

Microsurgical Treatment of Cranial Dural Arteriovenous Fistulas: A Case Series and Literature Review

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Abstract. Dural arteriovenous fistulas are pathological vascular malformations within the dura mater, characterized by abnormal connections between pial arteries and veins. These are rare lesions that can present with a variety of neurological symptoms, and, when ruptured, can result in a fatal hemorrhage. This disease can be managed by endovascular embolization, surgical resection, and stereotactic radiosurgery. Particularly with the advancement of endovascular techniques, surgery is less frequently used to treat these lesions. However, it remains a viable treatment option in certain cases. In this article, we present a series of 17 patients with dural arteriovenous fistulas treated at a single tertiary neurosurgical center. This study was conducted at São João University Hospital in Porto, Portugal. We retrospectively collected data from all patients who underwent microsurgical or endovascular treatment for dural arteriovenous fistulas between 2014 and 2023. We collected information regarding the patients' sex, age, and radiological classification of the dAVF, also, the treatment modality chosen, dAVF obliteration rate and information about any complications that have resulted from the treatment. Endovascular treatment had been attempted in 5 patients (29.4%), resulting in partial embolization of the dural arteriovenous fistulas in 3 patients (17.6%). In 2 patients (11.8%), embolization was attempted but deemed technically unfeasible. The remaining cohort, comprising 12 patients (70.6%), underwent surgical intervention as the primary treatment modality. Overall, all of the patients presented in this cohort underwent surgical resection. The factors why patients underwent surgical resection as the primary treatment modality were: endovascular embolization was deemed technically unfeasible due to the location in the anterior cranial fossa, or due to the multidisciplinary decision to operate on these lesions. Lesions were also operated on in the presence of a hematoma that required an evacuation. Immediate postoperative angiography showed that 94.1% (n = 16) of the patients achieved complete exclusion of the lesion. At the time of the latest follow-up, a second DSA was performed, and 88.23% (n = 15) of the patients showed complete obliteration of the lesion. 41.17 % of the patients (n = 7) had resolution of their pre-operative symptoms. 58.8 % (n = 10) remained symptomatic after the surgical procedure. The cumulative surgical complication rate in this cohort was 23.6% (n = 4). In this article, we also provide a comprehensive review of the literature regarding the treatment

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modalities that are available to treat this complex condition. In conclusion, surgical treatment is nowadays less frequently used, but it still remains a viable option for the treatment of dural arteriovenous fistulas. Our patient cohort demonstrated that selective treatment of these rare and complex lesions surgically is associated with high obliteration rates and relatively low rates of complications. Surgical treatment can be considered a primary treatment option when dealing with ethmoidal-type dural arteriovenous fistulas or others located within the anterior cranial fossa, and the presence of a hematoma requiring urgent evacuation.

Keywords: dural AVF, surgical resection, endovascular embolization, case series, literature review.

Mikrochirurginis duralinių arterioveninių fistulių gydymas: atvejų serijos analizė ir literatūros apžvalga

Santrauka. Kietojo smegenų dangalo arterioveninės fistulės yra patologinės kraujagyslinės malformacijos kietajame smegenų dangale, kurioms būdingos nenormalios jungtys tarp pialinių arterijų ir venų. Tai retos patologijos, galinčios pasireikšti įvairiais neurologiniais simptomais, o plyšimo atveju sukelti mirtiną kraujavimą. Ši liga gali būti gydoma endovaskuline embolizacija, chirurgine rezekcija ir stereotaksine radiocirurgija. Tobulėjant endovaskulinėms technikoms, chirurginis šių pažeidimų gydymas taikomas rečiau, tačiau tam tikrais atvejais jis išlieka tinkama gydymo galimybe.

Šiame straipsnyje pateikiame 17 pacientų, sergančių kietojo smegenų dangalo arterioveninėmis fistulėmis, gydytų viename tretinio lygio neurochirurgijos centre, seriją. Tyrimas buvo atliktas São João universitetinėje ligoninėje, Portugalijoje. Retrospektyviai surinkome duomenis apie visus pacientus, kuriems 2014–2023 m. buvo taikytas mikrochirurginis arba endovaskulinis gydymas dėl kietojo smegenų dangalo arterioveninių fistulių. Buvo surinkta informacija apie pacientų lytį, amžių, radiologinę dAVF klasifikaciją, pasirinktą gydymo metodą, dAVF obliteracijos dažnį ir visas pasireiškusias komplikacijas.

