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Case Report

Transarterial embolization of petrosal dural arteriovenous fistula (dAVF): Feasible and successful in the post-Onyx era

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ABSTRACT

Background: Intracranial dural arteriovenous fistula (dAVF) is a rare arteriovenous malformation with potentially severe complications. This study investigates the efficacy and safety of transarterial embolization (TAE) in treating petrous dAVFs through a retrospective analysis and literature review.

Case Description: A retrospective analysis of six patients with petrous dAVFs treated with TAE was conducted, accompanied by a systematic literature review to evaluate treatment outcomes. Data collection included patient characteristics, clinical presentation, Borden–Shucart and Cognard classifications, treatment specifics, and overall outcomes. TAE, particularly utilizing Onyx, demonstrated favorable outcomes in our six patients. Regarding literature review results, 102 articles were identified through PubMed Mesh tool search, but only five were included after careful evaluation. In addition, one article was manually added after searching for the remaining articles. Combining our six cases with literature findings, 79.8% (n = 75) of patients undergoing TAE achieved a cure with the technique, though Onyx was reported in only 13.9% (n = 13) of TAE cases. Complications were observed in 11.7% (n = 11) of TAE cases.

Conclusion: Our presented cases and literature review suggest that the TAE of dAVFs is feasible and curative for selected cases of petrous dAVFs. However, the complexity of these lesions and the availability of other treatment modalities should be taken into consideration to optimize cure rates and patient outcomes.

Keywords: Arteriovenous malformation, Dural arteriovenous fistula, Facial nerve ischemia, Onyx embolization, Petrous dural arteriovenous fistula (dAVF), Transarterial embolization, Vascular malformation

INTRODUCTION

Background

Intracranial dural arteriovenous fistula (dAVF) represents a subtype of arteriovenous malformations (AVMs) where dural arteries directly connect into veins within the walls of dural venous sinuses, bypassing capillary beds. The incidence is relatively low, approximately 0.15–0.29/100,000 people annually,[8,27] constituting 10–15% of all AVMs.[11] While many dAVFs lack a clear origin, evidence suggests associations with dural sinus thrombosis, trauma, infection, or prior craniotomy.[24] Manifestations can range from asymptomatic states[30] to potentially devastating complications, including hemorrhage, increased intracranial pressure, and even death. Hence, understanding management strategies and risk stratification is crucial.

Most risk stratification schemes rely on the angiographic characteristics of dAVFs, specifically considering the presence or absence of retrograde cortical venous drainage (CVD).[26] These schemes play a crucial role in risk assessment. The classifications proposed by Cognard *et al*.[9] and Borden *et al*.[7] have been instrumental in emphasizing venous flow patterns and the critical role of CVD in predicting clinical aggressiveness.

The primary goal in dAVF treatment is complete disconnection from venous drainage, achievable through endovascular, surgical, or stereotactic radiosurgery methods. Although endovascular treatment has become the first-line approach for most patients,[2,14] uncertainties persist, particularly in cases like petrous dAVF, where studies suggest a potential role for surgical intervention.[16,29]

Objectives

This investigation seeks to present a retrospective analysis of treated cases of petrous dAVF using transarterial embolization (TAE), shedding light on the effectiveness and safety of this approach. Furthermore, a literature review was conducted on PubMed to evaluate previously published cases of dAVF treated with TAE.

METHODS

Study design

Retrospective analysis of cases of petrous dAVF treated with TAE conducted at two specialized centers, from January 2020 to November 2023. Six patients with at least one follow-up with cerebral angiography within 3 months of the procedure were identified. In addition, a literature review was conducted on PubMed to evaluate previously published cases of petrous dAVF treated with TAE. Only studies describing a minimum of three cases using this technique were included. Given the inclusion of a small number of cases and the utilization of previously collected and anonymized data obtained with the requisite patient consent, ethical committee approval was deemed unnecessary.

