Onyx 18 embolisation of dural arteriovenous fistula via arterial and venous pathways: preliminary experience and evaluation of the short-term outcomes

^{1,2}X-A LONG, PhD, ¹T KARUNA, MD, ¹X ZHANG, PhD, ¹B LUO, PhD and ¹C-Z DUAN, PhD

¹Department of Neurosurgery, Neurosurgery Institute, Key Laboratory on Brain Function Repair and Regeneration of Guangdong, Zhujiang Hospital, Southern Medical University, Guangzhou, China, and ²Department of Neurosurgery, Affiliated Hospital of Guangdong Medical College, Zhanjiang, China

Objective: This paper mainly focuses on our preliminary experience and short-term outcome evaluation of embolisation of non-cavernous dural arteriovenous fistulas (ncsDAVFs) and cavernous sinus dural arteriovenous fistulas (csDAVFs) using Onyx 18 (ev3, Plymouth, MN), and in combination with coils, via arterial and venous approaches, respectively.

Methods: Between August 2008 and March 2010, 21 DAVFs (11 ncsDAVFs and 10 csDAVFs; age range: 28–68 years; 12 females and 9 males) were undertaken. Borden classification showed Type III in 1 and Type II in 10 ncsDAVFs, and Type II in 4 and Type I in 6 csDAVFs. Onyx 18 was used in 11 ncsDAVFs (10 via single feeder and 1 via 2 feeders). Onyx 18 or in combination with coils was used in 10 csDAVFs (9 via the inferior petrosal sinus and 1 via the superior ophthalmic vein).

Results: Total occlusion in immediate angiography was achieved in 18 cases (85.7%; 10 ncsDAVFs and 8 csDAVFs), and near-total occlusion in 1 ncsDAVF and 2 csDAVFs. Onyx 18 was migrated into normal vasculature in two ncsDAVFs without any sequelae. One csDAVF had VI cranial nerve palsy post-operatively, which completely recovered 2 weeks post-embolisation. Follow-up angiography at 3–12 months showed complete occlusion in 20 cases (95.2%; 10 ncsDAVFs and 10 csDAVFs). One ncsDAVF (4.8%) recurred after 3 months and was successfully re-embolised.

Conclusion: Preliminary results achieved after embolising 11 ncsDAVFs and 10 csDAVFs using Onyx 18 and in combination with coils via arterial and venous pathways, respectively, appeared to be safe, feasible and effective, as 95.2% of cases were totally occluded without any clinical sequelae.

Received 6 February 2011
Revised 31 May 2011
Accepted 20 July 2011

DOI: 10.1259/bjr/25192972

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Radiology

Dural arteriovenous fistulas (DAVFs) are the abnormal vascular shunts of dura mater that are usually found within or near the wall of dural venous sinuses [1]. Nevertheless, the location of DAVF lesions is not constant; it can occur in any part of dura and its subsidiaries. With the development of newer techniques and embolic materials in the world of interventional neuroradiology, endovascular therapy has now been developing as the primary treatment strategy to cure DAVFs, with successful results [2]. However, depending upon the location of fistula, its venous drainage pattern and its feeding vessels, approaching vascular pathways has to be considered carefully. Patients may present with intracranial haemorrhage, intracranial hypertension or brain herniation and other serious consequences depending upon the cortical venous reflux (CVR) pattern [3, 4].

For satisfactory embolisation of either type of DAVF, embolic material that can adequately disperse into whole fistulous channels is required. Onyx 18, which is made up of 6% ethylene vinyl alcohol (ensuring that it can

travel distally and penetrate deep into a target area, owing to its low viscosity) (ev3, Plymouth, MN) is a similar kind of non-adhesive liquid embolic agent having better penetration quality and has been widely used for the treatment of cerebral arteriovenous malformations [5]. However, literature about the use of Onyx 18 via either pathway to embolise DAVF is still limited.

