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Natural history, angiographic presentation and outcomes of anterior cranial fossa dural arteriovenous fistulas

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ABSTRACT

Background Anterior cranial fossa dural arteriovenous fistulas (ACF-dAVFs) are aggressive vascular lesions. The pattern of venous drainage is the most important determinant of symptoms. Due to the absence of a venous sinus in the anterior cranial fossa, most ACF-dAVFs have some degree of drainage through small cortical veins. We describe the natural history, angiographic presentation and outcomes of the largest cohort of ACF-dAVFs.

Methods The CONDOR consortium includes data from 12 international centers. Patients included in the study were diagnosed with an arteriovenous fistula between 1990–2017. ACF-dAVFs were selected from a cohort of 1077 arteriovenous fistulas. The presentation, angioarchitecture and treatment outcomes of ACF-dAVF were extracted and analyzed.

Results 60 ACF-dAVFs were included in the analysis. Most ACF-dAVFs were symptomatic (38/60, 63%). The most common symptomatic presentation was intracranial hemorrhage (22/38, 57%). Most ACF-dAVFs drained through cortical veins (85%, 51/60), which in most instances drained into the superior sagittal sinus (63%, 32/51). The presence of cortical venous drainage predicted symptomatic presentation (OR 9.4, CI 1.98 to 69.1, p=0.01). Microsurgery was the most effective modality of treatment. 56% (19/34) of symptomatic patients who were treated had complete resolution of symptoms. Improvement of symptoms was not observed in untreated symptomatic ACF-dAVFs.

Conclusion Most ACF-dAVFs have a symptomatic presentation. Drainage through cortical veins is a key angiographic feature of ACF-dAVFs that accounts for their malignant course. Microsurgery is the most effective treatment. Due to the high risk of bleeding, closure of ACF-dAVFs is indicated regardless of presentation.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Anterior cranial fossa dural arteriovenous fistulas (ACF-dAVFs) are rare vascular lesions and it is unclear what is the best treatment option.

⇒ Current knowledge about the clinical presentation, angioarchitecture and treatment outcomes of these fistulas is limited by small case series.

WHAT THIS STUDY ADDS

⇒ This is the largest cohort of ACF-dAVFs that describes in detail their clinical presentation, angioarchitecture and treatment outcomes.

⇒ This study showed that ACF-dAVFs are dangerous lesions with a high risk of hemorrhage, due to venous drainage through cortical pial veins.

⇒ The most effective treatment for ACF-dAVFs is microsurgery.

⇒ The presence of a large arterial afferent or a straight draining vein facilitates navigation into the fistula point, and effective and safe endovascular embolization.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Most ACF-dAVFs should be managed with microsurgery, unless favorable angioarchitecture allows safe and effective endovascular treatment.

INTRODUCTION

Anterior cranial fossa dural arteriovenous fistulas (ACF-dAVFs) are rare vascular malformations which pose management challenges.[1 2] Hemorrhage at presentation significantly increases the

risk of poor clinical outcomes,[3] and is associated with ensuing morbidity and mortality.[4] Due to their high risk of hemorrhage, these lesions warrant aggressive treatment even when found incidentally.[5–8] The angioarchitecture of these lesions with venous outflow through fragile pial veins increases the risk of hemorrhage.[5–8] The lack of large venous sinuses in the anterior fossa makes pial veins the de facto draining structures of ACF-dAVFs.

It is unclear which treatment modality of ACF-dAVFs is the best option. Microsurgery is highly effective[9–11]; however, possible complications include cerebrospinal fluid leakage, infection, retraction damage of the frontal lobe and injury to the olfactory nerves.[5 7] Endovascular embolization is less invasive, but may not be as effective as microsurgery.[6 12 13] We performed a comprehensive retrospective analysis of the CONDOR (Consortium for Dural Arteriovenous Fistula Outcomes Research) database and described the natural history, angiographic presentation, and treatment outcomes of 60 ACF-dAVFs.

METHODS

Patient population

As previously described, the CONDOR database is a comprehensive repository that gathers data about dAVFs from 12 centers.[14] Before data collection, approval from the institutional review boards at each institution was obtained. A total of 1077 dAVFs were included in the database. For this study, ACF-dAVFs diagnosed between 1990 and 2017 were extracted from the database. Each institution verified the accuracy of the data before transferring anonymized information to our institution for analysis.

Data collection and definition

Demographics, clinical presentation and treatment modalities were collected. Venous hyperdynamic symptoms (VHS) were defined as symptoms related to increased venous drainage, including tinnitus, bruits, chemosis/proptosis, ophthalmoplegia/diplopia and isolated headache not attributable to hemorrhage. Non-hemorrhagic neurological deficits (NHNDs) were defined as focal and global neurological deficits caused by venous hypertension. NHNDs included dementia, psychiatric symptoms, seizures, ataxia, sensory and motor deficits, aphasia/dysarthria, cranial nerve palsies (excluding cranial nerves III, IV and VI) and hydrocephalus. The angioarchitecture of each ACF-dAVF was defined by location, arterial feeders, sinus/venous drainage and the presence of sinus drainage obstruction. We analyzed the outcomes and complications of each treatment modality.