Endovaskulinis gydymas bandytas taikyti 5 pacientams (29,4 %), iš jų 3 pacientams (17,6 %) pasiekta dalinė kietojo smegenų dangalo arterioveninių fistulių embolizacija. Dviem pacientams (11,8 %) embolizacija buvo bandyta atlikti, tačiau pripažinta techniškai neįmanoma. Likusi 12 pacientų grupė (70,6 %) buvo gydyta chirurginiu būdu kaip pirminiu gydymo metodu. Visi šioje kohortoje pristatyti pacientai galiausiai buvo gydyti chirurgine rezekcija.

Priežastys, dėl kurių chirurginė rezekcija buvo pasirinkta kaip pirminis gydymo metodas, buvo šios: endovaskulinė embolizacija buvo techniškai neįmanoma dėl pažeidimo lokalizacijos priekinėje kaukolės dauboje arba dėl multidisciplininės komandos sprendimo operuoti šiuos pažeidimus. Chirurginis gydymas taip pat taikytas esant hematoma, kurią reikėjo evakuoti (pašalinti).

Skubi pooperacinė angiografija parodė, kad 94,1 % pacientų ($n = 16$) buvo pasiekta visiška pažeidimo ekskliuzija. Paskutinio stebėjimo metu atlikta pakartotinė DSA, kuri parodė, kad 88,23 % pacientų ($n = 15$) buvo pasiekta visiška pažeidimo obliteracija. 41,17 % pacientų ($n = 7$) išnyko priešoperaciniai simptomai, o 58,8 % pacientų ($n = 10$) po chirurginės procedūros simptomai išliko. Bendras chirurginių komplikacijų dažnis šioje kohortoje siekė 23,6 % ($n = 4$).

Šiame straipsnyje taip pat pateikiame išsamią literatūros apžvalgą apie gydymo metodus, taikomus šiai sudėtingai būklei gydyti. Apibendrinant galima teigti, kad chirurginis gydymas šiais laikais taikomas rečiau, tačiau vis dar išlieka tinkama kietojo smegenų dangalo arterioveninių fistulių gydymo galimybe. Mūsų pacientų kohorta parodė, kad selektyvus šių retų ir sudėtingų pažeidimų chirurginis gydymas yra susijęs su dideliu obliteracijos dažniu ir santykinai mažu komplikacijų dažniu. Chirurginis gydymas gali būti laikomas pirminiu gydymo pasirinkimu gydant etmoidinio tipo kietojo smegenų dangalo arteriovenines fistulas ar kitus pažeidimus, lokalizuotus priekinėje kaukolės dauboje, taip pat esant hematoma, kurią reikia skubiai pašalinti.

Raktažodžiai: kietojo smegenų dangalo arterioveninė fistulė (dAVF), chirurginė rezekcija, endovaskulinė embolizacija, klinikinių atvejų serija, literatūros apžvalga.

Introduction

Dural arteriovenous fistulas are pathological vascular malformations situated in the dura mater, characterized by abnormal connections between pial arteries and veins [1]. Although dural arteriovenous fistulas are relatively infrequent within the spectrum of neurosurgical disorders, they can manifest with a wide range of symptoms, from mild neurological deficits to severe ones, including potentially fatal hemorrhages [2]. Historically, neurosurgical resection has been the primary treatment approach for these lesions; however, contemporary treatment paradigms now encompass various modalities, including endovascular embolization and stereotactic radiosurgery. Advances in endovascular techniques have led to embolization becoming the first-line treatment option for dural arteriovenous fistulas. Nevertheless, microsurgical resection remains an important component of the treatment strategy, particularly in select cases where it may be considered the optimal approach [1,2].

In this article, we present a case series involving 17 patients diagnosed with dural arteriovenous fistulas who were treated at a tertiary neurosurgical center in Portugal. Additionally, we provide a comprehensive review of the current literature concerning the available treatment options for this condition.

Methods

This study was conducted at São João University Hospital in Porto, Portugal. We retrospectively collected data from all patients who underwent microsurgical or endovascular treatment for dural arteriovenous fistulas between 2014 and 2023.

- Inclusion criteria:
 - Patients older than 18 years of age.
 - Patients with confirmed dural arteriovenous fistula on angiography.
 - Patients who have been treated with surgical resection of the fistula or endovascular embolization.
 - Patients whose treatment modality has been selected by a multidisciplinary meeting between neurosurgeons and interventional radiologists.
- Exclusion criteria:
 - Patients younger than 18 years of age.
 - Patients who chose not to pursue either open surgical treatment or treatment with embolization.
 - Patients whose lesion was confirmed not to be a dural arteriovenous fistula on angiography imaging.