Here we present our preliminary experience about the use of Onyx 18 together with coils via arterial and venous pathways to embolise non-cavernous (ncsDAVF) and cavernous sinus dural arteriovenous fistulas (csDAVF), and their short-term outcome evaluation. We have detailed the embolisation techniques, their effectiveness and related complications.

Methods and materials

Patients

The study was approved by our institutional review board, and informed consent was obtained from all patients. From August 2008 to March 2010, 21 patients underwent endovascular treatment for DAVF. Among

Address correspondence to: Professor Chuan-Zhi Duan, Department of Neurosurgery, Zhujiang Hospital, Southern Medical University, 253# Industry Road, Guangzhou, Guangdong 510282, China. E-mail: doctor_duanZJ@163.com

them, 11 had ncsDAVFs and 10 had csDAVFs. There were 12 females and 9 males between 28 and 68 years of age, with a mean age of 51.6 ± 11.3 years. According to the Borden classification, there was Type III in 1 case and Type II in 10 cases of ncsDAVF, and Type II in 4 cases and Type I in 6 cases of csDAVF. The main presenting symptoms were headache (81.0%, 17 cases), chemosis (38.1%, 8 cases), proptosis (42.9%, 9 cases), periorbital bruit (85.7%, 18 cases), focal seizure (14.3%, 3 cases) and altered mental status (4.8%, 1 case). No cases presented with cranial nerve palsy. The baseline characteristics of the patients are summarised in Tables 1 and 2.

Embolisation procedures

Conventional cerebral angiography was done via percutaneous femoral artery under general anaesthesia to locate the target area on a plane angiographic unit. In addition to femoral vein access in csDAVF, the femoral artery was also catheterised for control angiogram. The patient was heparinised to maintain activated clotting times between 200 and 300 s. The fistulous site and its connections (*e.g.* arterial feeders, venous drainage pattern, collateral flows and dangerous vascular anastomosis) were well assessed. Based on location and characteristic haemodynamic changes in diagnostic angiography, embolisation approach was considered.

Transarterial embolisation in ncsDAVF

An Echelon™ series microcatheter (Micro Therapeutics, Irvine, CA) or a Marathon™ flow-directed catheter (ev3) was navigated over a micro guidewire (Transend™ series; Boston Scientific, Natick, MA; Silver Speed™-10 series, eV3; or Mirage® 008, ev3) to reach the distal aspect of the arterial pedicle supplying the fistula. Super-selective angiography was then performed to confirm optimal wedging of microcatheter. Onyx 18 was slowly injected using the “reflux–hold–reinjection” technique under real-time road-mapping. Whenever unwanted reflux or flow into an undesirable vessel was observed, injection was held for 20 s to 2 min to allow Onyx 18 polymerisation, and reinjection was carried out slowly, in a controlled manner, engendering a new road map (reflux–hold–reinjection technique).

Transvenous embolisation in csDAVF

A 6F ENVOY® guiding catheter (Cordis Corporation, Hialeah, FL) was positioned in the internal jugular vein and a microcatheter (Excel™ series, Boston Scientific, or Echelon series, Micro Therapeutics) was navigated into the cavernous sinus (CS) via the ipsilateral inferior petrosal sinus (IPS). In some cases, a diagnostic angiographic catheter was positioned in the external or internal carotid artery to delineate the target site under the road-mapping technique. We used a 0.035-inch Terumo Glidewire® (Terumo, Tokyo, Japan) to explore out IPS, where it was not opacified in angiography. Ready-made 6% Onyx 18 was then slowly injected into CS in a controlled manner. In those conditions where retrograde filling of draining veins in capillary phase was present, platinum coils (GDC® series, Boston Scientific; EDC series, NXT Series, eV3; Irvine, CA) were deployed near the draining vein outlets and the tip of the microcatheter was

wedged into the coil mesh before Onyx 18 injection. Onyx 18 injection was continued, allowing adequate penetration into all compartments of the CS.