Statistical analysis

SPSS 27.0 was used for statistical analysis. Continuous variables were expressed using mean and SD and categorical variables were expressed as frequency and percentages. We performed univariate logistic regression in variables of interest to predict symptomatic onset of ACF-dAVFs. Statistical significance was considered using a value of $p<0.05$.

RESULTS

Presentation

Sixty patients with ACF-dAVFs were included (table 1). The mean patient age was 61±12 years and 63% (38/60) of patients were men. Sixty-three percent of ACF-dAVFs (38/60) presented with symptoms and 37% (22/60) were discovered incidentally. The most common symptomatic presentation was hemorrhage (57%, 22/38) followed by NHNDs and VHS. Sixteen percent of symptomatic patients had both NHNDs and VHS (6/38), 16% NHNDs (6/38) and 11% VHS (4/38). Of the patients with NHNDs, 8% (1/12) had both focal and global NHNDs, while 75% (9/12) had focal and 17% (2/12) global NHNDs. Most ACF-dAVFs were idiopathic (93%, 56/60) versus post-traumatic (7%, 4/60), and most patients only had one dAVF (96%, 58/60) (table 1).

Table 1 Demographics

Variable	Value
Demographics	
Mean age, years ±SD	61±12
Men, % (n)	63 (38/60)
White, % (n)	87 (52/60)
Past medical history % (n)	
Past/current smoker*	50 (30/60)
Hypertension	43 (26/60)
Diabetes mellitus	15 (9/60)
History of malignancy	7 (4/60)
History of cerebrovascular accident	7 (4/60)
Currently pregnant or <6 weeks postpartum	5 (3/60)
History of head trauma*	15 (9/60)
History of cranial surgery <6 months before presentation*	5 (3/60)
Symptomatic presentation, % (n)	
Hemorrhage	57 (22/38)
NHND†	16 (6/38)
VHS‡	11 (4/38)
NHND and VHS	16 (6/38)
NHND at presentation % (n)	
Global neurological deficit	17 (2/12)
Focal neurological deficit	75 (9/12)
Global and focal neurological deficits	8 (1/12)
Etiology % (n)	
Spontaneous/idiopathic	93 (56/60)
Traumatic	7 (4/60)

*Missing values were managed as follows: smoking=13, history of head trauma=2, history of cranial surgery <6 months before presentation=1.
†Non-hemorrhagic neurological deficitis (NHNDs) included deficits caused by venous hypertension such as: dementia, psychiatric symptoms, seizures, ataxia, sensory and motor deficits, aphasia/dysarthria, cranial nerve palsies (excluding cranial nerves III, IV and VI) and hydrocephalus.
‡Venous hyperdynamic symptoms (VHS) included symptoms that were caused by increased blood flow such as: tinnitus, bruits, chemosis/proptosis, ophthalmoplegia/diplopia and isolated headache not attributable to hemorrhage.

Angioarchitecture

A total of 100 arterial feeders were identified in the 60 ACF-dAVFs. Forty-three percent of ACF-dAVFs had one arterial feeder (26/60), 48% two (29/60), 7% three (4/60) and 2% had four arterial feeders (1/60). The most common arterial feeders were the ethmoid arteries (40%, 40/100), followed by branches from the anterior cerebral artery (19%, 19/100), internal carotid artery branches such as inferolateral trunk, meningo-hypophyseal trunk, and the marginal tentorial branch (18%, 18/100), external carotid artery branches other than the middle meningeal artery (MMA) (13%, 13/100), and the MMA (10%, 10/100). Most ACF-dAVFs drained directly to a sinus through cortical veins (85%, 51/60). Few ACF-dAVFs had venous drainage through an intermediate vein that was not cortical (15%, 9/60). A univariate logistic regression analysis showed that direct cortical venous

Table 2 Univariate logistic regression to predict symptomatic presentation

	Univariate logistic regression		
Characteristics	**OR**	**95% CI**	**P value***
Age	1.01	0.97 to 1.06	0.642
Gender	0.84	0.29 to 2.51	0.755
Anticoagulant use	0.57	0.02 to 14.9	0.694
Diabetes	2.26	0.49 to 16.2	0.339
Number of arterial feeders	1.46	0,70 to 3.29	0.327
Presence of venous ectasia	0.69	0.23 to 1.99	0.497
Cortical venous drainage	9.42	1.98 to 69.1	**0.010**

*Value reported as p<0.05.

drainage predicted symptomatic status in ACF-dAVFs (OR 9.4, 95% CI 1.98 to 69.1, p=0.01) (table 2). The most common cortical venous drainage was into the superior sagittal sinus (SSS, 63%, 32/51), cavernous/petrous sinuses (8%, 4/51), the deep cerebral veins (4%, 2/51), and the transverse/sigmoid sinus (4%, 2/51) (figure 1). In 21% (11/51) of cases with cortical venous drainage the final draining sinus was not reported. Venous ectasia was present in 53% (32/60) of patients. Additionally, 13% (8/60) patients had intracranial aneurysms and 3% (2/60) had an associated arteriovenous malformation.

