Turk Neurosurg, 2023

Original Investigation

DOI: 10.5137/1019-5149.JTN.40189-22.2

Received: 02.04.2022
Accepted: 21.06.2022

Published Online: 03.04.2023

Embolization of Cavernous Sinus Dural Arteriovenous Fistula with Liquid Materials Under Transarterial Balloon Protection

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ABSTRACT

AIM: To analyze the clinical and angiographic outcomes of interventional embolization under transarterial balloon protection technique in patients with cavernous sinus dural arteriovenous fistulas.

MATERIAL and METHODS: In a single-center cohort of 30 patients undergoing cavernous sinus dural arteriovenous fistulas embolization under balloon protection. We collected their clinical symptoms, complications, mid-term follow-up angiographic results, and long-term clinical outcomes for the baseline characteristics.

RESULTS: Thirty patients with 31 lesions were included in this study. Immediate applications of angiographies after embolization indicated that complete obliteration occurred in 29 lesions (93.5% of 31 lesions). Two cases with permanent trigeminal nerve palsy were treated by arterial approach. Onyx dispersed into the internal carotid artery in one process, and salvage stent implantation was performed to prevent parent artery occlusion.

CONCLUSION: Interventional embolization with intra-arterial balloon protection is effective and safe with rarely occurring complications.

KEYWORDS: Cavernous sinus dural arteriovenous fistula, Intra-arterial balloon protection, Obliteration rate, Complications

INTRODUCTION

Cavernous sinus dural arteriovenous fistulas (CSDAVFs) are pathological arteriovenous shunts that extend into the cavernous sinus from dural branches of the external carotid artery (ECA) or internal carotid artery (ICA). On a global scale, the prevalence of CSDAVFs represents about 35% of all incidences of dural arteriovenous fistulas (4,13). With the development of materials and anatomy, interventional embolization has become the preferred treatment of CSDAVF (16,20). The interventional embolization under intra-arterial balloon protection in ICA was only reported as an effective and safe option for the treatment of direct carotid-cavernous fistulas (DCCF) (8,21) rarely reported in CSDAVFs. Thus, in this study, we collected patients' clinical and angiographic data to elucidate the effectiveness and safety of this technique used for the treatment of CSDAVFs.

MATERIAL and METHODS

Patients Selection and Clinical Data Collection

During 20 years, 122 patients with DAVFs involving cavernous sinus were admitted to our institution and diagnosed with CSDAVFs between January 1999 and December 2019. We reviewed these patients' clinical and angiographic data

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according to our hospital's approval by the Institutional Review Board and Ethics Committee (Date: Aug 17, 2017, Number: 81771266). Thirty of these patients met the following criteria for this study: 1) symptomatic CSDAVFs, 2) fistulas involving cavernous sinus, 3) fistula feeding by branches of ICA including meningohypophyseal trunk, inferolateral trunk, capsular artery, or recurrent meningeal branch from the ophthalmic artery, 4) time of follow-up angiographic exceeded at least six months.

The baseline characteristics (like age and gender), clinical data (like clinical symptoms and complications), and postoperative angiography outcomes were obtained from the patients' clinical records. Clinical diagnoses are classified according to guidelines in Lee et al. (14). Symptomatic categories include orbital (chemosis, proptosis, periorbital pain, and eyelid swelling), cavernous (third, fourth, fifth, and sixth cranial nerve palsy), ocular (blurred vision, eyeball pain, glaucoma, retinal hemorrhage, and increase in intraocular pressure), cerebral (hemorrhage, infarction, and seizure) and other types (tinnitus, bruit, and headache). All patients were followed up on (outpatient or telephone follow-up review). Determinations of clinical outcome at the time that patients were discharged and at follow-ups at our hospital were classified and divided into distinctive characteristic categories of deteriorated, stable, improved, and completely recovered.