Heparin was discontinued at the end of the procedure. Routine post-operative care was given to all patients in the neurosurgery intensive care unit. All patients were discharged at 2–3 weeks post-embolisation.

The angiographic result for each criterion was categorised into total occlusion (disappearance of arteriovenous shunt), near-total occlusion, (small residual shunt) and recurrence (fistula recanalisation in subsequent follow-up angiography) [6].

Results

Immediate angiographic results

Out of 11 ncsDAVFs, target embolisation was successfully achieved in 10 fistulas via a single arterial pathway (6 fistulas via the middle meningeal artery, MMA, 3 via the occipital artery and 1 via the ascending pharyngeal artery) and 1 ncsDAVF was embolised via the right occipital artery and left posterior meningeal artery (Case 3 in Table 1).

Among 10 csDAVFs, all were treated by the transvenous approach; 9 were embolised via the IPS approach and in 1 case, owing to failure of IPS catheterisation to reach target CS, embolisation was performed via the superior ophthalmic vein (SOV) by a direct puncture method. Coil volume ranged between 9.5 and 61.8 mm³ (mean 21.7 ± 17.2 mm³) in 8 cases of csDAVFs in which Onyx 18 in combination with coils was used (treatment outcome summarised in Tables 1–3).

Procedure-related complications

Onyx 18 was refluxed into normal vasculature in two ncsDAVFs (Cases 1 and 3 in Table 1). One case with csDAVF had VI cranial nerve palsy (Case 2 in Table 2) post-operatively, which became normal after 2 weeks. No patients had any clinical sequelae. Patency of involved draining venous sinuses was well preserved during transarterial embolisation of all ncsDAVFs.

Clinical follow-up

All 21 cases were clinically followed up for 1–12 months, (mean 5.9 ± 3.8 months) post-embolisation. In one case of ncsDAVF, periorbital bruit had recurred and was cured with an additional Onyx 18 embolisation via the arterial route (Case 7 in Table 1). Clinical symptoms gradually disappeared in the other 20 cases (10 ncsDAVFs and 10 csDAVFs) in 2 weeks to 3 months post-embolisation, and remained asymptomatic in subsequent follow-up periods (Tables 1–3).

Angiography follow-up

Angiography follow-up was scheduled at 3–12 months (mean 6.0 ± 3.6 months). One ncsDAVF (Case 7 in

Table 1. Characteristic features and outcome of 11 non-cavernous dural arteriovenous fistula cases