Treatment and outcomes

Eighty-eight percent (53/60) of ACF-dAVFs were treated (figure 2). Most ACF-dAVFs underwent microsurgery (66%, 35/53) or endovascular surgery (32%, 17/53). In one patient (2%, 1/53), radiosurgery was the primary treatment modality.

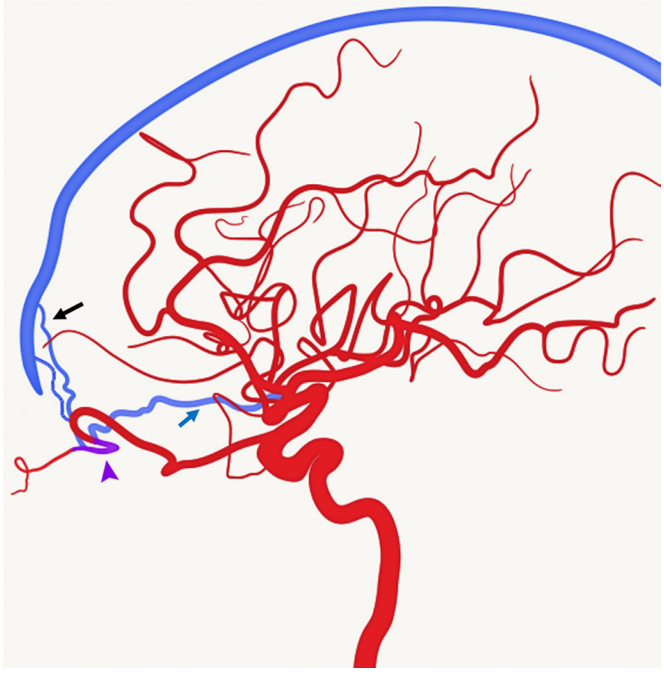

Figure 1 Classic neuroarchitecture of an anterior cranial fossa dural arteriovenous fistula. The main afferent is an ethmoidal artery, the fistula point is usually located at the cribiform plate (arrowhead), and venous drainage occurs through cortical veins (black arrow). In this case there is also a small intermediate vein that drains into the cavernous sinus (blue arrow).

Complete obliteration of the ACF-dAVFs was achieved in all patients who had microsurgery as their first line of treatment. There was a lower complication rate in patients treated with microsurgery (6%, 2/35) versus endovascular treatment (12%, 2/17). Complications after microsurgery included one infection and one right frontal hemorrhage.

The transarterial approach was the most common access route (82%, 14/17) for endovascular treatment. Only two ACF-dAVFs were accessed transvenously (12%, 2/17), and one was treated with a mixed approach (6%, 1/17). Inability to access the target arterial feeder led to embolization failure in 18% (3/17) of cases. The most common embolization agents used were Onyx (Medtronic) (42%, 6/14), Phil (Microvention) (14%, 2/14) followed by N-butyl cyanoacrylate (Codman) (20%, 3/14), coils (8%, 1/14), particles (8%, 1/14) and combined agents (8%, 1/14). Onyx achieved obliteration of the ACF-dAVF in 50% (3/6) of cases, Phil, N-butyl cyanoacrylate and coils in 100% (2/2, 3/3 and 1/1, respectively). Particles and combined agents did not achieve obliteration of any ACF-dAVF. Onyx was first used in 2006, Phil in 2016, N-butyl cyanoacrylate in 1997, coils in 2016, particles in 1994, and combined agents in 2008 (online supplemental table 1).

Complete obliteration of the ACF-dAVF was achieved in 53% (9/17) of patients who underwent endovascular surgery. Of these cases, 67% (6/9) achieved ACF-dAVF closure with one intervention and 33% (3/9) required a second intervention. Endovascular therapy was not effective in 47% (8/17) of patients. Causes for failure were persistent venous drainage (62%, 5/8) or the inability to access the target arterial feeder (38%, 3/8). Transient neurological complications occurred in two patients (12%, 2/17): partial occlusion of the ophthalmic artery with no permanent neurological deficit, and a partial transient cranial nerve III palsy.

Of the eight patients in whom endovascular therapy was not successful, 63% (5/8) underwent microsurgery, 12% radiosurgery (1/8) and 25% (2/8) did not pursue additional treatment. All patients who underwent microsurgery after a failed endovascular therapy achieved cure. Radiosurgery was not effective as both primary or secondary treatments.

Follow-up

All patients had radiological (mean ~13 months) and clinical (mean ~ 22 months) follow-ups. Of the seven untreated patients, 57% (4/7) were symptomatic. Seventy-five percent (3/4) of symptomatic untreated patients remained stable and 25% (1/4) developed worsening symptoms. All the asymptomatic untreated patients developed new onset symptoms at follow-up (3/3). At angiographic follow-up, spontaneous regression of the ACF-dAVF was observed in one (14%, 1/7) untreated ACF-dAVF.