Angiographic Features

Senior neurosurgeons and interventional neuro-radiologists reviewed the DSA, CT, or MR images, and one of them was not involved in the treatment. Fistula classification, location, balloon-type, and intravascular approach were extracted from the angiographic image. The classification of CSDAVFs was based upon the classification systems and guidelines in both Barrow et al. and Borden et al. (2,3). Materials used for embolization included liquids such as NBCA, Onyx (ethylene vinyl alcohol copolymer; Medtronic, Irvine, California, USA), and coils. If multiple times of balloon occlusion were needed, the time of balloon occlusion in ICA was 5 minutes every time. Results immediately following angiographies were classified into complete or partial obliteration based on the final angiographic image. Complete obliteration was characterized as the absence of venous drainage during the arterial phase in the angiography, and partial obliteration as the presence of venous drainage.

Endovascular Procedure

All procedures were performed under general anesthesia. Intravenous heparin (1000 U every hour during the endovascular procedure) was regularly administered to the patients after the initial intravenous heparin (5000 U) bolus. The transvenous approach via the common femoral vein was performed as the preferred treatment. After complete angiography evaluation, including bilateral ECA, ICA, and vertebral artery, a 6F guiding catheter was positioned in the ascending petrous portion of the ICA to allow shunt observation, acquisition of roadmaps, and angiographic monitoring. The balloon was then navigated into the ICA at the leading site of the fistula. Another 6F guiding catheter was positioned to the internal jugular or facial vein via the femoral vein. A microcatheter was navigated into the cavernous sinus through a transvenous approach which was applied via the posterior petrosal sinuses or ophthalmic vein. For cases with an unsuccessful transvenous approach, the microcatheter was navigated into the feeding artery through the 6F guiding catheter in ICA for Onyx injection by transarterial approach with transarterial balloon protection.

RESULTS

Clinical and Imaging Characters

Among the 30 patients, 21 were female and 9 were male, with an average age of 55 years (22-78 years). All patients were symptomatic. Among them, 24 (80%) had orbital symptoms, 11 (36.7%) had ocular symptoms, 9 (30%) had cavernous symptoms, and 7 (23.3%) had other symptoms.

Eighteen patients had left-sided lesions, twelve had right-sided lesions, and one had bilateral CSDAVF. Venous drainage patterns were classified according to the system described by Borden. 18 lesions were type I fistulas (58.1%), 10 type II fistulas (32.3%), and 3 type III fistulas (9.6%). Leptomeningeal venous drainage was present in 13 lesions (41.9%), and superior ophthalmic vein drainage was present in 23 lesions (74.2%). Twenty-four fistulas (77.4%) were supplied by branches of the ECA and ICA, and 7 (22.6%) were supplied by branches of bilateral ICA.

Immediate Postoperative Angiography

Sixteen lesions were treated with the arterial approach (51.6%, Table I), and fifteen with the venous approach (48.4%, Table II). Two types of balloons were used in these 31 procedures, including the Hyperform balloon (Medtronic, Irvine, CA, USA) (25.8%) and the Scepter balloon (MicroVention, Tustin, CA, USA) (74.2%), and the size was both 4 mm in diameter and 20 mm in length.

Complete obliteration of the fistulas after operation immediately was achieved in 28 patients with 29 lesions (93.5%). Complete obliteration of 2 patients was not achieved, but cortical venous reflux was eliminated at the completion of the procedure. In all processes, the navigation and dilation of the balloon were technically successful, and good preservation of the ICA was achieved in all cases. One patient in the group of transarterial approach suffered Onyx dispersion into ICA, and salvage stent implanted was performed for ICA preservation.

Imaging Follow up

During a mean duration in months of 11 ± 18 (range 6-102) radiological outcomes for all patients were characterized as having complete obliteration, and no patient showed deterioration of lesions during the follow-up period. The two patients with partial obliteration received angiographic follow-up after the operation, and follow-up angiography showed complete obliteration spontaneously in the two patients.