Case number	Sex (M/F)/ age (years)	Presentation	Location	Borden classification	Feeders	Drainage veins	Approach	Material	Immediate angiographic result	Complications	Clinical outcome		
											At discharge	Follow-up (outcome/ months)	Angiography follow-up (outcome/ months)
1	M/55	HA, seizure	Frontal region	III	Both OPA, IMA, STA, MMA	CVR and venous lake, SSS	Lt MMA	Onyx 18 ^a	Total occlusion	Onyx 18 ^a droplet escaped via the fistula into drainage vein, no clinical sequelae	Symptom free	Cured/6, 12	Cured/6
2	F/53	HA, BR	Rt TS, SS	II	Rt MHT, OA, STA, MMA	Lt TS, CVR	Rt OA	Onyx 18 ^a	Total occlusion	None	Symptom free	Cured/3, 6	Cured/3
3	F/41	HA, BR	TH	II	Lt PMA; Rt OA, STA	Rt TS, Lt TS, CVR	Lt PMA, Rt OA	Onyx 18 ^a	Total occlusion	Onyx 18 ^a droplet escaped via the fistula into Rt TS, no occlusion; no clinical sequelae	Symptom free	Cured/6	Cured/6
4	M/59	HA, BR	Rt TS	II	Rt OA, MMA, PAA	Lt TS, CVR	Rt MMA	Onyx 18 ^a	Total occlusion	None	Symptom free	Cured/3, 6	Cured/6
5	M/47	HA, BR	Lt TS, SS	II	Lt OA, MMA, PAA	Rt TS, CVR	Lt OA	Onyx 18 ^a	Total occlusion	None	Symptom free	Cured/3, 6	Cured/3
6	F/68	HA, BR	Lt SS	II	Lt APA, MMA	Rt TS, SS, CVR	APA	Onyx 18 ^a	Total occlusion	None	Symptom free	Cured/3, 12	Cured/3, 12
7	M/61	HA, BR, altered mental status	SSS, TH	II	Both STA, MMA, APA, PCA	SSS, CVR	Lt MMA	Onyx 18 ^a	Near-total occlusion	None	Improved	Recurrence/ 3, cured/12	Recurrence/ 3, cured/12
8	F/28	HA, BR	SSS	II	Both STA, MMA	SSS, CVR	Lt MMA	Onyx 18 ^a	Total occlusion	None	Symptom free	Cured/3, 6	Cured/3
9	M/57	HA, BR, seizure	Rt TS	II	Rt OA, MMA, MHT	Lt TS, CVR	Rt MMA	Onyx 18 ^a	Total occlusion	None	Symptom free	Cured/3, 6	Cured/6
10	M/58	HA, BR	Lt TS, SS	II	Lt OA, MMA, STA	Rt TS, CVR	Lt MMA	Onyx 18 ^a	Total occlusion	None	Symptom free	Cured/3, 6	Cured/3
11	M/52	HA, BR, seizure	Rt SS	II	Rt MHT, OA, MMA	Lt TS, CVR	Rt OA	Onyx 18 ^a	Total occlusion	None	Symptom free	Cured/3, 12	Cured/3

APA, ascending pharyngeal artery; BR, bruit; CVR, cortical venous reflux; F, female; HA, headache; IMA, internal maxillary artery; Lt, left; M, male; MHT, meningohypophyseal trunk; MMA, middle meningeal artery; OA, occipital artery; OPA, ophthalmic artery; PAA, posterior auricular artery; PCA, posterior cerebral artery; PMA, posterior meningeal artery; Rt, right; SS, sigmoid sinus; SSS, superior sagittal sinus; STA, superficial temporal artery; TH, torcular herophili; TS, transverse sinus.

^aOnyx 18 manufactured by ev3, Plymouth, MN.

Table 2. Characteristic features and outcome of 10 cavernous dural arteriovenous fistula cases