Of the 53 treated ACF-dAVFs, 64% (34/53) were symptomatic at presentation: 56% (19/34) had complete resolution of symptoms, 29% (10/34) had worsening of symptoms, and the rest (15%, 5/34) remained stable at follow-up. Sixty percent (6/10) of treated patients who had worsening of symptoms initially presented with intracranial hemorrhage and 40% (4/10) with NHNDs. In contrast to the untreated group, none of the asymptomatic treated patients developed new symptoms during follow-up.

Of the 35 patients who underwent microsurgery as a primary treatment, 63% (22/35) were symptomatic. At follow-up, 54% (12/22) of these patients had complete resolution of symptoms, while 14% (3/22) had stable symptoms and 32% (7/22) had worsening of symptoms. One patient who was successfully treated

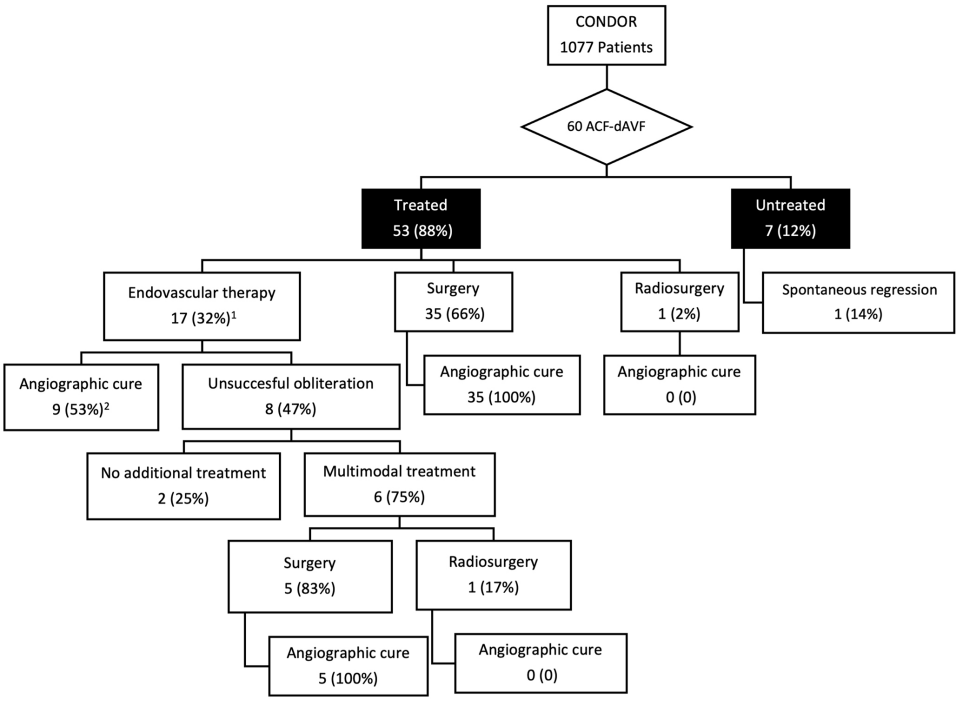

Figure 2 Treatment outcomes of ACF-dAVFs of the CONDOR database. [1]Endovascular therapy was the primary treatment, and 6/17 patients underwent secondary treatment with surgery or radiosurgery. [2]Three patients required a second procedure to achieve angiographic cure. ACF-dAVFs, anterior cranial fossa dural arteriovenous fistulas; CONDOR, Consortium for Dural Arteriovenous Fistula Outcomes Research.

with microsurgery had a de novo ACF-dAVF and required additional treatment.

In the endovascular group, 64% (11/17) of patients underwent endovascular intervention as the primary treatment. The rest (36%, 6/17) of patients in whom endovascular therapy was attempted were treated with multimodal treatment after unsuccessful endovascular intervention. Of the seven symptomatic patients who underwent endovascular therapy as a primary treatment, 14% (1/7) remained stable, 43% (3/7) had complete resolution of symptoms and 43% (3/7) had worsening of symptoms. One patient had new intracerebral hemorrhage 56 days after ACF-dAVF closure. This patient had a failed first transarterial endovascular procedure, but achieved successful ACF-dAVF closure in the second transarterial endovascular procedure. Eighteen percent (2/11) had angiographic recurrence of the ACF-dAVF at an average of 75 days post-treatment. Sixty-seven percent (4/6) of patients with multimodal therapy after failed endovascular surgery were symptomatic at onset. All of these patients (4/4) had resolution of symptoms at follow-up. The patient in whom radiosurgery failed as a primary treatment had stable symptoms at follow-up. Venous ectasia (OR 3.06, 95% CI 0.87 to 12.6, p=0.09) and age (OR 1.06, 95% CI 1 to 1.13, p=0.07) were associated with post-procedural worsening of symptoms (online supplemental table 2).

DISCUSSION

In the largest cohort of ACF-dAVFs with the longest follow-up, we characterized the influence of ACF-dAVF angioarchitecture on presentation, treatment strategy and outcome. Approximately 85% of ACF-dAVFs in our cohort exhibited cortical venous drainage and 53% had venous ectasia. Most ACF-dAVFs presented with intracranial hemorrhage, and the most effective treatment was microsurgery. Treated patients had more favorable outcomes than untreated patients.