In total, 17 patients were included in the study. All patients included had been discussed in a multidisciplinary team meeting, consisting of vascular neurosurgeons and interventional neuro-radiologists, where the specific features of the case were considered an indication for this specific therapeutic modality. If the open neurosurgical treatment had been chosen, the patient underwent a craniotomy and a resection of the dural arteriovenous fistula. If the endovascular embolization was chosen, the patient underwent an endovascular embolization of the fistula via transarterial or transvenous route. In the case of failure to treat the lesion by embolization, the surgical treatment was then pursued.

The dural arteriovenous fistulae at the time of diagnosis, according to the angiographic imaging, were classified according to the Borden and Cognard scales classifications, shown in Table 2 and Table 3.

Table 1. List of cases surveyed

Global population social, demographic, clinical, and radiological characteristics														
Sex	Age at the time of diagnosis	Radiological Presentation	Borden/Cognard	Arterial feeders	Main venous drainage	Associated vascular malformations	Pre-operative embolization	Clinical Presentation	Neurological presentation	Follow-up time (days)	Clinical outcome	Post-op complications	Radiological outcome	
1	M	61	Non-hemorrhagic	III/IV	MMA and STA	Transverse sinus	-	Not possible	Symptomatic	No focal neurological deficits, Headache	431	No neurological deficits	-	Complete exclusion
2	M	63	Hemorrhagic	III/V	Vertebral artery	SSS	PICA aneurysm	Partial	Symptomatic	No neurological deficits, headache	3511	No neurological deficits	Hydrocephalus	Complete exclusion
3	M	85	Hemorrhagic	III/IV	Ethmoidal artery	SSS	Venous aneurysm	Not performed	Symptomatic	Dysarthria	629	No neurological deficits	-	Complete exclusion
4	M	77	Hemorrhagic	III/III	MHT	Petrous sinus	AICA aneurysm	Not performed	Symptomatic	Central facial palsy, dysarthria, dysmetria	55	Death	-	Complete exclusion
5	M	63	Non-hemorrhagic	III/III	ACA	SSS	Multiple aneurysm	Not performed	Symptomatic	No neurological deficits, headache	949	Anosmia	-	Complete exclusion
6	M	63	Hemorrhagic	III/IV	OA and MMA	Transverse sinus	-	Not performed	Asymptomatic	No neurological deficits	571	Epilepsy	-	Complete exclusion
7	M	77	Non-hemorrhagic	III/III	OA and MMA	SSS	Venous aneurysm	Not possible	Asymptomatic	No neurological deficits	326	Right hemiparesis	-	Complete exclusion
8	M	44	Non-hemorrhagic	III/III	Ethmoidal artery	SSS	-	Not performed	Symptomatic	No focal neurological deficits, headache	857	No neurological deficits	-	Complete exclusion
9	M	66	Hemorrhagic	III/IV	Pericallosal artery	SSS	Venous aneurysm	Not performed	Symptomatic	Coma (GCS 6)	1380	Aphasia, PFP, hemiparesis	-	Complete exclusion
10	M	51	Non-hemorrhagic	III/IV	MMA, SCA, AICA	Petrous sinus	Giant venous aneurysm	Partial	Symptomatic	PFC and Loss of sensation	1117	Partial hearing loss	-	Complete exclusion
11	M	49	Hemorrhagic	III/IV	MMA	SSS	Venous aneurysm	Not performed	Symptomatic	Left Hemiparesis	1443	Hemiparesis, Epilepsy	Deep surgical site infection	Complete exclusion
12	M	57	Non-hemorrhagic	III/IV	MMA	AVM	Complex AVM	Partial	Symptomatic	No focal neurological deficits, headache	592	No neurological deficits	Superficial surgical site infection	Late reconstitution of fistula sites
13	M	37	Hemorrhagic	III/IV	MHT	Cerebellar cortical vein	-	Not performed	Symptomatic	No focal neurological deficits, headache	302	No neurological deficits	-	Complete exclusion
14	F	65	Hemorrhagic	III/V	OA	Bulbome-dullary vein	-	Not performed	Symptomatic	Gait instability and left hemiparesis	242	Gait instability	-	Complete exclusion
15	M	46	Non-hemorrhagic	III/V	Vertebral artery	Bulbome-dullary vein	-	Not performed	Symptomatic	Paraparesis	195	Paraparesis	-	Complete exclusion
16	M	45	Non-hemorrhagic	III/IV	OA, STA and MMA	SSS	-	Not performed	Symptomatic	No focal neurological deficits, headache	228	Foot Loss of sensation	New onset sensory deficit	Partial exclusion
17	M	60	Non-hemorrhagic	III/IV	Etmoidal artery	SSS	-	Not performed	Symptomatic	No focal neurological deficits, headache	24	No neurological deficits	-	Complete exclusion