Case number	Sex (M/F) / age (years)	Presentation	Location	Borden classification	Feeders	Drainage veins	Approach	Materials	Immediate angiographic result	Complications	Clinical outcome		
											At discharge	Follow-up (outcome/ months)	Angiography follow-up (outcome/ months)
1	F/47	HA, BR, Rt proptosis, chemosis	Rt CS	II	Rt MMA, IMA	Rt SOV, MTV	FV-IPS	Onyx 18 ^a , coils	Total occlusion	None	Symptom free	Cured/1, 12	Cured/12
2	F/38	Rt proptosis, chemosis	Rt CS, ICS	I	Both MHT; Rt MMA, IMA	Rt SOV	FV-IPS	Onyx 18 ^a , coils	Near-total occlusion	Transient VI cranial nerve palsy	Improved	Cured/3, 12	Cured/3, 12
3	F/66	BR, chemosis	Rt CS	I	Rt IMA, MMA; both MHT	Rt CS, IPS, SOV	FV-IPS	Onyx 18 ^a , coils	Total occlusion	None	Symptom free	Cured/6, 12	Cured/6
4	F/54	Rt proptosis, chemosis; BR	Rt CS	II	Rt MMA, MHT	Rt SOV, MTV	FV-IPS	Onyx 18 ^a	Total occlusion	None	Symptom free	Cured/3, 6	Cured/3
5	F/53	HA, BR, Lt proptosis, chemosis	Lt CS	I	Lt STA, IMA, MMA; both MHT	CS; Lt SOV	FV-IPS	Onyx 18 ^a , coils	Total occlusion	None	Symptom free	Cured/1, 3, 12	Cured/3
6	M/42	HA, BR; Rt proptosis	Both CS	I	Both MHT; Rt MMA, STA, IMA	Rt SOV	FV-IPS	Onyx 18 ^a , coils	Near-total occlusion	None	Improved	Cured/1, 3, 12	Cured/12
7	F/29	BR; Lt proptosis	Lt CS	I	Lt MHT, MMA, IMA	Lt SOV	FV-IPS	Onyx 18 ^a , coils	Total occlusion	None	Symptom free	Cured/1, 3, 12	Cured/6
8	F/64	BR; Lt proptosis	Lt CS	II	Lt MHT, MMA, OPA, IMA	Lt SOV, MTV	FV-IPS	Onyx 18 ^a , coils	Total occlusion	None	Symptom free	Cured/ 3, 6	Cured/3
9	M/44	HA, Rt proptosis, chemosis	Rt CS	I	Rt, IMA, MMA; both MHT	CS; Lt SOV	SOV	Onyx 18 ^a , coils	Total occlusion	None	Symptom free	Cured/3, 6	Cured/6
10	F/63	HA, BR, chemosis	Rt CS	II	Rt IMA, MMA, OPA; both MHT	Lt SOV, MTV	FV-IPS	Onyx 18 ^a	Total occlusion	None	Symptom free	Cured/3, 6, 12	Cured/3, 12

BR, bruit; CS, cavernous sinus; F, female; FV, femoral vein; HA, headache; ICS, intercavernous sinus; IMA, internal maxillary artery; IPS, inferior petrosal sinus; Lt, left; M, male; MHT, meningohypophyseal trunk; MMA, middle meningeal artery; MTV, middle temporal vein; OPA, ophthalmic artery; Rt, right; SOV, superior ophthalmic vein; STA, superficial temporal artery.

^aOnyx 18 manufactured by ev3, Plymouth, MN.

Table 3. Outcome of 21 patients with non-cavernous sinus and cavernous sinus dural arteriovenous fistulas

Presentation	Number	Immediate angiographic outcome		Embolitic agent		Complication	Follow-up angiography	
		Total occlusion	Near-total occlusion	Onyx 18 ^a	Onyx 18 ^a + coils		Total occlusion	Recurrence
ncsDAVF	11	10 (90.9%)	1 (9.1%)	11	0	2	10 (90.9%)	1 (9.1%)
csDAVF	10	8 (80.0%)	2 (20.0%)	2	8	1	10 (100%)	0
Total	21	18 (85.7%)	3 (14.3%)	13	8	3	20 (95.2%)	1 (4.8%)

csDAVF, cavernous dural arteriovenous fistula; ncsDAVF, non-cavernous dural arteriovenous fistula.

^aOnyx 18 manufactured by ev3, Plymouth, MN.

Table 1) recurred after 3 months of the initial embolisation phase. It was re-embolised and the fistula found to be totally occluded at 12-month follow-up angiography. In two csDAVFs cases (Cases 2 and 6 in Table 2) with near-total occlusion, total angiographic obliteration was found at 3- and 12-month follow-up angiography. In the other 18 DAVFs (10 ncsDAVFs and 8 csDAVFs), no recurrence was found during angiographic follow-up. Involved draining venous sinuses in all 11 cases with ncsDAVF were found patent, without any evidence of Onyx 18 cast (Tables 1–3; Figures 1–4).