Angioarchitecture and symptomatic presentation

The anterior ethmoidal artery (AEA) is the most common arterial feeder and most ACF-dAVFs drain to the SSS through cortical veins. In a meta-analysis of 48 fistulas, Xu *et al* reported that 93% of ACF-dAVFs were fed by the AEA, and at least 50% had bilateral AEA involvement.[15] Similarly, Baskaya *et al* described 100% AEA involvement in a review of 50 ACF-dAVFs.[16] Other common arterial feeders include branches of the external carotid artery, such as the MMA, and the sphenopalatine artery. The fistula point is usually in the cribriform plate, followed by drainage into the SSS and/or cavernous sinus via cortical/pial veins.[15] There is no dural sinus in the anterior cranial fossa, and drainage into proximal sinuses occurs through fragile, enlarged pial veins in the frontal sulci (figure 1).[10] Increased venous drainage through cortical veins may lead to venous engorgement that could ultimately result in intracranial hemorrhage.[11] Half of the patients in our cohort had venous ectasia at presentation. Direct drainage through small cortical veins increases the risk of bleeding.[17] The arterialization of these venous structures correlates with symptomatic presentation (OR 9.42, CI 1.9 to 69.1, p=0.01) (table 2). The origin and trajectory of the AEAs is highly variable,[18] which may explain why ACF-dAVFs have a very variable angioarchitecture.

Treatment outcomes

Microsurgery was the most effective treatment modality for ACF-dAVFs in the CONDOR database. Possible surgical complications include infection, retraction damage of the frontal lobe, cerebrospinal fluid leak, and anosmia due to injury to the olfactory nerves.[5 7] In our cohort we had a 6% (2/35) complications rate that included an infection and a postoperative frontal hemorrhage.

Endovascular embolization has the potential of achieving complete obliteration.[5–7 19] However, it has a higher failure rate

compared with microsurgery.[1] A meta-analysis that included 81 patients concluded that microsurgery is superior to endovascular therapy in achieving complete ACF-dAVF obliteration.[1] Only 53% of patients in our cohort achieved complete obliteration through endovascular treatment, and 33% required more than one embolization. In our cohort, recurrence was only observed in ACF-dAVFs treated with endovascular embolization. Endovascular complications may vary depending on the approach. The transarterial approach usually requires navigation through the AEA with risk of retinal infarction,[7 9 20] while the transvenous approach may lead to hemorrhage due to perforation of cortical venous pouches.[21 22] Twelve percent of patients who underwent endovascular therapy (2/17) had complications. Similar to other studies,[5 6] in the CONDOR database the transvenous route for embolization was more effective than the transarterial approach. Endovascular therapy can be attempted as first line treatment in patients with favorable angiographic characteristics. However, a detailed analysis of the angioarchitecture is crucial in deciding the best approach. Anatomical characteristics such as the presence of short and superficially draining veins favor a transvenous approach.[23] A hypertrophied and not very tortuous ophthalmic artery may be a reasonable choice in reaching the fistula point for embolization.[20 22] Most of these fistulas do not have prominent arteriovenous shunting due to the small size of the arterial feeders. Consequently, to achieve proper penetration of the liquid embolic agent, the microcatheter has to be positioned as close as possible to the fistula point. Hence, endovascular therapy should be avoided in patients with substantial cortical venous drainage or a tortuous ophthalmic artery.[11]

Radiosurgery is rarely used due to the low success rate and delayed cure.[23] Radiosurgery was used in two cases: as a primary treatment and as part of multimodal treatment after endovascular intervention. In both cases radiosurgery was not effective.

Only one ACF-dAVF (2%, 1/60) had documented spontaneous radiological regression. Previous series have not documented spontaneous regression; this may be due to the small sample size and lack of follow-up in asymptomatic patients. Nonetheless, once an ACF-dAVF is identified, close angiographic monitoring and treatment are warranted due to the presence of cortical venous drainage and high risk of hemorrhage.[5 7] Furthermore, approximately 58% (4/7) of untreated patients had worsening or new onset symptoms.

LIMITATIONS

Data were reported by each center, and images were not evaluated by a core laboratory. However, centers followed strict guidelines for data collection. CONDOR comprises 27 years of data, with data collection starting in 1990. Hence, endovascular approaches encompass a broad variety of techniques and devices. Recent developments in endovascular catheters, liquid embolic agents and imaging may achieve a higher rate of successful embolizations. This is a non-randomized retrospective case series. Patient selection for either endovascular or surgical interventions may have been influenced by individual perceptions of relative safety and efficacy. This study was not powered to identify post-treatment predictors of worse clinical outcome. This may be explained by heterogeneity of the patient population and treatment modalities throughout the study.

CONCLUSION

Most patients with ACF-dAVFs are symptomatic at presentation. Most ACF-dAVFs have cortical venous drainage. Drainage to the sinus through cortical veins is associated with symptomatic onset. Microsurgery is more effective than endovascular therapy and radiosurgery in achieving complete fistula closure. A detailed analysis of the angioarchitecture may lead to the best treatment choice. Treatment of ACF-dAVFs is warranted due to symptomatic presentation, angioarchitecture with cortical venous drainage, and symptom worsening on follow-up.

