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ORIGINAL ARTICLE

Isolated sinus dural arteriovenous fistulas: a single-center experience in 44 patients

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Abstract

Background Isolated sinus dural arteriovenous fistulas (DAVFs) constitute a rare and distinctive subtype of DAVF, typically found in small case numbers or case reports. The optimal treatment for this DAVF type remains unclear.

Objective This study aims to further detail the treatment outcomes of isolated sinus DAVFs in a sizable cohort from a single center.

Methods A retrospective study was undertaken on a consecutive series of patients with isolated sinus DAVFs treated at a single institution from 2002 to 2022. The article delineates the clinical presentation, angiographic features, treatment strategy, clinical and angiographic outcomes, and complications.

Results The cohort consisted of 31 males and 13 females, with an average age of 52.0 ± 15.5 years (range, 16–83). The success rate for trans-arterial embolization (TAE) was 97.3% (36/37). Transvenous embolization (TVE) with the reopening technique was successful in 3 of 4 patients (75.0%). Two open burr-hole TVE cases (66.7%, 2/3) and one surgery (100%) resulted in immediate complete closure of the fistula. Immediate complete occlusion was achieved in 93.2% (41/44) of cases. There was one major complication (2.3%, 1/44) and two fistulas recurred (9.5%, 2/21).

Conclusions The majority of isolated sinus DAVFs can be effectively treated with TAE using Onyx. TVE and surgery serve as alternative techniques when arterial access is deemed inappropriate or when complete occlusion cannot be attained with TAE. Complete embolization of isolated sinus DAVFs by TAE can typically be achieved without delay.

Keywords Dural arteriovenous fistula · Isolated sinus · Cortical venous drainage · Embolization · Technique

Abbreviations

DAVF	Dural arteriovenous fistula
DSA	Digital subtraction angiography
IQR	Interquartile range
MMA	Middle meningeal artery
MRA	Magnetic resonance angiography
mRS	Modified Ranking score
OA	Occipital artery
TAE	Transarterial embolization
TVE	Transvenous embolization

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Introduction

Intracranial dural arteriovenous fistulas (DAVFs) represent anomalous connections between the dural or pial arteries and the dural venous sinus or cortical veins. These fistulas constitute approximately 10% to 15% of all intracranial vascular malformations [7]. The manifestation and prognosis of DAVFs vary significantly based on the location of the fistula and the venous drainage pattern [5, 7, 19]. DAVFs exhibiting cortical venous drainage are aggressive lesions associated with an elevated annual risk of future hemorrhage [29, 33]. Isolated DAVFs refer to fistulas positioned between a meningeal artery and an isolated segment of a dural venous sinus, and they uniformly involve cortical venous drainage [5, 14].

Following the Borden [5] and Cognard [7] classification, isolated sinus DAVFs fall into Borden type III or Cognard

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type IIb/III/IV/V [3, 23, 34]. Notably, in these DAVFs, the isolated sinus is non-functional and can be entirely closed. However, individualized treatment strategies may be dictated by the angioarchitecture of isolated sinus DAVFs [9, 11–14, 17, 18, 20, 24, 28, 30, 34]. Treatment options predominantly encompass trans-arterial embolization (TAE), transvenous embolization (TVE), open "burr-hole" assisted TVE, and surgery [9–14, 16, 20, 24, 30]. Despite this, various treatment strategies have been reported in numerous case studies [9, 11, 13, 17, 30]. Only a handful of comprehensive retrospective studies have scrutinized the effectiveness of distinct treatment modalities for isolated sinus DAVFs [10, 14, 16, 20]. In 2011, Lekkhong et al. employed an endovascular transvenous reopening technique, deploying coils and/or glue in 10 patients with an isolated venous sinus segment [20]. In 2016, Kim et al. documented transarterial Onyx embolization of an isolated dural sinus segment fistula treated with balloon catheter assistance, resulting in a substantial increase in the rate of immediate complete occlusion [16]. In 2022, Hendriks et al. proposed a standardized treatment model for isolated sinus DAVFs after treating 20 patients with TAE, TVE, open burr-hole TVE, and surgery [14]. Fujita et al. recently explored differences between ipsilateral and contralateral transvenous approaches in 18 patients with isolated sinus DAVFs [10].

Previous studies have typically concentrated on singular treatment strategies with limited sample sizes. In this report, we present a relatively extensive single-center experience in treating isolated sinus DAVFs.

Methods

Study design

This retrospective study examined a consecutive series of patients with isolated sinus DAVFs who underwent treatment at a single institution. A total of 44 patients with isolated DAVFs underwent treatment at our hospital from 2002 to 2022. Approval for this study was obtained from the ethics committee of our hospital, and adherence to the STROBE guidelines was ensured [35].

Data collection and definition

Clinical data, encompassing medical records, operative reports, and angiographic data, were systematically collected. Parameters such as age, gender, clinical presentation, angiographic findings, treatment techniques, angiographic and clinical outcomes, and complications were thoroughly reviewed. Follow-up included admission, outpatient visits, and telephone consultations. Most patients were contacted by telephone to ascertain their status post-treatment. Radiological follow-up involved magnetic resonance angiography (MRA) and digital subtraction angiography (DSA). The modified Rankin Scale (mRS) score was utilized for assessing patients during preoperative, postoperative, and follow-up periods.