Clinical Follow-up

The primary symptoms of 23 patients improved immediately after treatment, 7 patients (orbital symptoms in N=5,

Table I: Clinical Features of 15 Patients with CSDAVFs Treated by Transarterial Approach Under Intra-Arterial Balloon Protection

No	Gender/ age	Presentation	Barrow	Borden	Drainage vein	Targeting vessel	Immediate result	Complication	Imaging follow-up		Clinical follow up		
									Duration	Result	Duration	Primary symptom	Complication
1	F/40	proptosis, chemosis	D	II	SOV, CV	Ipsilateral APA	near complete	Abducens nerve paralysis	8	complete	12	complete recovery	complete recovery
2	F/73	periorbital pain	D	III	CV	Ipsilateral MMA	complete	NA	102	complete	102	complete recovery	NA
3	F/76	proptosis, blurred vision	D	I	SOV	Ipsilateral APA	near complete	NA	6	complete	12	improved	NA
4	F/26	proptosis, bruits, tinnitus	B	I	SOV	Ipsilateral MMA	complete	NA	6	complete	59	complete recovery	NA
5	F/43	proptosis, chemosis	B	II	SOV, CV, IPS	Ipsilateral MMA	complete	NA	10	complete	12	improved	NA
6	M/66	proptosis, chemosis	D	I	SOV, IPS	Ipsilateral MMA	complete	NA	6	complete	52	complete recovery	NA
7	M/78	proptosis, chemosis, blurred vision, diplopia	D	II	SOV, CV	Ipsilateral MMA	complete	Oculomotor nerve paralysis	6	complete	48	improved	complete recovery
			B	II	SOV, CV	Ipsilateral MMA	complete	-	6	complete	-	-	-
8	F/22	proptosis, chemosis, diplopia	D	I	SOV	Ipsilateral FRA	complete	Trigeminal nerve involvement	6	complete	46	complete recovery	stable
9	F/64	proptosis, chemosis	D	II	SOV, CV	Ipsilateral MMA	complete	NA	6	complete	37	complete recovery	NA
10	F/41	chemosis, blurred vision	B	I	SOV, IPS	Ipsilateral APA	complete	NA	6	complete	35	complete recovery	NA
11	F/69	chemosis, diplopia	D	II	CV	Ipsilateral MMA	complete	Trigeminal nerve involvement	9	complete	27	complete recovery	complete recovery
12	F/51	proptosis, chemosis	D	II	SOV, CV, IPS	Ipsilateral RMA	complete	NA	7	complete	32	complete recovery	NA
13	M/39	chemosis, diplopia	D	I	SOV	Ipsilateral MMA	complete	Trigeminal nerve involvement	6	complete	18	complete recovery	stable
14	M/67	blurred vision	D	III	CV	Ipsilateral MMA	complete	NA	6	complete	18	improved	NA
15	M/3	proptosis, chemosis, periorbital pain, diplopia	D	I	SOV	Ipsilateral MMA	complete	NA	6	complete	12	improved	NA

SOV: *Superior ophthalmic vein,* ***CV:*** *Cortical vein,* ***IPS:*** *Inferior petrol sinus,* ***MMA:*** *Middle meningeal artery,* ***APA:*** *Ascending pharyngeal artery,* ***RMA:*** *Recurrent meningeal artery.*

Table II: Clinical Features of 15 Patients with CSDAVFs Treated by Transvenous Approach Under Intra-Arterial Balloon Protection