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Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by IRB 201608786, DAVF Consortium, The University of Iowa. Consent was not obtained

from patients as this was a retrospective analysis.

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Supplementary material

Supplementary Table 1. Embolic agents used for endovascular therapy

Transarterial approach	Success rate n/total (%)	Year introduced (range of use)
Onyx	2/5 (40)	2006 (2006-2013)
Phil	1/1 (100)	2016
n-BCA	3/3 (100)	1997 (1997-2016)
Particles	0/1 (0)	1994
Combined agents	0/1 (0)	2008
Transvenous approach		
Onyx	1/1 (100)	2011
Phil	1/1 (100)	2017
Mixed approach		
Coils	1/1 (100)	2016

Supplementary Table 2. Predictors of post-treatment worsening of symptoms

Characteristic	OR[1]	95% CI[1]	p-value
Age	1.06	1.00, 1.13	0.07
Hemorrhage at presentation	0.69	0.18, 2.34	0.6
Venous ectasia	3.06	0.87, 12.6	0.09
Cognard grade	0.77	0.38, 1.58	0.5
Cortical venous drainage	0.61	0.13, 3.31	0.5

[1]OR = Odds Ratio, CI = Confidence Interval

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Your Name: Ali Alaraj

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Your Name: Andrew Durnford

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Your Name: Ashrita Raghuram

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Your Name: Bradley Gross

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5	Payment or honoraria for lectures, presentations, speakers bureaus, manuscript writing or educational events	☒ **None**	
6	Payment for expert testimony	☒ **None**	
7	Support for attending meetings and/or travel	☒ **None**	
8	Patents planned, issued or pending	☒ **None**	
9	Participation on a Data Safety Monitoring Board or Advisory Board	☒ **None**	
10	Leadership or fiduciary role in other board, society, committee or advocacy group, paid or unpaid	☒ **None**	

		Name all entities with whom you have this relationship or indicate none (add rows as needed)	Specifications/Comments (e.g., if payments were made to you or to your institution)
11	Stock or stock options	☒ **None**	
12	Receipt of equipment, materials, drugs, medical writing, gifts or other services	☒ **None**	
13	Other financial or non-financial interests	☒ **None**	

Please place an "X" next to the following statement to indicate your agreement:

☒ I certify that I have answered every question and have not altered the wording of any of the questions on this form.

ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: Ching-Jen Chen

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

In the interest of transparency, we ask you to disclose all relationships/activities/interests listed below that are related to the content of your manuscript. "Related" means any relation with for-profit or not-for-profit third parties whose interests may be affected by the content of the manuscript. Disclosure represents a commitment to transparency and does not necessarily indicate a bias. If you are in doubt about whether to list a relationship/activity/interest, it is preferable that you do so.

The author's relationships/activities/interests should be defined broadly. For example, if your manuscript pertains to the epidemiology of hypertension, you should declare all relationships with manufacturers of antihypertensive medication, even if that medication is not mentioned in the manuscript.

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Time frame: Since the initial planning of the work			
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			Click the tab key to add additional rows.
Time frame: past 36 months			
2	Grants or contracts from any entity (if not indicated in item #1 above).	☒ **None**	
3	Royalties or licenses	☒ **None**	

		Name all entities with whom you have this relationship or indicate none (add rows as needed)	Specifications/Comments (e.g., if payments were made to you or to your institution)
4	Consulting fees	☒ **None**	
5	Payment or honoraria for lectures, presentations, speakers bureaus, manuscript writing or educational events	☒ **None**	
6	Payment for expert testimony	☒ **None**	
7	Support for attending meetings and/or travel	☒ **None**	
8	Patents planned, issued or pending	☒ **None**	
9	Participation on a Data Safety Monitoring Board or Advisory Board	☒ **None**	
10	Leadership or fiduciary role in other board, society, committee or advocacy group, paid or unpaid	☒ **None**	

		Name all entities with whom you have this relationship or indicate none (add rows as needed)	Specifications/Comments (e.g., if payments were made to you or to your institution)
11	Stock or stock options	☒ **None**	
12	Receipt of equipment, materials, drugs, medical writing, gifts or other services	☒ **None**	
13	Other financial or non-financial interests	☒ **None**	

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ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: Colin Derdeyn

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

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3	Royalties or licenses	☒ **None**	

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5	Payment or honoraria for lectures, presentations, speakers bureaus, manuscript writing or educational events	☒ **None**	
6	Payment for expert testimony	☒ **None**	
7	Support for attending meetings and/or travel	☒ **None**	
8	Patents planned, issued or pending	☒ **None**	
9	Participation on a Data Safety Monitoring Board or Advisory Board	☒ **None**	
10	Leadership or fiduciary role in other board, society, committee or advocacy group, paid or unpaid	☒ **None**	