Discussion

DAVF, which accounts for 10–15% of all intracranial vascular malformations, is one of the challenging cerebrovascular diseases to identify and cure with satisfactory results [1, 2]. Owing to its peculiar haemodynamic character and angioarchitecture complexity, multiple feeders are usually found. Some fistulas are supplied by small and tortuous arterial branches, and some of them drain with CVR, which is the main sign of high-grade DAVF, and such fistulas may be the most difficult to treat without any

Figure 1. Digital subtraction angiography showing embolisation of cavernous dural arteriovenous fistula via the undeveloped inferior petrosal sinus. (a, b) Arteriography of right internal and external carotid arteries and (c, d) arteriography of left internal carotid artery showing dural arteriovenous fistula of right cavernous sinus and intercavernous sinus (arrow). (e) Guide wire guiding through the non-visualised inferior petrosal sinus (arrow). (f) Deployed coils. (g) Cast of Onyx 18. (h–j) Completed occlusion at 3 months post embolisation (arrow).

Figure 2. Digital subtraction angiography showing embolisation of cavernous dural arteriovenous fistula via IPS. (a, b) Arteriography of right internal carotid artery and (c, d) arteriography of right external and left internal carotid artery showing dural arteriovenous fistula of both cavernous sinuses. (e, f) Microcatheter guiding via inferior petrosal sinus. (g, h) Arteriography of right internal carotid artery and (i, j) arteriography of right external left internal carotid artery showing complete occlusion at 3-months post-embolisation (arrow).

Figure 3. Digital subtraction angiography showing complete occlusion of torcular herophili dural arteriovenous fistula via transarterial approach. (a) Left vertebral arteriography and (b, c) arteriography of right external carotid showing dural arteriovenous fistula at torcular herophili. (d) Cast of Onyx 18 reflux (arrow). (e) Left vertebral arteriography and (f) right external carotid arteriography showing complete occlusion of dural arteriovenous fistula.

Figure 4. Digital subtraction angiography showing complete occlusion of frontal region dural arteriovenous fistula via middle meningeal artery. (a, b) Arteriography of right internal and external carotid artery and (c, d) arteriography of left internal and external carotid artery showing dural arteriovenous fistula on frontal region. (e) Microcatheter guiding through the left middle meningeal artery (arrow). (f) Cast of refluxed Onyx 18 (arrow). (g, h) Arteriography of right and left internal carotid artery and (i, j) arteriography of right and left external carotid showing complete occlusion at 6 months post-embolisation. IMA, internal maxillary artery; LICA, left internal carotid artery; LIMA: left internal maxillary artery; LMMA: left middle meningeal artery; LOA, left ophthalmic artery; LSTA: left superficial temporal artery; MMA: middle meningeal artery; OA, ophthalmic artery; RECA: right external carotid artery; RICA: right internal carotid artery; RIMA: right internal maxillary artery; ROA, right ophthalmic artery; RSTA: right superficial temporal artery; STA: superficial temporal artery.

complications or fistulae residue [2, 7, 8]. The treatment modalities include craniotomy surgery, radiation therapy and endovascular treatment. Endovascular treatment is still the preferred therapy to treat DAVF, with the highest success rate [2]. Liquid embolic agents such as N-butyl 2-cyanoacrylate (NBCA) have been used [9], but due to its high adhesiveness and early polymerisation quality, microcatheter tip gluing into the vessel wall and early reflux are anticipated. As it requires single-column injection with rapid microcatheter withdrawal, repeated and long duration injection is generally not allowed. Thus this kind of material penetrating into whole fistulous network is limited, resulting in incomplete occlusion [10–12].

Onyx 18 has emerged as a non-adhesive, well-penetrating embolic agent, composed of ethylene vinyl alcohol polymer. It is dissolved in dimethyl sulphoxide solvent (DMSO), and added with the particles of tantalum powder

for a contrast medium. It precipitates as sponge-like clumps and becomes permanent emboli when it reaches the target region [5]. Multiple catheterisations and slow controlled injection are mandatory for total embolisation of DAVF, which is impossible using other adhesive materials in a single setting [12, 13].