No	Gender/ age	Presentation	Barrow	Borden	Drainage vein	Target vessel	Immediate result	Complication	Imaging FU		Clinical FU		
									Duration	Result	Duration	Primary symptom	Complication
1	F/71	proptosis, diplopia	D	I	IPS	Ipsilateral IPS	complete	NA	6	complete	12	improved	NA
2	M/61	bruits	D	II	SOV, CV, IPS	Ipsilateral IPS	complete	NA	7	complete	12	complete recovery	NA
3	M/44	diplopia	D	I	CV	Ipsilateral IPS	complete	Oculomotor paralysis	6	complete	12	improved	complete recovery
4	F/74	diplopia	B	I	SOV	Ipsilateral IPS	complete	NA	6	complete	47	improved	NA
5	F/60	Orbital pain, blurred vision	D	I	IPS	Ipsilateral IPS	complete	Oculomotor paralysis	7	complete	44	improved	complete recovery
6	F/66	proptosis, periorbital pain, diplopia	D	I	SOV	Ipsilateral IPS	complete	NA	6	complete	42	complete recovery	NA
7	F/37	proptosis	D	II	CV, IPS	Ipsilateral SOV	complete	NA	42	complete	42	complete recovery	NA
8	F/39	chemosis, blurred vision, diplopia, bruits	D	I	SOV, IPS	Ipsilateral IPS	complete	NA	6	complete	12	improved	NA
9	F/54	chemosis, blurred vision, diplopia	D	I	IPS	Contralatera IPS	complete	Trigeminal nerve involvement	6	complete	12	improved	complete recovery
10	F/51	proptosis, chemosis, blurred vision	D	I	SOV, PV	Ipsilateral SOV	complete	NA	6	complete	19	complete recovery	NA
11	F/60	chemosis, blurred vision	B	I	SOV	Ipsilateral SOV	complete	NA	6	complete	17	complete recovery	NA
12	F/54	chemosis	D	II	SOV, CV, IPS	Ipsilateral IPS	complete	NA	16	complete	16	complete recovery	NA
13	F/70	chemosis, blurred vision	D	I	SOV, IPS	Ipsilateral IPS	complete	NA	6	complete	16	complete recovery	NA
14	M/41	diplopia	B	III	CV	Ipsilateral IPS	complete	NA	6	complete	16	improved	NA
15	F/50	proptosis, chemosis, periorbital pain,	D	I	SOV	Ipsilateral IPS	complete	NA	8	complete	13	complete recovery	NA

SOV: *Superior ophthalmic vein,* ***CV:*** *Cortical vein,* ***IPS:*** *Inferior petrol sinus,* ***MMA:*** *Middle meningeal artery,* ***APA:*** *Ascending pharyngeal artery,* ***RMA:*** *Recurrent meningeal artery,* ***PV:*** *Pterygoid vein.*

cavernous symptoms in N=1, and ocular symptoms in N=1) had results that indicated there was deterioration of the symptoms characterized during the perioperative period before discharge. However, all such patients were found to have improved by the time the last follow-up occurred. Across a mean duration time post-treatment of 28 ± 21 (range: 12 to 102) months, the results indicated that symptoms recovered entirely in 62.1% of patients and improved in 37.9% at the last follow-up period. The symptoms of diplopia (N=6) and visual disturbance (N=5) were hard to recover completely.

Complication

Cranial nerve palsy occurred in 8 patients after embolization of CSDAVF, including paralysis of the oculomotor nerve (3 cases, 10%), trigeminal nerve (4 cases, 13.3%), and abduct nerve (1 case, 3.3%). No patients experienced any balloon-related complications, such as vascular rupture, vascular dissection, or distal emboli. A concurrent neurological examination showed that 6 patients with cranial nerve palsy recovered completely. Both patients with permanent neurological deficits were treated through an arterial approach. No mortality occurred during or after endovascular treatment. Onyx dispersion into ICA occurred in 1 patient, and stent implantation was performed to cover Onyx to prevent ICA occlusion.

Illustrative Case

Case 13

This 51-year-old woman presented with severe proptosis and chemosis. (Figure 1) Cerebral angiography revealed a left CSDAVF fed by the middle meningeal artery and recurrent meningeal branch of the left ophthalmic artery. The fistula was drained into the sphenoparietal sinus with cortical venous reflux. The microcatheter was navigated into the recurrent meningeal branch of the left ophthalmic artery for Onyx injection. Onyx was injected to embolize the fistula under the protection of a Scepter balloon inflation in the ICA. However, Onyx dispersed into the ICA via the gap between the inflated balloon and the wall of the ICA. Angiography after the procedure showed complete obliteration of the fistula and no effect on the blood flow in the ICA by the Onyx. Stent implantation was performed to cover Onyx to prevent ICA occlusion in the future, and an antiplatelet agent (aspirin, 100mg/day) was administered after the procedure. The follow-up angiography after six months revealed complete obliteration of the fistula and ICA patency. The patient remained asymptomatic at the 32-month follow-up.