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11	Stock or stock options	☐ **None**	
		Euphrates vascular	
12	Receipt of equipment, materials, drugs, medical writing, gifts or other services	☒ **None**	
13	Other financial or non-financial interests	☐ **None**	
		noNO	Data and safety monitoring services
		Penumbra, Inc	Data and safety monitoring services

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ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: Diederik O. Bulters

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

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8	Patents planned, issued or pending	☒ **None**	
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12	Receipt of equipment, materials, drugs, medical writing, gifts or other services	☒ **None**	
13	Other financial or non-financial interests	☒ **None**	

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ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: Edgar A Samaniego

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

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4	Consulting fees	☐ **None**	
		Medtronic	
		Rapid Medical	
5	Payment or honoraria for lectures, presentations, speakers bureaus, manuscript writing or educational events	☒ **None**	
6	Payment for expert testimony	☒ **None**	
7	Support for attending meetings and/or travel	☒ **None**	
8	Patents planned, issued or pending	☒ **None**	
9	Participation on a Data Safety Monitoring Board or Advisory Board	☒ **None**	
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12	Receipt of equipment, materials, drugs, medical writing, gifts or other services	☒ **None**	
13	Other financial or non-financial interests	☐ **None**	
		Microvention	Proctor

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ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: Enrico Giordan

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

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8	Patents planned, issued or pending	☒ **None**	
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ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: Ethan Winkler

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

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8	Patents planned, issued or pending	☒ **None**	
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ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: Giuseppe Lanzino

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

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ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: Gregory J Zipfel

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

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5	Payment or honoraria for lectures, presentations, speakers bureaus, manuscript writing or educational events	☒ **None**	
6	Payment for expert testimony	☒ **None**	
7	Support for attending meetings and/or travel	☒ **None**	
8	Patents planned, issued or pending	☒ **None**	
9	Participation on a Data Safety Monitoring Board or Advisory Board	☒ **None**	
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11	Stock or stock options	☒ **None**	
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ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: Isaac Josh Abecassis

Manuscript Title: **Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas**

Manuscript Number (if known): Click or tap here to enter text.

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4	Consulting fees	☐ **None**	
		InNeuroCo	
		Remedy Robotics	
5	Payment or honoraria for lectures, presentations, speakers bureaus, manuscript writing or educational events	☒ **None**	
6	Payment for expert testimony	☒ **None**	
7	Support for attending meetings and/or travel	☒ **None**	
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		Remedy Robotics	
12	Receipt of equipment, materials, drugs, medical writing, gifts or other services	☒ **None**	
13	Other financial or non-financial interests	☒ **None**	

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ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: Jason P Sheehan

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

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13	Other financial or non-financial interests	☒ **None**	

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☒ I certify that I have answered every question and have not altered the wording of any of the questions on this form.

ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: Jessica Smith

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

In the interest of transparency, we ask you to disclose all relationships/activities/interests listed below that are related to the content of your manuscript. "Related" means any relation with for-profit or not-for-profit third parties whose interests may be affected by the content of the manuscript. Disclosure represents a commitment to transparency and does not necessarily indicate a bias. If you are in doubt about whether to list a relationship/activity/interest, it is preferable that you do so.

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Time frame: Since the initial planning of the work			
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			Click the tab key to add additional rows.
Time frame: past 36 months			
2	Grants or contracts from any entity (if not indicated in item #1 above).	☒ **None**	
3	Royalties or licenses	☒ **None**	

		Name all entities with whom you have this relationship or indicate none (add rows as needed)	Specifications/Comments (e.g., if payments were made to you or to your institution)
4	Consulting fees	☒ **None**	
5	Payment or honoraria for lectures, presentations, speakers bureaus, manuscript writing or educational events	☒ **None**	
6	Payment for expert testimony	☒ **None**	
7	Support for attending meetings and/or travel	☒ **None**	
8	Patents planned, issued or pending	☒ **None**	
9	Participation on a Data Safety Monitoring Board or Advisory Board	☒ **None**	
10	Leadership or fiduciary role in other board, society, committee or advocacy group, paid or unpaid	☒ **None**	

		Name all entities with whom you have this relationship or indicate none (add rows as needed)	Specifications/Comments (e.g., if payments were made to you or to your institution)
11	Stock or stock options	☒ **None**	
12	Receipt of equipment, materials, drugs, medical writing, gifts or other services	☒ **None**	
13	Other financial or non-financial interests	☒ **None**	

Please place an "X" next to the following statement to indicate your agreement:

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ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: Junichiro Satomi

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

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8	Patents planned, issued or pending	☒ **None**	
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12	Receipt of equipment, materials, drugs, medical writing, gifts or other services	☒ **None**	
13	Other financial or non-financial interests	☒ **None**	

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ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: Linder Wendt

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

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13	Other financial or non-financial interests	☒ **None**	

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ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: Louis J Kim

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

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4	Consulting fees	☐ **None**	
		Microvention	
5	Payment or honoraria for lectures, presentations, speakers bureaus, manuscript writing or educational events	☒ **None**	
6	Payment for expert testimony	☒ **None**	
7	Support for attending meetings and/or travel	☒ **None**	
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11	Stock or stock options	☒ **None**	
12	Receipt of equipment, materials, drugs, medical writing, gifts or other services	☒ **None**	
13	Other financial or non-financial interests	☐ **None**	
		Spi Surgical	Co-founder