Table 2. Borden classification [3]

Type	Description
Type I	Direct drainage into a dural sinus without cortical venous reflux
Type II	Direct drainage into a dural venous sinus with a retrograde flow into cortical veins
Type III	Direct drainage into cortical veins

Table 3. Cognard classification [4]

Type	Description
Type I	Antegrade drainage into a sinus or meningeal vein
Type IIa	Retrograde drainage into a sinus or meningeal vein
Type IIb	Reflux into cortical veins
Type II a+b	Reflux into both sinus and cortical veins
Type III	Direct cortical venous drainage without venous ectasia
Type IV	Direct cortical venous drainage with venous ectasia
Type V	Spinal venous drainage

The data collected: Social, demographic, clinical, and radiological data. Surgical outcome: post-operative neurological status, postoperative complications, and radiological results. Patient cohort demographics, clinical presentation, and radiological characteristics. The whole cohort is displayed in Table 3 and summarized in Table 4. The patient outcomes were then grouped into primary and secondary outcome groups. The primary outcomes were measured as successful or unsuccessful exclusion of the dural arteriovenous fistula and the resolution of the pre-procedure neurological deficits. The secondary outcomes were measured as complications such as late-onset hydrocephalus, postoperative wound infections, and new-onset neurological deficits.

Patient characteristics

Table 4. Summary of demographic and radiological characteristics

Sex n(%)	M	16(94.1)
	F	1(5.9)
Median age (years)		61 (47.5 – 65.5)
Radiological presentation n(%)	Hemorrhagic	9(52.9)
	Non-hemorrhagic	8(47.1)
Clinical presentation n(%)	Symptomatic	15(88.2)
	Asymptomatic	2(11.8)
Borden Classification n(%)	III	17(100)
Cognard Classification n(%)	III	4(23.5)
	IV	10(58.8)
	V	3(17.7)

A comprehensive overview of patient characteristics is detailed in Tables 3 and 4. The cohort predominantly comprised male patients, accounting for 94.1% of the population. The median age at the time of treatment was 61 years. A significant portion of the cohort presented with a hemorrhage on the initial CT scan, with 52.9% experiencing hemorrhage compared to 47.1% who did not. Focal neurological deficits were observed in the majority of our patients, constituting 88.2% of the

cohort. All dural arteriovenous fistulas in this study were classified as Borden Class III (100%). By utilizing the Cognard classification system, the most frequently observed lesion type was classified as Cognard IV (58%), followed by Cognard III, which was identified in 23.5% of the cases ($n = 4$), and Cognard V, observed in 17.7% ($n = 3$).

Results

Primary outcomes

Endovascular treatment had been previously attempted in 5 patients (29.4%), resulting in partial embolization of the dural arteriovenous fistulas in 3 patients (17.6%). In 2 patients (11.8%), embolization had been attempted but was ultimately deemed technically unfeasible. The remaining cohort, comprising 12 patients (70.6%), underwent surgical intervention as the primary treatment modality. The decision to pursue surgical treatment was influenced by factors such as the inability to treat the lesion endovascularly and the specific anatomical location of the dural arteriovenous fistula. Additionally, the presence of an intraparenchymal hematoma necessitating evacuation also influenced the need for hematoma evacuation and microsurgical treatment of the AVF. The reasons why endovascular embolization was not completed are summarized in Table 5.

Table 5. Dural arteriovenous fistulas treated primarily through microsurgery. 12 patients in total

Reason	N(%)
Multidisciplinary decision – inability to implement endovascular treatment	5(29.4)
Other indications for surgery (e.g.: need of evacuation of intracranial hematoma)	5(29.4)
Dural arteriovenous fistula location (located in anterior cranial fossa)	2(11.7)

The median follow-up in this cohort was an average of 666 days. After the surgical treatment was completed, a follow-up DSA was performed during the same hospital stay.

Immediate postoperative angiography showed that 94.1% ($n = 16$) of patients achieved complete exclusion of the lesion; one patient presented with signs of persistent shunting on the postoperative DSA. A second surgery was considered as the treatment option, but the patient refused surgical treatment, and observation with serial imaging over time was pursued instead.

At the time of the latest follow-up, a second DSA was performed, and 88.23% ($n = 15$) of the patients had shown complete obliteration of the lesion. In one patient, late reconstitution of the fistula sites was observed. For this patient, adjuvant endovascular embolization was chosen as the treatment modality.