Variables and outcomes

Patient data encompassing age, gender, clinical presentation, Borden–Shucart type, Cognard type, arterial feeders, venous drainage, details of the first treatment, subsequent treatments, curative treatment, initial angiographic outcome, final angiographic outcome, and treatment complications were extracted from medical records and neuroimaging reviews. In addition, magnetic resonance angiography reports were scrutinized for comprehensive final follow-up data. The study focused on these variables to provide a succinct yet comprehensive analysis of key factors and outcomes pertinent to the research objectives.

Statistical analysis

We present the variables, all of which are categorical, in the form of proportions or percentages.

RESULTS

Baseline patient characteristics

A total of 6 patients with petrous dAVF treated with TAE were analyzed [Table 1; Figures 1 and 2] with a mean age of 56 years. Of these, 3 patients (50%) were female and 3 (50%) were male. Incidental diagnosis occurred in only 1 patient (17%), while 3 (50%) experienced some form of intracranial bleeding at presentation, including 1 with intraventricular hemorrhage (17%) and 2 with intraparenchymal hemorrhage (33%), one of whom also had subarachnoid hemorrhage (17%). Among the remaining 2 symptomatic patients at presentation, 1 had left-sided bruit (17%), and the other experienced a transient episode of aphasia and right-sided weakness (17%).

Baseline dAVF characteristics

All dAVFs analyzed in this study were located in the petrous region, encompassing superior petrosal sinus dAVFs, inferior petrosal sinus dAVFs, and petrous apex dAVFs. According to the Borden–Shucart classification, all cases were classified as type III. Among them, one was categorized as Cognard type III (17%), and the remaining five were identified as Cognard type IV (83%) [Table 2].

Regarding vascular supply, only one dAVF was exclusively supplied by one artery, the superior cerebellar artery, while all others received contributions from at least two arteries. The middle meningeal artery supplied five dAVFs (83%), the occipital artery supplied four (67%), the meningohypophyseal trunk supplied three (50%), the ascending pharyngeal artery supplied three (50%), and the internal maxillary artery supplied two (33%).

In terms of venous drainage, the basal vein of Rosenthal was the main drainage in five dAVFs (83%). The brainstem veins drained two cases (33%), and the deep-superficial middle cerebral veins were involved in one case (17%).

Table 1. Description of our cases.

Patient	Age	Sex	Clinical Presentation	Location	Borden type	Cognard type	Feeders	Venous drainege	First Treatment	Secondary Treatments	Curative Treatment	Initial Angiographic Outcome	Final Angiographic Outcome	Treatment Complications
1	49	Female	Left-sided bruit	Petrous	III	IV	Left MMA and left MHT	BV	TAE, Onyx	None	TAE, Onyx	Complete oclusion	Complete oclusion	None
2	47	Female	Headache and somnolence, with intraventricular hemorrhage	Petrous	III	IV	Left MMA, left MHT, Left APA, Left OA	BVR, BV and deep-superficial MCV	TAE, Onyx	None	TAE, Onyx	Partial occlusion	Complete oclusion	None
3	48	Male	Transient episode of aphasia and right-sided weakness	Petrous	III	III	Left SCA	BVR	TAE, Onyx	None	TAE, Onyx	Complete oclusion	Complete oclusion	None
4	70	Female	Intraparenchymal hemorrhage	Petrous	III	IV	Left IMAX, left MMA, left and rightl MHT, left OA	Cerebellar vein into BVR	TAE, Onyx	None	TAE, Onyx	Complete oclusion	Complete oclusion	Seizures post procedure that completely resolved; MRI showed small pre-post gyri infarcts with minor deficits (mild left hand grip weakness) that completely resolved after couple days
5	64	Male	Intraparenchymal hemorrhage and SAH	Petrous	III	IV	Left IMAX, left MMA, left OA, left APA	BVR	TAE, Onyx	None	TAE, Onyx	Complete oclusion	Complete oclusion	None
6	60	Male	Incidental finding	Petrous	III	IV	Left MMA, left APA, left OA	BVR	TAE, Onyx	None	TAE, Onyx	Complete oclusion	Complete oclusion	None