Transarterial embolisation of non-cavernous dural arteriovenous fistula

The transarterial approach includes super-selective catheterisation and delivery of embolic material into dural branches of the fistula. ncsDAVF typically drains directly into leptomeningeal veins or into major large dural venous sinuses, like transverse sinus and sigmoid sinus. Optimal patency of this venous drainage is mandatory. If embolic

material is aggressively used via the transvenous approach, the anatomical structure and physiological function of the corresponding sinus will be sacrificed, which may change venous outflow into other sinuses, or even into cortical veins. This can result in intracranial haemorrhage [2, 14]. For these reasons, we prefer transarterial embolisation for non-cavernous sinus-type DAVF.

In 9 of 11 ncsDAVFs, complete fistulous obliteration was obtained via the transarterial approach without reflux into any involved sinuses. Transarterial embolisation for ncsDAVF is an ideal technique for permanent fistulous occlusion and to preserve patency of draining venous sinuses [2–4], but owing to inadequate dispersion of other embolic material than Onyx 18 into all fistulous connections, pedicles of arterial feeders could prematurely be occluded, which could ultimately result in fistula remnants and recurrence [9, 10, 13]. It has also been recently reported that the complete occlusion rate after transarterial embolisation of ncsDAVF with polyvinyl alcohol (PVA) particles, NBCA or a combination of them was only 27.3–30.0% [10, 15]. Similarly, in the study of Théaudin et al [16] on DAVFs that were embolised via the transarterial approach using Embospheres (Merit Medical Systems, South Jordan, UT), all remained symptomatic.

In our series, 10 ncsDAVFs were embolised via only one single arterial feeder and 1 ncsDAVF was occluded via 2 feeders. MMA (6 of 11 ncsDAVFs) was the most commonly approached vessel. One of the ncsDAVFs (Case 1 in Table 1; Figure 4) with multiple feeders, involving the frontal region, was totally occluded via one feeding artery (MMA). Feeding branches originated from the bilateral ophthalmic artery, maxillary artery, superficial temporal artery and MMA. CVR with dilated venous pouch was drained into the superior sagittal sinus in a retrograde fashion. Although the feeders were longer and tortuous, we selected the left anterior branch of the MMA and complete occlusion was finally achieved. Because of the rich connection network existing between fistulas and arterial feeders, Onyx 18 could penetrate well into all fistulous connecting networks, even through the smaller and single artery branch from high to low pressure, until all connections were completely occluded. Due to its non-adhesive character, repeated injection for longer duration is allowed, while an endovascular surgeon provides sufficient control over its tapping to prevent outflow deep into the venous circulation or into other normal vasculature.

Transvenous embolisation of cavernous dural arteriovenous fistula

Because of the abundant supply of fine and tortuous vessels from external and internal carotid arteries, fistulas could not be safely and successfully accessed via the lis arterial pathway [9, 17]. Moreover, csDAVFs usually have smaller-diameter fistulous openings, which may result in difficulty in selective transarterial catheterisation, and the risk of retrograde reflux, vessel perforation and haemorrhage is higher when inadvertent embolisation is done. Furthermore, when high-flow cavernous sinus-type fistula is embolised via the arterial pathway, the chance of liquid embolic agent migration into arterialised draining veins is anticipated, causing distal venous occlusion and consequent venous infarction or haemorrhage [2].

As the CS is not a main draining venous sinus, total sinus occlusion is usually considered for complete fistulous obliteration. However, CS, being a multiseptated structure with a basal network of abundance venous channels, deploying only coils for dense packing is impracticable and more costly. To occlude the whole CS in both anterior and posterior compartments needs a large number of coils for dense packing. However, residual fistulas are still prone to occur, despite deploying a sufficient number of coils [18]. Since coil volume above 200 mm³ is usually expected to manifest post-operative cranial nerve palsy [18], the role of Onyx 18 in combination with coils seems to be crucial. Therefore, for total occlusion of CS, we first deployed detachable coils and then Onyx 18 was slowly injected. Here, coils provided a double benefit: first, they facilitated obtaining flow reduction within venous channels; and, second, they provided secure anchoring to Onyx 18 cast. Furthermore, the use of coils together with Onyx 18 reduced the amount of coils for dense packing, providing optimal cost benefits, and the coil volume used in eight csDAVF cases was considerably reduced to 9.5–61.8 mm³.