An isolated sinus refers to a dural venous sinus entirely occluded on both sides of the arterialized segment. Complete occlusion is defined as the absence of visualization of the isolated sinus or shunted cortical vein in the delayed venous phase on the completion angiogram.

Treatment options

The available treatment modalities were: (1) TAE alone, with or without balloon- or coil assistance; (2) TVE alone; (3) Open burr-hole TVE; (4) Open surgery.

Achieving cure through TAE to close the fistulous point using an embolic agent is more readily accomplished when there is direct cortical venous drainage (Cognard III-IV) compared to direct sinus drainage (Cognard I-II). Isolated sinus DAVFs, which are characterized by a non-functional sinus, follow treatment strategies similar to high-grade DAVFs, involving the closure of the isolated sinus and drainage veins. In our center, TAE is typically the initial choice, provided there is suitable arterial access such as a large and straight posterior branch of the middle meningeal artery (MMA) or transosseous branches of the occipital artery (OA), and no dangerous anastomoses. The transvenous approach may lead to perforation of healthy veins during navigation to the isolated segment of the sinus, potentially requiring craniectomy. Open burr-hole TVE and surgery are both considerably more invasive. If multiple arterial routes fail to completely occlude isolated sinus DAVFs, TVE and surgery can serve as backup options.

Trans-arterial embolization

For TAE, the Marathon (Medtronic, USA) or Headway microcatheters (Microvention, USA) are positioned near the fistula as closely as possible to await Onyx casting (Fig. 1). The Magic (Balt, France) microcatheters with nBCA (Glubran2, Gem, Italy) are commonly employed in the same session as a corrective measure if angiography reveals residual opacification along the sinus after TAE with Onyx. In some instances, a dual-lumen balloon catheter (Scepter-C, Microvention, Tustin, California) or a Marathon microcatheter (Medtronic, USA) are positioned near the fistula to await Onyx casting before inserting an Echelon-10 microcatheter (Medtronic, USA) into the artery to perform coiling, a technique known as the "Pressure cooker technique" (PCT) [4, 6]. The PCT involves inserting a coil and glue plug between the tip and detachment zone of a pre-positioned DMSO-compatible microcatheter. This technique aims to allow for

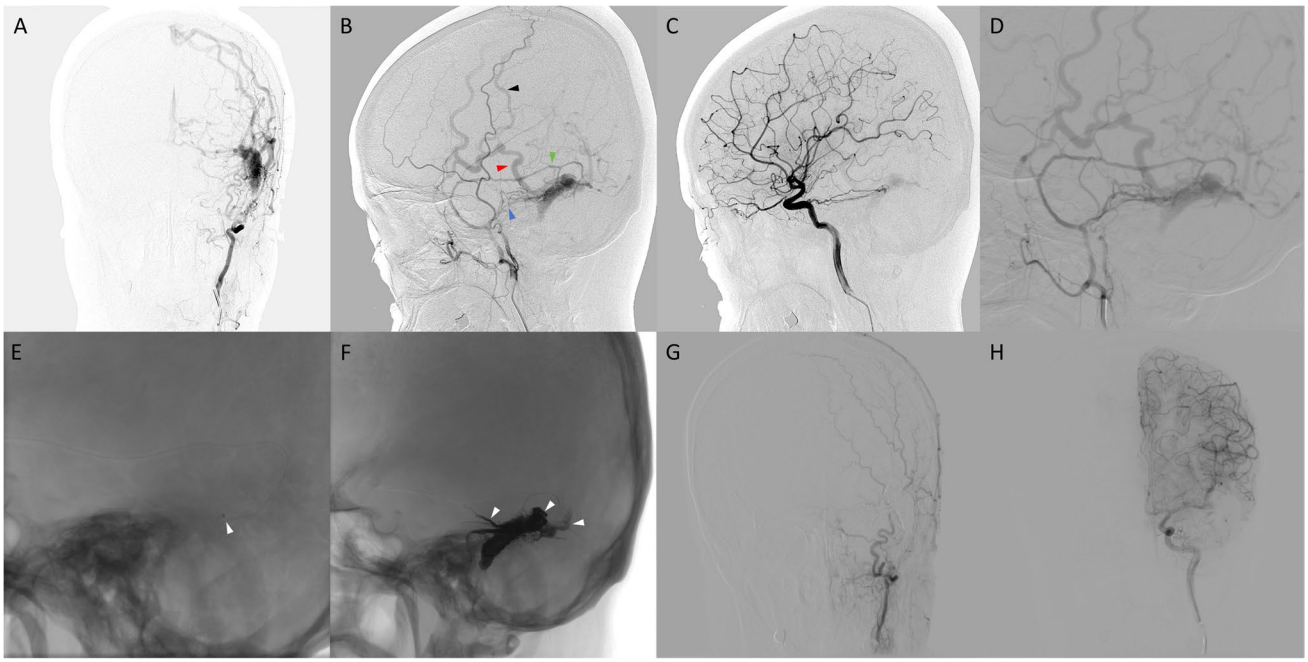

Fig. 1 A woman in her 50 s with a headache. **A**-**C** Angiography reveals a left isolated transverse sinus dural arteriovenous fistula, supplied by the left meningohypophyseal trunk, petrous (B, blue arrow), posterior branch (B, green arrow) of the left middle meningeal artery, multiple transosseous branches of the left occipital artery, draining to the vein of Labbé (B, red arrow), and the vein of Trolard (black arrow). **E**, **F** The Headway microcatheter tip is positioned near the fistulous point via the posterior branch of the middle meningeal artery (E, white arrowhead). Note the Onyx cast in the isolated sinus, extending into cortical veins (F, white arrowheads). **G**, **H** No recurrence is observed 7 months after complete embolization