AMA, accessory meningeal artery; ant, anterior division; APA, ascending pharyngeal artery; BV, brainstem veins; BVR, Basal vein of Rosenthal; class, classification; GKRS, gamma knife radiosurgery; ILT, inferolateral trunk; IMAX, internal maxillary artery; ITA, inferior tympanic artery; MCV, middle cerebral vein; MHT, meningohypophyseal trunk; MMA, middle meningeal artery; OA, occipital artery; post, posterior division; PV, petrosal vein; RMA, recurrent meningeal artery; RPC, reverse pressure-cooker; SA, stylomastoid artery; SAH, subarachnoid hemorrhage; SCA, superior cerebellar artery; TAE, transarterial embolization, VST, venous sinus thrombosis.

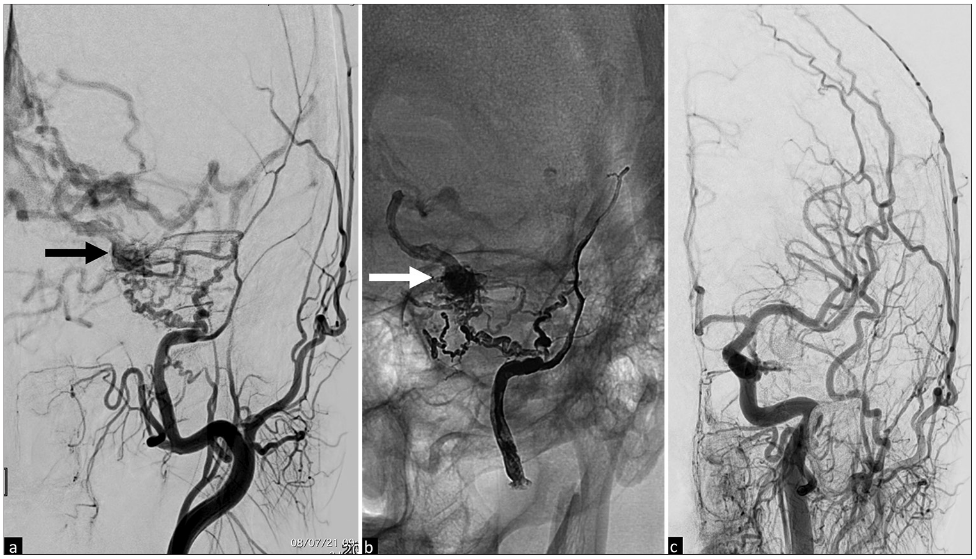

Figure 1: (a) Selective left external carotid artery angiogram showing a petrosal dural arteriovenous fistula (dAVF) (arrow) fed by branches of the left middle meningeal artery draining into superior petrosal vein, the basal vein of Rosenthal and deep Sylvian vein. (b) Plain X-ray showing the Onyx cast after embolization (arrow). (c) Left common carotid artery 10-month follow-up angiography showing complete occlusion of the petrosal dAVF.

Procedure characteristics and outcomes

All cases presented in this study were treated with TAE using Onyx as the primary and only therapeutic technique. In one case (17%), the initial post-procedural angiographic control demonstrated partial occlusion of the dAVF, while all five remaining cases (83%) exhibited complete occlusion in the initial angiographic control. One patient experienced post-procedural complications, including seizures that were completely resolved. Magnetic resonance imaging revealed small pre and post-central gyri infarcts with minor deficits characterized by mild left-hand grip weakness that completely resolved after a couple of days. In the latest angiographic follow-up, all patients showed complete occlusion of the dAVF.