In the case of resolution of pre-procedure neurological deficits, 41.17% of the patients ($n = 7$) had resolution of their pre-operative symptoms. 58.8 % ($n = 10$) remained symptomatic after the surgical procedure. One patient died after the procedure due to a massive pulmonary embolism in the postoperative period (5.8 % $n = 1$).

Secondary outcomes

The cumulative surgical complication rate in this cohort (Table 4) was 23.6% ($n = 4$). Complications encountered included surgical site infections (11.8%, $n = 2$), one case requiring revision of the surgical site. Late-onset hydrocephalus was encountered in one patient (5.9%), and a ventriculoperitoneal shunt was implanted. New-onset neurological symptoms were observed in a single patient who developed mild paresthesia in one foot, which improved over time. The postoperative complications are summarized in Table 6.

Table 6. Postoperative complications. 4 patients in total

Description	N(%)
Surgical site infections	2(11.8)
Late hydrocephalus	1(5.9)
New neurological-deficit	1(5.9)

Illustrative cases

Case I

An 85-year-old male presented to the emergency department complaining of a sudden onset of headache. Upon examination, she was alert, oriented, and was given a GCS score of 15. No focal neurological deficits were observed during the neurological examination. A head CT was performed, and a right frontal intracerebral hematoma protruding into the subdural space was discovered. Due to the unusual location of the ICH, CT angiogram and later DSA were performed for differential diagnosis. A right frontobasal dural arteriovenous fistula was confirmed, receiving feeders from an ethmoidal artery and associated with a giant frontobasal aneurysm. The venous drainage was observed to be through the superior longitudinal sinus (Figure 1A). The patient was discussed in a multidisciplinary team meeting, and the surgical treatment option was chosen due to the location in the anterior cranial fossa, ethmoidal type of the dural arteriovenous fistula, and the frontobasal aneurysm that it was associated with. The patient underwent a right unilateral frontal craniotomy and exclusion of the AFV. A DSA was performed after surgery and showed a complete exclusion of the dural AVM (Figure 1B). Postoperatively, no focal neurological symptoms were observed. The post-operative course was uneventful.

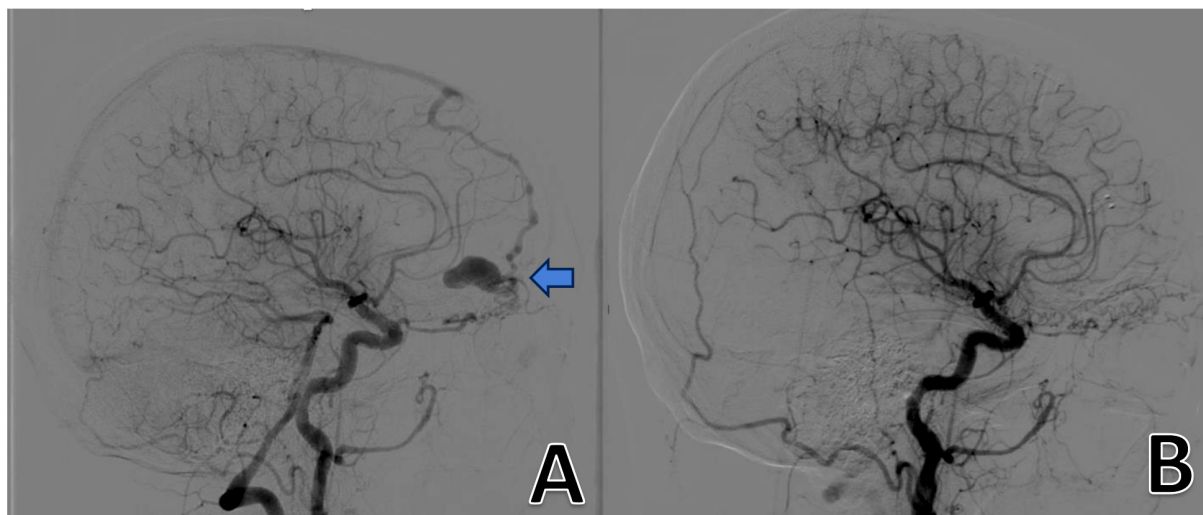


Figure 1. Case I (A - preoperative DSA showing frontobasal dural arteriovenous fistula, associated with giant venous aneurysm; B - postoperative angiography showing complete exclusion of the lesion)