continuous injections of Onyx while preventing reflux [6]. The dual-lumen balloon microcatheters are used to precisely select the main branch responsible for the fistulous connections. After positioning the balloon in the desired location, the wire is removed and the balloon inflated, creating a temporary plug. The lesion is then completely occluded with Onyx injections. This method can also be considered a modification of the pressure cooker method (Fig. 2) [4, 8].

Transvenous embolization

The reopening procedure involves positioning a 5 or 6 French guiding catheter proximate to the obstructed section of the dural venous sinus. This facilitates the creation of a pathway for advancing a microcatheter through the thrombosed segment and into the isolated sinus segment. An Echelon microcatheter, for instance, can be employed for this purpose.

Open burr-hole transvenous embolization

For open burr-hole TVE, direct access to the dural venous sinus is achieved through a surgically created burr hole, utilizing a 3 or 4 Fr vascular sheath with a Marathon, Headway, or Echelon 10 (Medtronic, USA) microcatheter.

Surgery

The retrosigmoid approach is utilized to ligate the drainage vein.

Statistical analysis

Continuous variables were presented as mean and standard deviation, while categorical variables were expressed as frequency and percentages.

Results

Patient and DAVF baseline characteristics

Between 2002 and 2022, our institution treated 44 patients with isolated sinus DAVFs. The patients had an average age of 52.0 ± 15.5 years (range, 16–83), with 70.5% (31/44) being male. Intracranial hemorrhage was observed in ten patients (22.7%, 10/44). Headache was the most prevalent symptom (47.7%, 21/44), followed by dizziness (34.1%, 15/44), seizures (13.6%, 6/44), tinnitus (13.6%, 6/44), ocular symptoms (13.6%, 6/44), aphasia (11.4%, 5/44), functional decline in limbs (11.4%, 5/44), venous hypertensive

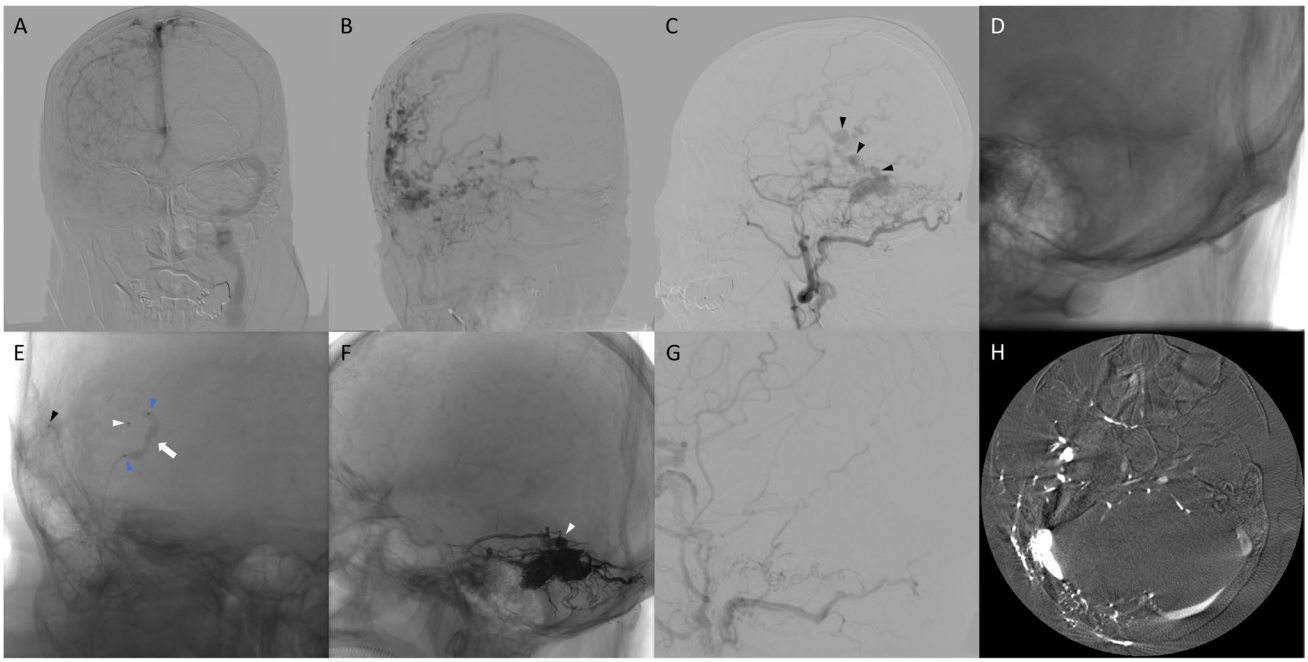

Fig. 2 An octogenarian with visual blurring and papilledema. **A**-**C** Anteroposterior and lateral angiography reveals a right isolated transverse sinus dural arteriovenous fistula, supplied by multiple branches of the left middle meningeal artery and occipital artery, with drainage to temporal cortical veins. Multiple varices are noted in the drainage vein (black arrows). **D**-**F** Transarterial embolization is performed via the posterior branch of the middle meningeal artery and the occipital artery. A scepter C balloon microcatheter is threaded through a transosseous branch of the right occipital artery (E, white arrow), another microcatheter tip is positioned in the right posterior branch of the middle meningeal artery close to the fistula, and Onyx is cast in the isolated sinus, arterial feeders, and extension of the drainage vein (F, white arrow). The inflated balloon acts as a temporary plug, preventing Onyx reflux and allowing more Onyx to pass through the feeders and fistula. **G**, **H** Final angiogram and 3DCT show complete occlusion of the fistula and isolated transverse sinus