Literature review

A total of 102 articles were identified through the PubMed Mesh tool search, from which five articles were selected after full-text review.[3,18,19,20,22] In addition, one article was manually added after searching for remaining articles not found through the constructed search,[5] resulting in a total of six articles included in this review. In one of the studies, petrosal vein–draining dAVFs were classified as petrous dAVFs.[22] Similarly, in another study, we inferred that the dAVFs were petrous lesions based on the description of their drainage pattern.[20]

Combining the results from these articles with our six presented cases [Table 3], a total of 116 cases of petrous dAVFs were analyzed. The average age across these cases was 55.7 years. Among the cases, 22.4% (*n* = 26) experienced some form of intracranial hemorrhage, 17.2% (*n* = 20) reported headaches, 8.6% (*n* = 10) presented with auditory symptoms (pulsatile tinnitus and/or bruit), 7.7% (*n* = 9) were incidentally found (asymptomatic), and 50% (*n* = 58) exhibited other symptoms such as cranial nerve involvement, aphasia, or other focal deficits.

The initial treatment was TAE in 80.2% (*n* = 93), surgery in 15.7% (*n* = 17), transvenous embolization (TVE) in 4.3% (*n* = 5), Gamma Knife radiosurgery (GK) in 0.9% (*n* = 1), and 0.9% (*n* = 1) information regarding the first treatment was unavailable. Regarding subsequent treatments, only 0.9% (*n* = 1) underwent TAE, 13.8% (*n* = 16) had surgery, and 2.6% (*n* = 3) underwent TVE.

Regarding the curative treatment, 79.8% (*n* = 75) of patients undergoing TAE achieved cure with the technique, 100% (*n* = 33) with surgery, 50% (*n* = 3) with TVE, and 100% (*n* = 1) with GK. Onyx was used in only 13.9% (*n* = 13) of the cases undergoing TAE. Complications were observed in 11.7% (*n* = 11) of the cases undergoing TAE, 9.1% (*n* = 3) of surgery cases, and 20% (*n* = 2) of cases treated with other techniques. The average follow-up duration was 37.6 months.

DISCUSSION

Efficacy and Strategies of TAE for Petrous dAVFs

TAE strategies for intracranial dAVFs are designed to achieve closure at both the fistulous point and the proximal aspect of the draining vein. However, several authors have questioned