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ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: Michael R. Levitt

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

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Time frame: past 36 months			
2	Grants or contracts from any entity (if not indicated in item #1 above).	☐ **None**	
		Stryker	
		Volcano Philips	
		Medtronic	
3	Royalties or licenses	☒ **None**	

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8	Patents planned, issued or pending	☒ **None**	
9	Participation on a Data Safety Monitoring Board or Advisory Board	☒ **None**	
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11	Stock or stock options	☐ **None**	
		Cerebrotech	Equity interest
		Propio	Equity interest
		Synchron	Equity interest
12	Receipt of equipment, materials, drugs, medical writing, gifts or other services	☒ **None**	
13	Other financial or non-financial interests	☐ **None**	
		JNIS	Member of editorial board

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Date: 5/11/2022

Your Name: Minako Hayakawa

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

In the interest of transparency, we ask you to disclose all relationships/activities/interests listed below that are related to the content of your manuscript. "Related" means any relation with for-profit or not-for-profit third parties whose interests may be affected by the content of the manuscript. Disclosure represents a commitment to transparency and does not necessarily indicate a bias. If you are in doubt about whether to list a relationship/activity/interest, it is preferable that you do so.

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ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: Pui Man Rosalind Lai

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

In the interest of transparency, we ask you to disclose all relationships/activities/interests listed below that are related to the content of your manuscript. "Related" means any relation with for-profit or not-for-profit third parties whose interests may be affected by the content of the manuscript. Disclosure represents a commitment to transparency and does not necessarily indicate a bias. If you are in doubt about whether to list a relationship/activity/interest, it is preferable that you do so.

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Sanchez S, *et al. J NeuroIntervent Surg* 2022;0:1–6. doi: 10.1136/jnis-2022-019160

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ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: R. Michael Meyer

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

In the interest of transparency, we ask you to disclose all relationships/activities/interests listed below that are related to the content of your manuscript. "Related" means any relation with for-profit or not-for-profit third parties whose interests may be affected by the content of the manuscript. Disclosure represents a commitment to transparency and does not necessarily indicate a bias. If you are in doubt about whether to list a relationship/activity/interest, it is preferable that you do so.

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ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: Ridhima Guniganti

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

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ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: Robert M. Starke

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

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4	Consulting fees	☐ **None**	
		Penumbra	
		Abbott	
		Medtronic	
		InNeuroCo	
		Cerenovous	
5	Payment or honoraria for lectures, presentations, speakers bureaus, manuscript writing or educational events	☒ **None**	
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ICMJE DISCLOSURE FORM

Date: 5/11/2022

Your Name: Rose Du

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

Manuscript Number (if known): Click or tap here to enter text.

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			Click the tab key to add additional rows.
Time frame: past 36 months			
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3	Royalties or licenses	☒ **None**	

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4	Consulting fees	☐ **None**	
		Grand Rounds	
5	Payment or honoraria for lectures, presentations, speakers bureaus, manuscript writing or educational events	☒ **None**	
6	Payment for expert testimony	☒ **None**	
7	Support for attending meetings and/or travel	☒ **None**	
8	Patents planned, issued or pending	☒ **None**	
9	Participation on a Data Safety Monitoring Board or Advisory Board	☒ **None**	
10	Leadership or fiduciary role in other board, society, committee or advocacy group, paid or unpaid	☒ **None**	

		Name all entities with whom you have this relationship or indicate none (add rows as needed)	Specifications/Comments (e.g., if payments were made to you or to your institution)
11	Stock or stock options	☒ **None**	
12	Receipt of equipment, materials, drugs, medical writing, gifts or other services	☒ **None**	
13	Other financial or non-financial interests	☐ **None**	
		National Institute of Health	Other services

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Date: 5/11/2022

Your Name: Ryan Phelps

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

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Date: 5/11/2022

Your Name: Sebastian Sanchez

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

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Date: 5/11/2022

Your Name: Sepideh Amin-Hanjani

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

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Date: 5/11/2022

Your Name: Stephanie H. Chen

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

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Date: 5/11/2022

Your Name: J Marc C van Dijk

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

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Date: 5/11/2022

Your Name: W Christopher Fox

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

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Date: 5/11/2022

Your Name: Waleed Brinjikji

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

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4	Consulting fees	☐ **None**	
		Johnson and Johnson	
		Microvention	
		Medtronic Vascular	
		Stryker	
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11	Stock or stock options	☐ **None**	
		Marblehead Medical LLC	
12	Receipt of equipment, materials, drugs, medical writing, gifts or other services	☒ **None**	
13	Other financial or non-financial interests	☐ **None**	
		MIVI neurovascular	Data and safety monitoring services

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Date: 5/11/2022

Your Name: Yoshiteru Tada

Manuscript Title: Natural History, Angiographic Presentation and Outcomes of Anterior Cranial Fossa Dural Arteriovenous Fistulas

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