myelopathy (9.1%, 4/44), and dementia (9.1%, 4/44). One patient was asymptomatic (2.3%, 1/44). The median mRS score at presentation was 2 (IQR 1 to 3).

Four patients (9.1%, 4/44) presented with multiple DAVFs. In 36 patients (81.8%, 36/44), isolated sinus DAVFs were located in the sigmoid/transverse sinus, with 27 (75.0%, 27/36) on the left. Eight patients (18.2%, 8/44) had an isolated DAVF of the superior sagittal sinus. 41 patients (93.2%, 41/44) had multiple feeders. The MMA was the most common arterial feeder (88.6%, 39/44), followed by the OA (84.1%, 37/44), the ascending pharyngeal artery (25.0%, 11/44), the posterior meningeal artery (18.2%, 8/44), the meningohypophyseal trunk (15.9%, 7/44), the posterior auricular artery (11.4%, 5/44), the superficial temporal artery (9.1%, 4/44), and the posterior cerebral artery (2.3%, 1/44). Venous drainage in all cases was categorized as Borden type III due to the complete occlusion of the dural venous sinus on both sides of the arterialized sinus segment, resulting in cortical venous drainage and the absence of normal cerebral venous drainage in the involved segment [5]. Isolated sinus DAVFs with perimedullary venous drainage were classified as Cognard type V [7]. The detailed baseline characteristics of the 44 treated patients with isolated DAVFs are summarized in Table 1.

Treatment options and outcomes

The predominant treatment options encompassed TAE alone (81.8%, 36/44), TVE alone (9.1%, 4/44), open burrhole TVE (6.8%, 3/44), and surgery (2.3%, 1/44). Transarterial approaches involved the utilization of Onyx, nBCA, Onyx with coil, or balloon-assisted embolization. Transvenous approaches utilized Onyx, nBCA, and coil. Notably, six patients (13.6%, 6/44) were referred to our institution for endovascular therapy after partial embolization in other facilities.

In total, 44 patients underwent treatment in 53 procedures. Thirty-seven patients received TAE in 45 procedures. Immediate complete occlusion was achieved in 29 out of 37 cases (78.4%, 29/37). Four patients underwent a second TAE, resulting in complete fistula occlusion. Two patients underwent a second and third TAE, also achieving complete occlusion. One patient, unsuccessfully treated with trans-arterial Onyx embolization via the OA, subsequently underwent successful surgery. Another patient declined further treatment after incomplete embolization with Onyx via the posterior meningeal artery. The overall complete occlusion rate for TAE was 97.3% (36/37).

Table 1 Baseline characteristics of 44 patients with isolated sinus dural arteriovenous fistulas

Variables	*N*(%)
Sex, *n*	44
Male/Female	31/13
Age,mean(SD,years)	52.0 ± 15.5
Presentation[1]	44
Hemorrhage	10(22.7)
Headache	21(47.7)
Dizziness	15(34.1)
Seizures	6(13.6)
Tinnitus	6(13.6)
Ocular symptoms	6(13.6)
Aphasia	5(11.4)
Functional decline in limbs	5(11.4)
VHM	4(9.1)
Dimentia	4(9.1)
Incidental	1(2.3)
Previous treatment[2]	6(13.6)
Treatment modalities	44
TAE alone	36(81.8)
TVE alone	4(9.1)
Open burr-hole TVE	3(6.8)
TAE failed → Surgery	1(2.3)
DAVF side	44
Left side	27(61.4)
Right side	9(20.5)
Midline	8(18.2)
Location	44
Transverse sinus	19(43.2)
Transverse-sigmoid junction	7(15.9)
Sigmoid sinus	10(22.7)
Superior saggital sinus	8(18.2)
Mid 1/3	5(62.5)
Post 1/3	3(37.5)
Number of feeders	44
One	3(6.8)
Multiple	41(93.2)
Arterial feeders[3]	44
Middle meningeal artery	39(88.6)
Occipital artery	37(84.1)
Ascending pharyngeal artery	11(25.0)
Posterior meningeal artery	8(18.2)
Meningohypophyseal trunk	7(15.9)
Posterior auricular artery	5(11.4)
Superficial temporal artery	4(9.1)
Posterior cerebral artery	1(2.3)
Venous Drainage[4]	44
Temporal/occipital cortical vein	29(65.9)
Superior petrosal sinus-petrosal vein	9(20.5)
Frontal/parietal cortical vein	8(18.2)
Perimedullary venous system	5(11.4)
Cognard type	44
III	29(65.9)
IV	10(22.7)
V	5(11.4)
Varix of drainage vein	10(22.7)
mRS ≥ 2[5]	
preoperative	31(73.8)
follow-up	6(14.3)
Follow-up period(months,median,IQR)[5]	64.5(31.5–111.0)