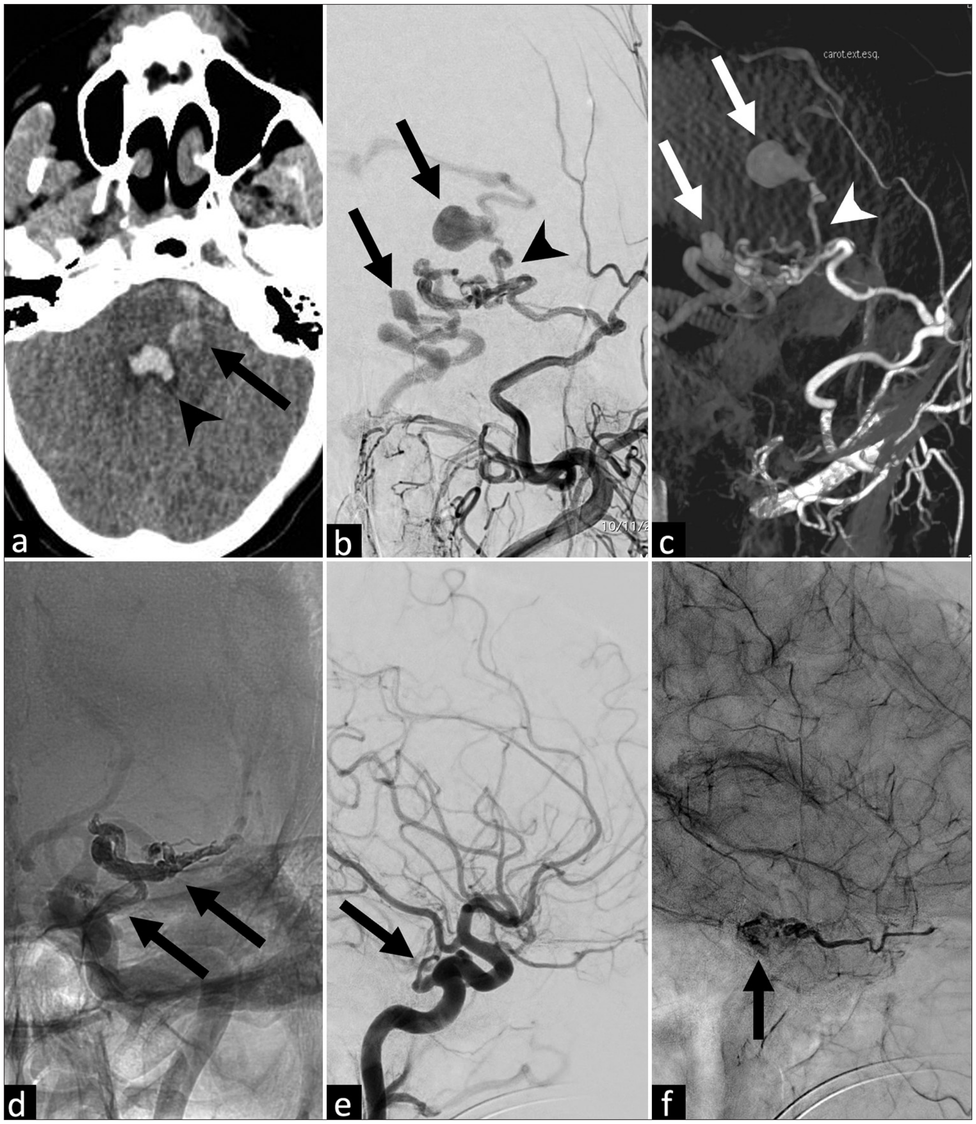

Figure 2: (a) Head computed tomography angiography showing intraventricular hemorrhage (arrowhead) with venous aneurysms and ectasia of brainstem veins (arrow) suggestive of a dural arteriovenous fistula (dAVF). (b) Selective left external carotid artery angiography and (c) 3D MIP reconstructions showing a left petrosal dAVF supplied by branches of the left middle meningeal artery draining into the brainstem and temporal veins with venous aneurysms (arrows). (d) Selective left internal carotid artery (ICA) angiogram without subtraction showing the Onyx cast adjacent to the petrosal bone and branches from the ICA previously supplying the arteriovenous shunt (arrow). (e) Common carotid artery final angiogram early arterial and (f) early venous phases showing complete occlusion of the dural arteriovenous shunt and stasis of dilated branches of the meningohypophyseal trunk (arrow) previously supplying the fistula.

the effectiveness of TAE as a standalone curative therapy.[1,6] Occluding arterial feeders without penetrating the proximal segment of the draining vein is typically ineffective due to the complex anastomotic network of dural branches that may continue to supply the lesion. Proximal ligation of arterial feeders can stimulate the development of new, more intricate feeders, complicating the endovascular approach by disconnecting initially accessible pathways.[4] While proximal occlusion may reduce intraoperative blood loss during microsurgical disconnection, its utility diminishes when pursuing an endovascular cure.[6]

Before committing to TAE, the feasibility of attaining a suitable distal position with the microcatheter must be assessed. A distal position increases the chance of cure and allows for the preservation of the vasa nervorum proximal to cranial nerves

Table 2. Borden–Shucart and Cognard dural arteriovenous fistulas classification.