Case II

A 50-year-old male presented to the emergency department, complaining about left facial numbness and paresthesia on the left side of the face. These symptoms were rapidly progressing. The patient was admitted to the neurosurgery department after a lesion was suspected in the cranial CT in the region of the pons. Significant associated edema was observed. The patient's condition deteriorated rapidly,

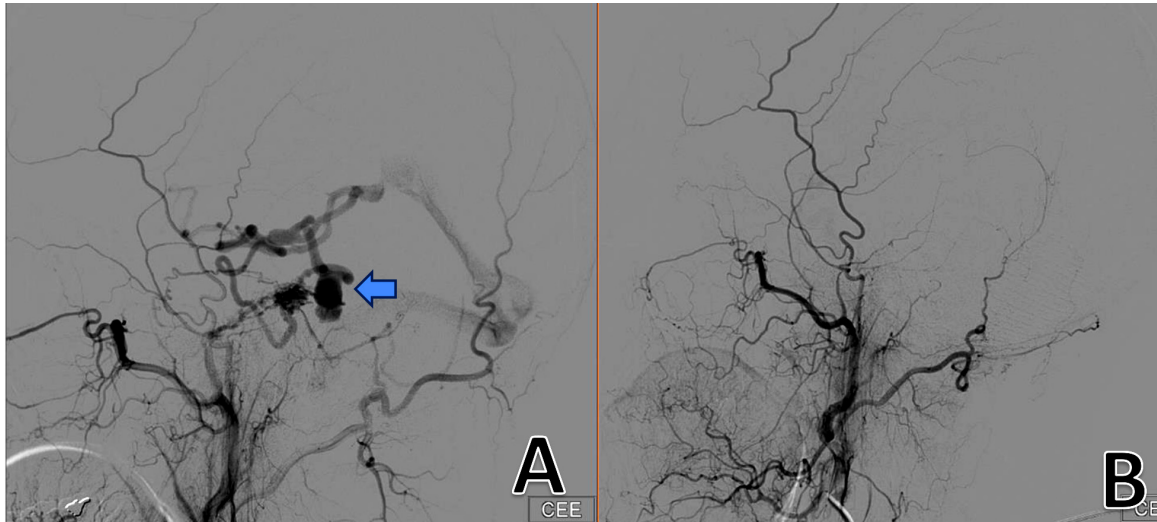


Figure 2. Case II (A – Preoperative DSA showing dural arteriovenous fistula with medial meningeal artery and meningohipophyseal trunk feeders, associated with a giant venous aneurysm. B – Postoperative DSA showing complete exclusion of the lesion)

