinjikji, and Dr. Perrini certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript. Dr. Lanzino reports being a consultant for Covidien/Medtronic.

Informed consent The nature of this article did not require informed consent.

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