Borden–Shucart classification			Cognard classification		
Type	**Venous drainege site**	**CVD**	**Type**	**Venous drainege site and Flow pattern in sinus**	**CVD**
I	Exclusively into a dural sinus with antegrade flow	No	I	Exclusively into a dural sinus with antegrade flow	No
			IIa	Exclusively into a dural sinus with retrograde flow	No
II	Into a dural sinus with both antegrade and retrograde flow into cortical veins	Yes	IIb	Exclusively into a dural sinus with antegrade flow	Yes
			IIa+b	Exclusively into a dural sinus with retrograde flow	Yes
III	Exclusively into cortical veins in a retrograde fashion	Yes	III	Drains directly into cortical veins, without venous ectasia	Yes, without venous ectasia
			IV	Drains directly into cortical veins, with venous ectasia	Yes, with venous ectasia
			V	Type V: Drains exclusively into spinal perimedullary veins	Yes

CVD, cortical venous drainage.

while avoiding external carotid to internal carotid artery anastomoses, ensuring a reasonable safety margin for ethylene-vinyl alcohol copolymer arterial reflux.[12] In instances where these favorable conditions are lacking, alternative treatment modalities such as TVE or microsurgical disconnection should be considered.[6] In the case of petrous dAVFs, this caution is even more critical. A comprehensive understanding of the facial nerve arterial arcade – an anastomotic arch of arteries in the petrous temporal bone supplying the geniculate ganglion and tympanic segment of the facial nerve – is crucial.[12,23] The risk of iatrogenic facial nerve palsy is higher when embolizing petrous dAVFs due to their frequent supply from the vessels forming the facial nerve arterial arcade.[12,17,18,21] Consequently, petrous dAVFs present unique challenges. Their proximity to the facial arcade increases the risk of facial nerve ischemia and permanent deficits, with additional concerns about reflux to the carotid artery. Therefore, open microsurgery is often recommended in such cases. These instances underscore the importance of understanding the anatomy, approaching treatment with caution, and recognizing the boundaries that must be respected. Furthermore, liquid embolic agents such as Onyx should be used judiciously as they introduce potential risks: they may infiltrate the vasa nervorum, causing damage to the facial arcade, and traverse small anastomoses between the internal and external carotid arteries, leading the embolic agent into the pial arteries and subsequent ischemic complications.

Clinical outcomes and advances

An intriguing study by Bhatia *et al.*[5] presented factors favoring an attempt at primary TAE (non-arcade feeders accessible, direct fistulous connection with no nidus, and a reasonable safety margin <20 mm to facial arcade supply), yielding favorable outcomes in terms of safety with preservation of facial nerve function in all cases. Similarly, our cases demonstrated that, in selected patients, treating petrous dAVFs with TAE using the Onyx liquid embolic system is feasible and quite attractive. However, this was not always the case. Before the Onyx era, TAE achieved success in only about 50% of cases,[10,15] and the transvenous approach was predominantly favored. The endovascular access to the small cortical veins of Borden type III and Cognard III and IV dAVFs in the petrous pyramid is usually risky, leading to neurosurgical treatment as the primary approach. With the advent of innovative technologies, especially Onyx, a successful era of TAE for complex cases was inaugurated,[6,13,25,28] making it the single approach in some instances,[6,13,25] resulting in a significant increase in TAE angiographic cure rates to approximately two-thirds of cases in the Onyx era.[6]

Limitations and generalizability

Although our review compiled a total of 116 cases of petrous dAVF from six different articles, including our cases, the studies exhibited significant variations that preclude the generalization of the results. Factors such as publication date and the consequent availability of techniques at the time, the materials used (notably, only 13.9% of TAE cases reported the use of Onyx), and, except for Bhatia *et al.*[5] study, a lack of clarity in the criteria for selecting the treatment modality exemplifies aspects that impede an accurate and precise comparison of outcomes.

Table 3. Literature review results of petrous dural arteriovenous fistulas.