Case 25

The 51-year-old woman presented with proptosis, chemosis, and visual disturbance (Figure 2). Cerebral angiography revealed a left CSDAVF fed by accessory meningeal artery and meningohypophyseal trunk drained into the superior ophthalmic and pterygoid vein. A microcatheter was navigated into a superior ophthalmic vein through a facial vein for embolization. Coils and Onyx were used to emboli the fistula in the presence of a Scepter balloon inflated in the ICA. Angiography after the procedure showed complete obliteration of the fistula, and the follow-up angiography after six months revealed complete obliteration of the fistula. The primary symptom recovered completely at the 19-month follow-up.

DISCUSSION

In this study, we reported the results of a consecutive time-series experiment in which we treated CSDAVFs with liquid materials and evaluated the effectiveness and safety of the application of intra-arterial balloon protection. Complete obliteration was performed in all cases in our series in the follow-up without balloon-related complications. The main contributors of CSDAVF were from dural branches of the ICA trunk or ECA, and flow rates were lower in CSDAVF compared to CCF. CSDAVFs are also dangerous lesions that can cause intracranial hemorrhage, vision degradation, or other neurological deficit. Endovascular embolization through the venous approach has been the standard treatment for CSDAVFs owing to its safety and efficacy, but the transarterial approach was still the alterative selection (6,15). To CSDAVF feeding by branches of ICA, there is still a significant risk of liquid materials leaking into ICA (1).

To date, the literature has mainly described direct carotid-cavernous fistula assessment with balloon addition during embolization of cavernous sinus lesions (5,8,21,22). DCCF was analyzed according to the classifications established by Barrow et al. (2). They found that direct arteriovenous shunt between the ICA and the cavernous sinus, with noted characteristically larger fistulous orifices and significant flow rate. The technique was also reported by Zenteno et al. and Elhammady et al. (5,22) as a means to help increase microcatheter purchase and help avoid and reduce the levels of reflux of liquid materials into arterial circulation. Moreover, using the inflated balloon has been shown to be helpful in identifying the fistula's accurate location by successive microcatheter angiography runs with the temporary ICA occlusion (8). If Willis's circle is imperfect, using a balloon occlusion could lead to a transient ischemic attack or acute infarction (10). Prolonged balloon occlusion within internal carotid arteries during liquid material injection may induce hypoperfusion status, causing effects to become significantly worse and could result in acute infarction.

The obliteration rate of CSDAVF with embolization was found to vary from 80% to 100% using coils and NBCA and varied from 76.9% to 100% using coils and Onyx (11,12,17,18). Independent of the reported embolization strategies, the symptom improvement rate was found to vary from 70.0% to 94.1% (9,12,17,19). In our study, we observed fistula occlusion rates similar to those reported in the literature. Appropriate application of balloon protection in the ICA will allow the operator to inject liquid material more quickly, and temporary occlusion of the arteriovenous bag by balloon dilation will improve the ease and speed of dispersal of the liquid material into the fistula and other feeding arteries.

Similar to DCCF, the use of an inflated balloon occlusion can assist in helping to identify the accurate location of the fistula by microangiography in some cases with the application of a greater flow rate of injected liquid materials.