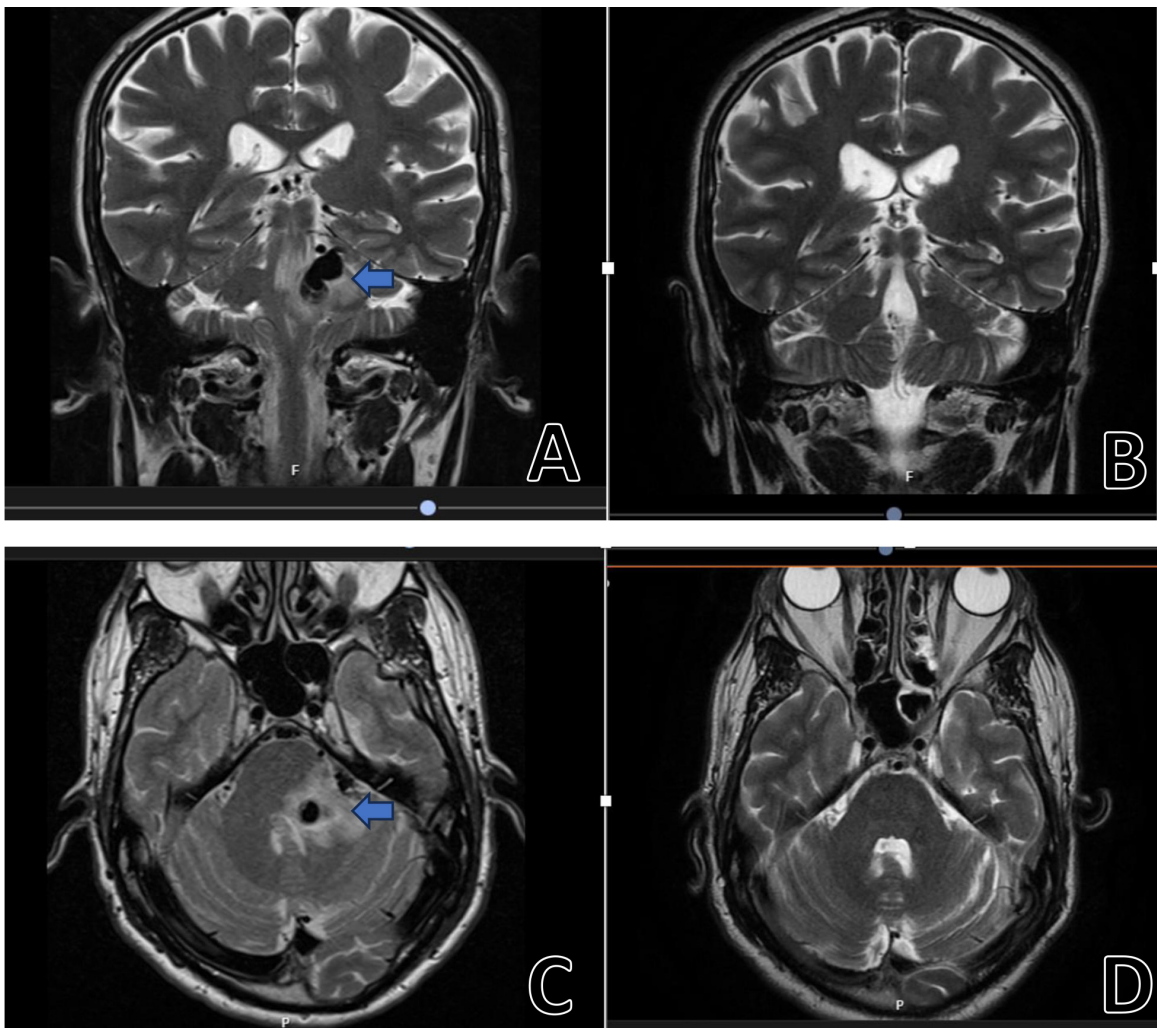


Figure 3. Case II (A – Coronal T2 MRI presents a dural arteriovenous fistula located in the pons, with associated edema. B – Postoperative MRI showing exclusion of the lesion. C – Axial FLAIR preoperative MRI showing the previously described lesion. D – Axial T2 postoperative MRT showing the exclusion of the lesion)

with a decline in the mental status and a GCS score of less than 8. The patient was admitted to the ICU and intubated. A brain MRI was performed. A lesion in the pons was observed. The lesion itself appeared iso/hypodense on the T2 and FLAIR sequences (Figure 3 A and C). A DSA was performed – a dural arteriovenous fistula with medial meningeal artery and meningohypophyseal trunk feeders, and associated with a giant venous aneurysm. (Figure 2A). The venous drainage appeared to be through peri-medullary veins and sinus rectus. There were several attempts to embolize the dural arteriovenous fistula with no success, which justified the decision to pursue surgical treatment. The patient underwent a retrosigmoid craniotomy and exclusion of the AVE. A DSA was performed after the surgery and showed a complete exclusion of the dural AVM (Figure 2B). He was extubated on the second day and later discharged to a rehabilitation facility. A 6-month postoperative MRI showed no remnants of the lesion and complete resolution of the brainstem edema (Figure 3 B and D).

Discussion

Intracranial dural arteriovenous fistulas, also known as dural arteriovenous shunts, are pathological connections between dural and pial arteries and veins within the dura mater, comprising the walls of the dural sinuses, bone traversing emissary veins, and bridging venous structures [1]. These lesions were first described by Razzoli in 1881, and the first angiographic evidence of this disease was published by Sachs in 1931. Dural arteriovenous fistulas are considered a rare pathology, accounting for 10–15% of all intracranial vascular malformations [2]. However, cases of selected lesions remaining fully asymptomatic and/or resolving spontaneously have been reported in the literature; therefore, their incidence might be underreported [5]. Dural arteriovenous fistulas are most often located near the transverse and cavernous sinuses, but they can occur at any location within the intracranial dura mater [6].

The current treatment modalities go from conservative management to endovascular embolization, stereotactic radiosurgery, and microsurgical resection.