DAVF dural arteriovenous fistula, *IQR* interquartile range, *mRS* modified ranking scale, *SD* standard deviation, *SSS* superior saggital sinus, *TAE* trans-arterial embolization, *TVE* transvenous embolization, *VHM* venous hypertensive myelopathy

[1]Various symptoms may be present in one patient

[2]After partial embolization in other hospitals, six patients were admitted to our hospital

[3]One DAVF might have multiple arterial feeders

[4]There might be several drainage veins in a DAVF

[5]Based on 42 (42/44,95.5%) patients who were either admitted, outpatients, or telephoned for follow-up

Four patients underwent TVE alone in four procedures. In three patients (75%, 3/4), the fistula was completely obliterated in the first attempt. The patient who experienced incomplete embolization declined further treatment but remained stable during a 10-year follow-up with MRA.

Three patients underwent open burr-hole TVE in three procedures. Immediate complete occlusion was achieved in two patients (66.7%, 2/3). The patient with failed complete embolization remained stable during a 15-year follow-up via telephone.

Overall, 41 patients achieved a cure either immediately or on DSA follow-up (93.2%, 41/44) with a median follow-up period of 7 months (IQR 6.0 to 11.0).

Trans-arterial embolization

The MMA served as the primary arterial access in 32 out of 45 procedures (71.1%, 32/45). Complete occlusion was achieved in 27 procedures. However, in five procedures using Onyx via the MMA, direct complete closure of the fistula was not achieved. The PCT involving balloon-assisted or coil assistance was employed in four procedures, resulting in complete occlusion of the fistulas.

TAE via OA was conducted in 11 procedures, with complete occlusion attained in eight procedures. The PCT was utilized in five procedures via the OA, resulting in complete occlusion of the fistulas. Attempts at embolization via the posterior meningeal artery in two procedures were unsuccessful.

Onyx without PCT achieved success in 26 out of 34 procedures, while nBCA was successful in one out of three procedures.

Transvenous embolization

Endovascular TVE proved successful in three out of four procedures. In one case, near-complete occlusion was achieved using coils and nBCA before the availability of Onyx, and the patient remained stable.

Open burr-hole transvenous embolization

Due to the absence of suitable arterial access and the failure of the transvenous reopening technique, open burr-hole TVE was employed in three cases. Near-complete occlusion (residual opacification along the sinus) was achieved in one case using coils and Onyx, and the patient remained stable without imaging follow-up.

Complications

One major complication was identified, involving the perforation of a venous pedicle during an ipsilateral transvenous approach through the internal jugular vein to the sigmoid sinus. Timely coil embolization averted hemorrhage. Upon one-year follow-up after treatment, the mRS score was 0.

Follow-up

Out of the 44 patients, 42 (95.5%, 42/44) underwent follow-up either as inpatients, outpatients, or through telephone consultations. After complete embolization, 4 patients (9.5%, 4/42) reported exacerbated symptoms, but none experienced fistula recurrence. Four years post-treatment, one patient's mRS was 4 (pre-treatment mRS = 3). MRA or DSA follow-up was conducted for 32 patients (72.7%, 32/44), with 21 (65.6%, 21/32) having DSA follow-up. The follow-up periods for DSA and MRA (months, median, IQR) were 7.0 (6.0–11.0) and 12.0 (7.0–22.5) months, respectively. Three patients who did not undergo complete embolization were followed up, and all remain stable (follow-up periods: 21, 15, and 8 years after treatment). Two patients (9.5%, 2/21) underwent re-treatment due to fistula recurrence 8 and 11 months after complete occlusion. The fistulas were located in the transverse sinus and the superior sagittal sinus. Balloon-assisted Onyx embolization via the occipital artery and open burr-hole TVE with Onyx were performed, respectively, to achieve complete occlusion. One of the patients is illustrated in Fig. 3A-G.

The detailed characteristics and outcomes of each treatment modality for the 44 isolated DAVFs are summarized in Table 2.

Discussion

Treatment outcomes

According to the literature, managing isolated sinus DAVFs typically involved different treatment approaches for achieving complete occlusion. However, in our center, the majority were successfully occluded with TAE. Immediate complete occlusion was achieved in 41 isolated sinus DAVFs (93.2%, 41/44). TAE was the primary treatment modality for most cases (81.8%, 36/44), with a high cure rate (97.2%, 35/36). The outcomes of TAE with Onyx were favorable (76.5% success rate), while TAE with nBCA showed less ideal results (33.3% success rate). nBCA was typically employed as a corrective measure in the same session if angiography revealed residual opacification along the sinus after TAE with Onyx. The utilization of the PCT significantly increased the rate of immediate complete embolization (100% vs. 76.5%). TVE demonstrated success with coils and Onyx (100%, 3/3) but not with nBCA. The open burr hole approach and surgery, used as backup, achieved immediate complete occlusion in 75% of cases (3/4). One major complication (venous perforation) occurred during TVE (2.3%, 1/44). Two fistulas recurred on follow-up DSA (9.5%, 2/21).