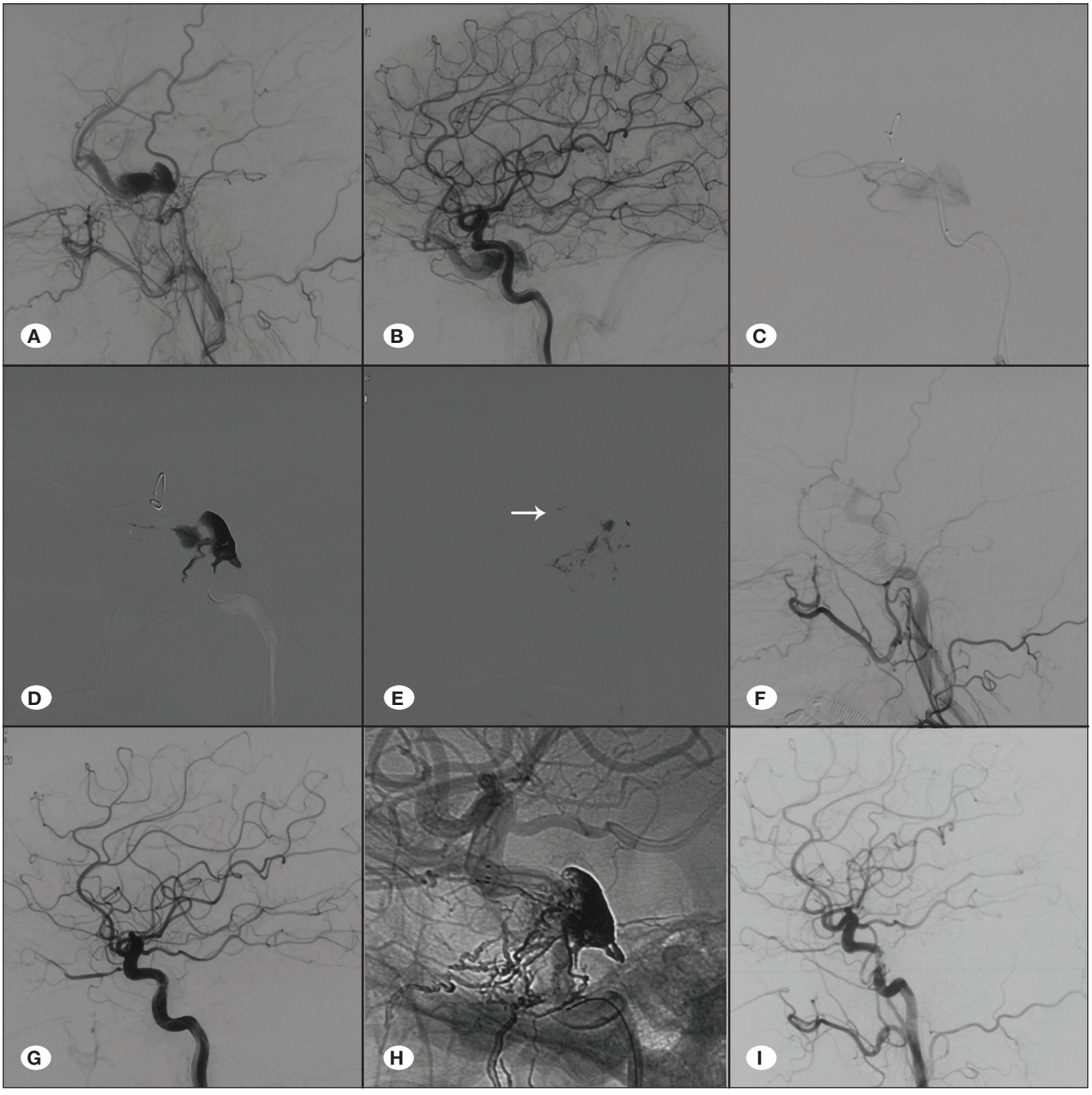

Figure 1: Illustration of a representative case with intra-arterial balloon protection of CSDAVF. **A, B)** Cerebral angiography showed a left CSDAVF fed by middle meningeal artery and recurrent meningeal branch of the left ophthalmic artery (Barrow D). The fistula was drained into the sphenoparietal sinus with cortical venous reflux (Borden II). **C)** Microcatheter was navigated into recurrent meningeal branch of the left ophthalmic artery. **D)** Onyx was injected to embolize the fistula in the presence of a Scepter balloon (Microvention, CA, USA) inflated in the ICA. **E)** Onyx dispersed into the ICA via the gap between inflated balloon and wall of ICA (white narrow). **F, G)** Complete obliteration of the fistula was achieved and the blood flow of ICA was not affect significantly by the Onyx. **H)** Stent implantation was performed to cover Onyx to prevent ICA occlusion. **I)** Seven months after the procedure, the patient underwent a follow-up angiography, which showed complete obliteration of fistula and ICA patency.