Endovascular treatment

Management of dural arteriovenous fistulas using endovascular embolization is mainly considered first-line treatment for most of these lesions. The techniques used for embolization include trans-arterial, transvenous, and direct puncture, which is used infrequently [7]. In the case of trans-arterial embolization, the obliteration of feeding branches aims at reducing blood flow to the shunt but can be limited by difficulties in catheterizing feeding arteries and compromising the complete obliteration of the dural arteriovenous fistulas. As such, the trans-arterial embolization method can usually be applied as an adjunct treatment to stabilize the dural arteriovenous fistulas before other procedures (surgery or radiotherapy) are attempted [7]. The most recently used embolization method has become transvenous embolization due to its association with higher rates of complete arteriovenous fistula obliteration. This method is most prominently utilized in treating dural arteriovenous fistulas of the cavernous, sigmoid, and transverse sinuses [1,7,8]. Various materials can be used for dural arteriovenous fistula embolization. In the case of the trans-arterial route, liquid embolic agents are commonly used, like Onyx, PHIL, or Squid. In the transvenous approach, coiling of the draining veins or their occlusion with liquid embolization agents is the preferred method [9–11].

Surgical treatment

Despite being used less frequently due to the advancement of endovascular techniques, surgical treatment remains an effective alternative for the treatment of dural arteriovenous fistulas. It can be chosen when the patient presents with a hemorrhage that requires evacuation or serious neurologi-

cal deficits, such as seizures or paresis [12], which was the case for more than a half of our patient group. Open surgical treatment also holds a role in treating fistulas that are difficult to access endovascularly, or those that cannot be conveniently accessed endovascularly [13,14], and therefore it is also a mainstay treatment option for ethmoidal dural arteriovenous fistulas.

Some dural arteriovenous fistulas are located in the anterior cranial fossa. For these lesions, surgical treatment is associated with far superior results in both obliteration rates and patient outcomes [15]. Also, open surgical treatment can be used in reserved cases where endovascular approaches have previously failed to completely obliterate the dural arteriovenous fistula [16].

In the case of a dural arteriovenous fistula of the transverse-sigmoid sinus region, the surgical procedure involves skeletonization of the involved sinus and the coagulation of dural feeding arteries and arterialized cortical veins [17]. In the case of dural arteriovenous fistulas without direct drainage into a dural sinus, the lesion is managed with the cortical draining vein being disconnected from the fistula point by bipolar coagulation or micro clips [18].

Stereotactic radiosurgery

SRS is often reserved as the last treatment option for dural arteriovenous fistulas. This method is thought to induce endothelial cell damage and subsequent thrombosis of the fistula, which leads to occlusion of the lesion [20]. Similarly with the treatment of cerebral AVMs, the obliteration of the dural arteriovenous fistula can take months, during which time the risk of bleeding is still present [21,22]. More benign Cognard grade I or Borden grade I dural arteriovenous fistulas are considered good candidates for treatment with SRS. These lesions are associated with a higher rate of obliteration without bleeding during the post-treatment latency period [21]. Stereotactic radiosurgery is also an option for high-grade arteriovenous fistulas when surgical or endovascular treatment approaches have failed to achieve obliteration or are deemed too dangerous to perform [20]. Treatment with SRS, according to the literature, can produce a complete obliteration rate from 50% to 93% [20,21,23]. However, the average latency period of dural arteriovenous fistula closure is reported as 23 months after the procedure, and the annual rebleeding rate is reported as high as 2.6% [23,24]. Therefore, despite being effective, this treatment method carries a significant risk of hemorrhagic events in susceptible cases. We do not present any patients treated with this method in our cohort.

Conclusions

Even though surgical treatment is nowadays less frequently used, it still remains a viable option for the treatment of dural arteriovenous fistulas. Our patient cohort demonstrated that selectively treating these rare and complex lesions surgically is associated with high obliteration rates and relatively low rates of complications. Surgical treatment can be considered a primary treatment option when dealing with ethmoidal-type dural arteriovenous fistulas or others located within the anterior cranial fossa. Treating these lesions surgically is also a viable option when a patient presents with severe neurological symptoms and/or hemorrhage that requires evacuation, as well as when endovascular embolization methods have failed.

Multidisciplinary team discussion should remain the focus of adequate decision-making on an individual-patient basis.

Limitations of the study

This study has several limitations. The biggest of these is its retrospective nature and a small sample size. To accurately determine one method's superiority over another, the clinical study should be prospective in its nature. The lack of patient randomization is also a limiting factor. No stereotactic

radiosurgery cases were included in this study since our center does not possess this treatment modality. Therefore, more prospective randomized trials should be conducted in the future in larger sample sizes so that to fully evaluate the optimal treatment method for various locations of dural arteriovenous fistulas.

Author contributions

D. J.: conceptualization, methodology, formal analysis, investigation, writing – original draft preparation, writing – review and editing, visualization.

C. S. S.: conceptualization, methodology, formal analysis, investigation, writing – original draft preparation, writing – review and editing.

P. A. S.: conceptualization, writing – review and editing.

A. V.: writing – review and editing.

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