There have been small case series on isolated sinus DAVFs with various treatment approaches [9–14, 16, 17, 20, 24, 30]. Only a few relatively large cohort studies have been reported [11, 14, 16, 28]. According to Hendriks et al. [14] their TAE results showed that MMA embolization was successful in 6 out of 9 procedures (66.7%, 6/9), and complete occlusion was achieved in 77.8% of cases (7/9). Their endovascular TVE proved successful in 6 out of 9 procedures (66.7%, 6/9), with complete occlusion achieved in 6 out of 8 cases (75%). Open surgical skeletonization was performed successfully in one patient (100%), and an open burr-hole transvenous approach in three patients (100%). Spontaneous thrombosis occurred in 2 cases on follow-up DSA. Eighteen isolated sinus DAVFs (90%, 18/20) were immediately completely occluded. When performing TVE, one major complication (cerebellar hematoma) occurred (5%, 1/20). No recurrence of the fistulas has been reported. In comparison to their study, our findings show that TAE has better outcomes (97.2% vs. 77.8%), a lower complication rate, and more than twice as many cases as their study.

Lekkhong et al. demonstrated the successful application of a transvenous reopening technique in 10 patients with isolated sinus DAVFs [20]. Fujita et al. reported on 18 isolated sinus DAVFs treated with TVE using either an ipsilateral or contralateral approach, achieving a 94% complete obliteration rate, a 5.6% recurrence rate, and a 5.6% complication rate (hemorrhage) [10]. Although the