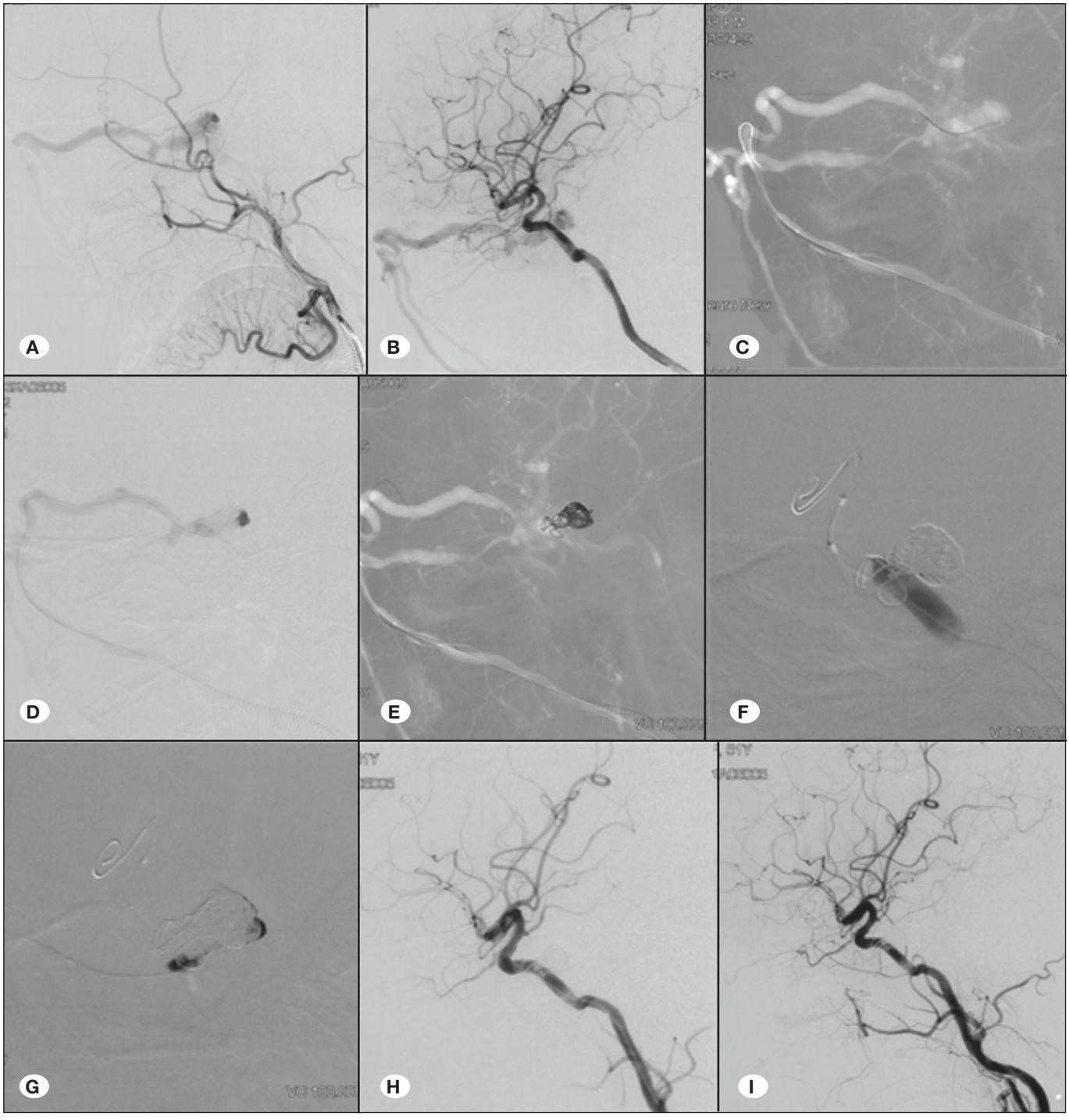

Figure 2: Illustration of a transvenous approach with intra-arterial balloon protection of CSDAVF. **A, B)** Cerebral angiography revealed a left CSDAVF fed by accessory meningeal artery and meningohypophyseal trunk. The fistula was drained into the superior ophthalmic vein and pterygoid vein. **C, D)** Microcatheter was navigated into superior ophthalmic vein through facial vein for embolization. **E-G)** Coils and Onyx was used to emboli the fistula in the presence of a Scepter balloon inflated in the ICA. **H-I)** Angiography after embolization showed complete obliteration of the fistula and the follow-up angiography after 6 months revealed complete obliteration of the fistula.

In patients with DCCFs, patients usually can tolerate temporary ICA occlusion well because of a relatively complete circle of Willis and adaptation of the steal phenomenon (10,21). Although Willis's circle in most CSDAVFs was incomplete, and some physicians have expressed concerns about the potential thromboembolic risk that could result from balloon dilation in ICA for temporary protective occlusion, no significant differences were observed in our study for the group with balloon protection in this study. The dispersion into the ICA of liquid materials was observed to have taken place in 1 process without signs of complication. This process was performed through the transarterial approach, and the only liquid material applied was Onyx. Low balloon inflation was why Onyx dispersion into ICA occurred, which was described in 1 case (Figure 1). Therefore, a high-compliance balloon was suitable for balloon occlusion, like Hyperform and Scepter in our series. The high compliance and visibility of the balloon are beneficial for better maneuverability and tightness in ICA. In addition, our results indicate that increased attention should be given to ensure efforts when deflating the balloon after Onyx injection. Due to Onyx's unique freezing properties, the Onyx could have been flushed away when the balloon was deflated. Applying a slow deflation rate of the balloon will help ensure a complete solidification of the Onyx cast by slowly diffusing DMSO away with blood flow. A blank roadmap could be used to monitor the displacement of the Onyx case when deflating the balloon.