Reference	No. of Cases (Petrous dAVFs)*	Mean age	Clinical Presentation					First Treatment					Secondary Treatments			Curative Treatment#			TAE material					Treatment Complications*			Median follow-up (months)
			Hemorrhage	Headache	Pulsatile tinnitus and/or bruit	Asymptomatic	Other	TAE	Surgery	TVE	GKRS	Not available	TAE	Surgery	TVE	TAE	Surgery	TVE	Onyx	Glue	Coils	Other	Not available	TAE	Surgery	Other	
Our study	6	56	3	1	1	1	2	6 (100%)	-	-	-	-	-	-	-	6 (100%)	-	-	6 (100%)	-	-	-	-	1 (17%)	-	-	42.7
Bhatia 2022	15	63	2	4	3	5	5	8 (50%)	3 (18.7%)	3 (18.7%)	1 (6.2%)	1 (6.2%)	-	4 (26.7%)	1 (6.2%)	5 (62.5%)	7 (100%)	3 (100%)	1 (12.5%)	4 (50%)	1 (12.5%)	2 (25%)	2 (25%)	3 (37.5%)	2 (28.6%)	-	N/A
Li 2018	64	49	8	12	0	3	41	56 (87.5%)	8 (12.5%)	-	-	-	-	7 (11%)	-	49 (87.5%)	15 (100%)	-	-	-	-	-	56 (100%)	4 (7.1%)	-	-	70.3
Mitsuhashi 2009	10	51.5	5	1	0	0	5	10 (100%)	-	-	-	-	-	1 (10%)	-	8 (80%)	1 (100%)	-	-	10 (100%)	-	-	-	N/A	N/A	N/A	40
Barnwell 1990	5	60	0	1	4	0	4	3 (60%)	-	2 (40%)	-	-	-	-	2 (40%)	1 (33.3%)	-	4 (100%)	-	-	-	3 (100%)	-	1 (33.3%)	-	2 (50%)	17.2
Lv 2008	6	45.5	4	1	2	0	1	6 (100%)	-	-	-	-	1 (16.7%)	-	-	6 (100%)	-	-	6 (85.7%)	-	-	-	-	2 (28.6%)	-	-	10.7
Liu 2009	10	65	4	N/A	N/A	N/A	N/A	4 (40%)	6 (60%)	-	-	-	-	4 (40%)	-	-	10 (100%)	-	-	-	-	-	4 (100%)	0 (0%)	1 (10%)	0 (0%)	45
Total	116	55.7	26 (22.4%)	20 (17.2%)	10 (8.6%)	9 (7.7%)	58 (50%)	93 (80.2%)	17 (14.7%)	5 (4.3%)	1 (0.9%)	1 (0.9%)	1 (0.9%)	16 (13.8%)	3 (2.6%)	75 (79.8%)	33 (100%)	7 (87.5%)	13 (13.9%)	14 (14.9%)	1 (1%)	5 (5.3%)	62 (66%)	11 (11.7%)	3 (9.1%)	2 (20%)	37.6

*With some form of treatment
#At least angiographic evidence of complete occlusion or absence of symptoms
dAVFs, dural arteriovenous fistulas; GKRS, gamma knife radiosurgery; N/A, not available; TAE, transarterial embolization; TVE, transvenous embolization.

Moreover, there is a substantial risk of selection and publication bias inherent in this study modality, as successfully treated cases with a particular approach are more likely to be published and selectively exposed to the scientific community. Another potential source of systematic error in our review, driven by the selection criteria favoring studies describing at least 3 TAE cases, is the limited inclusion of petrous dAVFs primarily treated with surgery (15.7%). This poses the risk of selectively including cases where surgery was utilized for refractory cases of TAE, potentially biasing the results in favor of surgical treatment.

CONCLUSION

Our findings suggest that TAE using Onyx is a feasible and effective treatment for petrous dAVFs. However, the potential advantages of surgical approaches, as highlighted by existing literature, should not be overlooked. Future studies should aim to compare these treatment modalities directly, taking into account patient-specific factors and anatomical complexities to optimize outcomes. Detailed descriptions of arterial supply and venous drainage are crucial for enhancing treatment planning and reducing complications.

Ethical approval

Institutional Review Board approval is not required.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent.

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Nil.

Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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