In some studies, the inability of NBCA to penetrate freely into all compartments of CS has been documented [10–12]. Only 56–81% of csDAVFs were found to be occluded in the initial phase of embolisation using such materials [10, 11, 19]. In our study, eight csDAVFs were satisfactorily occluded using Onyx 18 together with coils, and because of low pressure in retrograde filling of draining veins, two csDAVFs were embolised using only Onyx 18. Complete angiographic obliteration was observed in all of them during follow-up. We found that Onyx 18 could satisfactorily penetrate well along the pressure gradient of multiseptated CS.

In general, the success rate of IPS catheterisation with no visualisation of IPS in angiograms is reported as 30–50% [19–21]. In our cases, IPS was successfully accessed in 9 out of 10 csDAVFs (90%). In one csDAVF, where IPS was not visualised angiographically, we adopted 0.035 guidewire to explore its potential passage (Case 2 in Table 2; Figure 1). As a result, none of our cases with csDAVF required a transarterial approach. When IPS is not opacified, thicker or a little more rigid guidewire can be used, gently, for navigation. Alternative access via SOV or facial vein, as well as a direct transorbital puncture of CS, can also be done [9, 19], but these vessels are more dilated and tortuous, having a thin wall, where manipulation is more difficult and the chance of vessel perforation is higher [22]. Therefore IPS is found to be a conveniently accessible route, with shorter distance compared with more tortuous and longer arteries.

Complications and limitations

In our study, all csDAVFs were embolised via the venous pathway and one case (10%) had VI cranial nerve palsy as an immediate post-embolisation complication, which is relatively less than in the study of Nishino et al [18]. In this study, cranial nerve palsy as a per-operative complication occurred in 39.4% of cases and mass effect caused by coil volume of >200 mm³ was predicted as a cause of nerve injury [18]. But the coil volume used in our case was 61.8 mm³, which was less than one-third of the volume expected to cause nerve damage. As Onyx 18 was injected after deploying few coils in our cases, coil

volume was significantly decreased, so the space-occupying effect of embolised coils was greatly reduced. Thus we predicted that in this case of csDAVF, transient VI cranial nerve injury might be due to excessive manipulation of microcatheter or microwire during navigation. A small amount of Onyx 18 was migrated into venous sinuses in two ncsDAVF cases; however, both of them remained clinically asymptomatic. Excessive Onyx 18 reflux into the venous system can lead to sinus occlusion or can course down into pulmonary vessels, causing pulmonary infarction. Moreover, if Onyx 18 migration occurs in "dangerous vascular anastomosis", cerebral embolism or intracranial haemorrhage may be the outcome. But none of these devastating complications were seen in our cases.

Though Onyx 18- or DMSO-related complications were nil in our study, some authors have reported unfavourable events like catheter entrapment, rupture and vasospasm due to angiotoxicity caused by both Onyx 18 and DMSO [23, 24]. In addition, the cost factor and radiation dose associated with use of Onyx 18 need to be further assessed with a large number of patients in expanded clinical trials with long-term follow-up.

Conclusion

Onyx 18 was found to be safe and effectual for either type of DAVF. Preliminary results achieved after an initial attempt to embolise ncsDAVF and csDAVF using Onyx 18 and in combination with coils via arterial and venous pathways, respectively, appeared to be promising, since total embolisation was gained in 95.2% (20/21) of our cases without any clinical sequelae.

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