Although complications related to balloon application were not found in our series, the high rate of others complications was unsatisfactory. In our series, complications with permanent symptoms occurred only in the transarterial access group, which is why transarterial access is not the preferred treatment option (15). Branches of the ECA are the most commonly used arteries for embolization, and many potential anastomotics connect the external cerebral arterial system and the ICA system, increasing the risk of embolization for reflux and stroke, such as the neuromeningeal trunk of the ascending pharyngeal artery (7). Onyx refluxing in the feeding artery of the trigeminal nerves occurred in the 2 patients suffered from hemifacial hypesthesia after the operation. Compared with the transarterial approach, Onyx dispersion into ICA was not found when the transvenous approach was performed. Onyx dispersion in the cavernous sinus was not easy to refuse into the feeding artery. Therefore, the technique of transarterial balloon protection might not be necessary with the transvenous approach. There is no absolute theoretical contraindication to this technique for treating CSDAVFs. Accordingly, complete cerebral vascular angiographies that include anterior and posterior communication are indispensable and required features of this approach. Balloons with suitable sizes could entirely cover all feeding arteries and should be fully inflated in the process.

CONCLUSION

We are the first to summarize endovascular embolization with intra-arterial balloon protection in CSDAVFs. However, in order to assess efficacy and safety, increasingly detailed examination of cases and outcomes, as well as results based on longer repeat follow-up times, are still required. Based on our findings, however, there is good reason to believe that the intra-arterial balloon protection technique is a feasible, effective, and safe adjunct approach for the treatment of CSDAVFs with few and only rare complications.

ACKNOWLEDGEMENTS

This work was supported by the National Natural Science Foundation of China (No 81771266), and Natural Science Foundation of Liaoning Province (No 2021BS031).

AUTHORSHIP CONTRIBUTION

Study conception and design: QL
Data collection: JNL
Analysis and interpretation of results: JNL, CHS
Draft manuscript preparation: JNL
Critical revision of the article: YX, JML
Other (study supervision, fundings, materials, etc...): JNL, CHS
All authors (JNL, CHS, YX, JML, QL) reviewed the results and approved the final version of the manuscript.

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