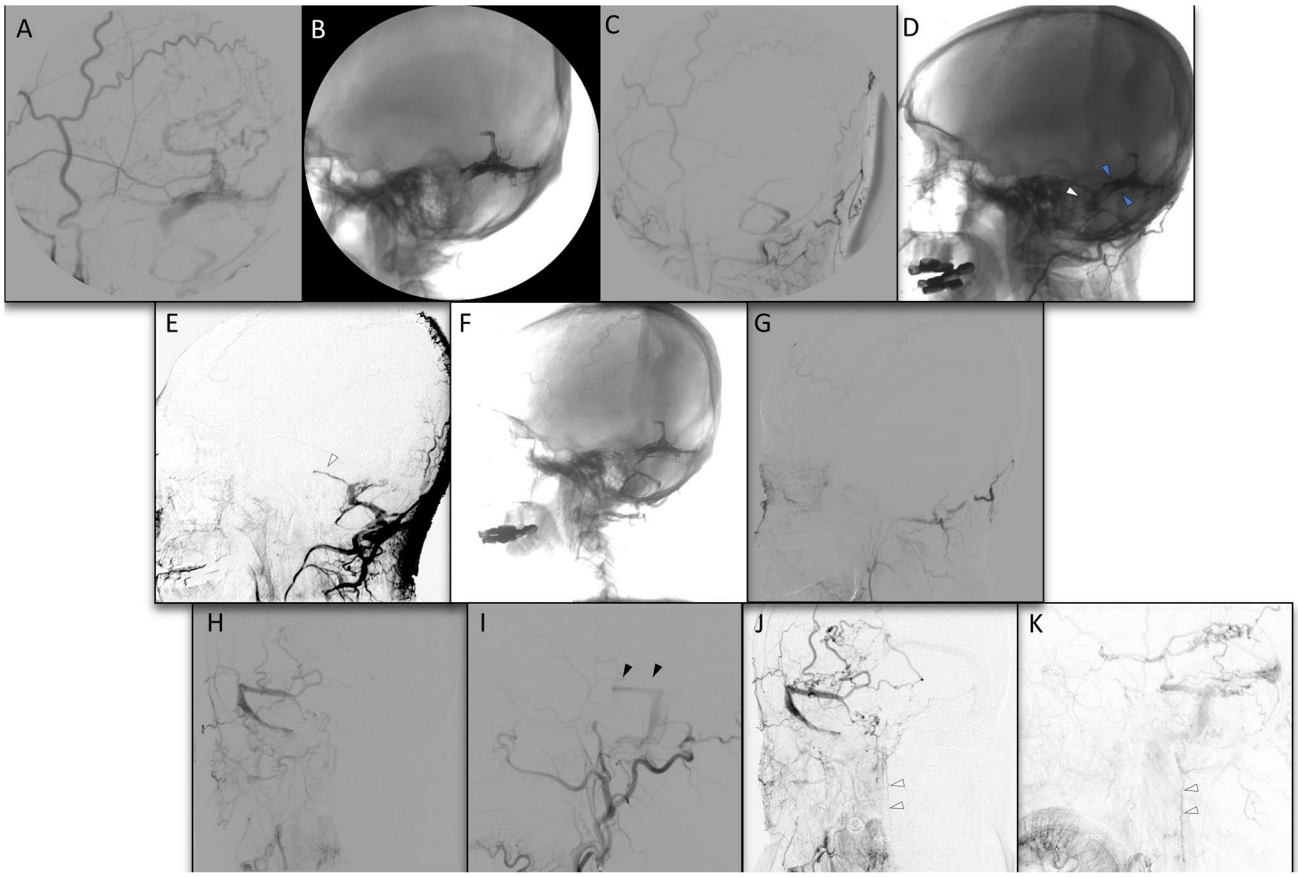

Fig. 3 A patient in his 40 s with headache, tinnitus, and visual blurring (**A**-**G**), and another patient in his 60 s with dizziness (**H**–**K**). **A**-**C** Onyx achieved complete occlusion via the middle meningeal artery. **D**-**E** Lateral view of the right occipital artery injection 11 months post-complete embolization reveals fistula recurrence. The fistula (D, white arrowhead) is adjacent to the Onyx cast (D, blue arrowheads). Cortical venous reflux is evident (E, white arrowhead). **F**-**G** Balloon-assisted transarterial embolization through the occipital artery is performed, resulting in complete occlusion. **H**-**I** Injection of the right external carotid artery reveals a Cognard type V isolated sigmoid sinus dural arteriovenous fistula draining into the superior petrosal sinus (I, black arrowheads), superior petrosal vein, and ultimately the perimedullary venous system (J, K, white arrows)

use of TVE in our study was limited and resulted in a 75% success rate (excluding one case treated before the Onyx era), the success rate could potentially be 100%.

Endo et al. gained access to the isolated sinus in 8 patients through a burr-hole craniotomy, followed by direct puncture and sinus packing [9]. In one of our cases, open burr-hole TVE with coils and Onyx led to near-complete embolization (residual opacification along the sinus). This patient did not undergo DSA follow-up, but clinical symptoms remained stable. The fistula might have closed spontaneously after the formation of a subsequent thrombus. Compared with "burr-hole" assisted TVE or surgery, endovascular treatment is less invasive and has become the preferred approach nowadays.

Angioarchitecture

DAVFs located at the transverse sinus/sigmoid sinus and superior sagittal sinus can receive supply from the MMA (posterior branch/petrous branch), the OA (transosseous branch), the ascending pharyngeal artery (jugular and hypoglossal branches), the posterior meningeal artery, the posterior auricular artery, the superficial temporal artery, the tentorial branches of the meningohypophyseal trunk, the posterior inferior cerebellar artery, the anterior inferior cerebellar artery, pial branches of the anterior and middle cerebral artery, and others [15, 36]. Because the isolated sinus has both a proximal and distal segment occluded, the venous drainage primarily involves the superior petrosal sinus, the vein of Labbé, the vein of Trolard, and the cortical and deep

Table 2 Results of treatment modalities

Variables	*N*(%)	
Fistulas	44	
Complete occlusion	41(93.2)	
TAE alone	35(85.4)	
MMA alone	25(71.4)	
OA alone	5(14.3)	
MMA → OA	2(5.7)	
OA → MMA	1(2.9)	
OA → MMA → OA	1(2.9)	
PMA → MMA	1(2.9)	
TVE alone	3(7.3)	
Open burr-hole TVE	2(4.9)	
TAE failed → Surgery	1(2.3)	
OA	1(100)	
Near-complete occlusion	2(4.5)	
Open burr-hole TVE	1(50.0)	
TVE alone	1(50.0)	
Incomplete occlusion	1(2.3)	
TAE alone	1(100)	
PMA	1(100)	
Procedures	53	Complete occlusion (according to procedures)[1]
TAE	45(84.9)	35(77.8)
MMA	32(71.1)	27(84.3)
Onyx	28(87.5)	23(82.1)
Balloon-assisted Onyx	3(9.4)	3(100)
nBCA	1(3.1)	1(100)
OA	11(24.4)	8(72.7)
Onyx	5(45.5)	3(60.0)
Balloon-assisted Onyx	3(27.3)	3(100)
nBCA	1(9.1)	0
Onyx + Coil	1(9.1)	1(100)
Onyx + Coil + nBCA	1(9.1)	1(100)
PMA	2(4.4)	0
Onyx	1(50)	0
nBCA	1(50)	0
TVE	4(7.5)	3(75.0)
Onyx + Coil	3(75.0)	3(100)
nBCA + Coil	1(25.0)	0
Open burr-hole TVE	3(5.7)	2(66.7)
Onyx + Coil	1(33.3)	0
Onyx + Coil + nBCA	2(66.7)	2(100)
Surgery	1(1.9)	1(100)
Follow-up imaging[2]	32(72.7)	
DSA	21(65.6)	
Follow-up period(months,median,IQR)	7.0(6.0–11.0)	
MRA	13(40.6)	
Follow-up period(months,median,IQR)	12.0(7.0–22.5)	
Recurrence[3]	2(9.5)	
Clinical outcome[4]	42(95.5)	
Asymptomatic	22(52.4)	

Table 2 (continued)

Symptoms persisted but improved	16(38.1)
Symptoms worsening	4(9.5)
Complications[5]	1(2.3)

DSA digital subtraction angiography, *MMA* middle meningeal artery, *MRA* magnetic resonance angiography, *OA* occipital artery, *PMA* posterior meningeal artery, *TAE* trans-arterial embolization, *TVE* transvenous embolization

[1]Based on 53 procedures

[2]Based on 32 (32/44, 75.0%) patients who had DSA or MRA follow-up. Two of the patients had both DSA and MRA at different times. Two of the patients had DSA re-examinations twice

[3]Based on 21 patients with DSA follow-up

[4]Based on 42 (42/44,95.5%) patients who were either admitted, outpatients, or telephoned for follow-up

[5]Based on 44 patients who received treatment at our facility

medullary veins surrounding the sinus. There is a possibility of brainstem and spinal vein drainage occurring through the superior petrosal sinus and petrosal vein (Fig. 3H-K) [23, 27, 34].

It's noteworthy that isolated sigmoid/transverse sinus DAVFs are predominantly located on the left side (75% vs. 25% in our study) [14]. This aligns with the left-side tendency of a hypoplastic transverse sinus, which is more susceptible to sinus stenosis and thrombosis [21, 25].

Due to the occlusion of the isolated sinuses on both sides, this type of DAVF can only drain into the cortical veins surrounding the venous sinuses. This leads to high pressure in the cortical veins, resulting in hemorrhage, brain edema, intracranial venous hypertension, among other complications. Consequently, the majority of cases of this type of DAVF present with symptoms (97.7%), and immediate treatment initiation is warranted upon discovery.

There may be disagreement regarding the Cognard classification of isolated sinus DAVFs. Isolated sinus DAVFs are unquestionably classified as Borden Type III, as defined in the original Borden article [5]. However, some literature categorizes them into Cognard types IIb [32], IIa + b, III [22], or IV [3, 16]. Cognard type V isolated sinus DAVFs also exist and have been previously described [2, 23, 31, 34]. They are undoubtedly aggressive lesions that necessitate prompt treatment upon discovery, irrespective of the classification method used.

Endovascular techniques

An isolated DAVF differs from a typical lateral sinus or superior sagittal sinus DAVF in that the trapped sinus segment can be safely sacrificed without concern for the surrounding brain drainage. This is attributed to the brain's inability to utilize it for normal drainage. The use of balloon sinus protection or adjunct sinus stenting during embolization was considered unnecessary. Even if the sinus channel is preserved, the remaining sinus in an isolated sinus DAVF will eventually lose its function due to the lack of blood flow, as compensatory venous drainage pathways are already in place. The treatment goal is to completely occlude the isolated segment, mirroring the objective of treating high-grade DAVFs (Cognard type III/IV), which involves closing off the fistulas and drainage veins.

Trans-arterial Onyx embolization using a dual-lumen balloon catheter or coil (pressure cooker) minimizes reflux and allows for the antegrade flow of Onyx to the fistulous point and drainage vein [4, 14, 16]. In our center, TAE is always attempted as long as there is suitable arterial access and the ability to avoid dangerous anastomoses. A notable 97.2% (35/36) of the fistulas can be cured by TAE without complications. TVE is typically suitable for DAVFs without appropriate arterial access (too thin or tortuous; dangerous anastomoses) or arterial feeders dispersed throughout the sinus and separated from each other. However, during navigation towards the isolated sinus, veins may be perforated, necessitating craniectomy. In our study, we encountered a situation where a venous pedicle was accidentally punctured while using an ipsilateral transvenous approach via the internal jugular vein to reach the sigmoid sinus. Fortunately, prompt coil embolization effectively prevented any bleeding. If both TAE and TVE fail, open burr-hole TVE or surgery will be chosen as a backup.

Follow-up

In this study, complete occlusion is defined as the absence of any visual representation of the isolated sinus or shunted cortical vein on the completion angiogram during the delayed venous phase. However, Onyx may have only been angiographically "silent," potentially due to a significant slowing of flow through the fistula rather than an actual cure [1]. A follow-up angiogram conducted 3–6 months later would be better suited to differentiate between a genuine cure and an initial angiographic occlusion. The two recurring cases could possibly be attributed to the aforementioned reasons (Fig. 3A-G). Because Onyx is not exceptionally prothrombotic (unlike nBCA), any remaining channels through the fistula may serve

to recruit additional arterial supply, resulting in the perceived recurrence of an initially angiographically occult fistula [26]. Therefore, during embolization, it is necessary to occlude the venous sinus cavity as tightly as possible and a short segment of the draining vein.

Study limitations

This study is subject to certain constraints as it is a retrospective, single-center investigation. Limitations include self-report bias and the absence of core laboratory adjudication. Follow-up with DSA was conducted for only 21 cases (47.7%, 21/44), potentially impacting result accuracy. While MRA is a valuable diagnostic tool, it cannot entirely substitute for DSA in terms of sensitivity. Consequently, the recurrence rate of DAVFs might be underestimated not only in this study but also in similar ones [10, 14, 16]. There have been advancements in techniques and materials during the study, notably the introduction of the novel material "Onyx." As this is a single-center study, treatment outcomes heavily depend on the operators' experience and preferences, with our center's most proficient operators excelling at TAE. Therefore, the study's findings may not be generalizable to other centers.

Conclusion

This is the most extensive study on treating isolated sinus DAVFs. TAE proves effective in treating the majority of isolated sinus DAVFs, akin to most high-grade DAVFs (Cognard types III/IV). TVE and surgical intervention serve as alternative methods when suitable arterial access is unavailable or complete occlusion is unattainable with TAE. The majority of isolated sinus DAVFs can be promptly and entirely embolized through TAE.

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Data availability Data are available upon reasonable request.

Code availability Not applicable.

Declarations

Ethics approval This retrospective study involved human participants and was approved by Ethics Committee of Xuanwu Hospital, Capital Medical University [2017; 010].

Consent to participate Consent obtained from parent(s)/guardian(s).

Consent for publication Consent obtained from parent(s)/guardian(s).

Conflicts of interest None.

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