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ORIGINAL ARTICLE

Flow diverter manages very small aneurysm of the internal carotid artery

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Abstract

Background: Endovascular aneurysm coiling is a minimally invasive method to manage intracranial aneurysms. However, aneurysm coiling may fail in very small aneurysms (VSAs); thus, flow diverter (FD) is recommended as an alternative in these difficult aneurysms. Herein, we report our experience and outcomes of FD to treat VSA of the internal carotid artery (ICA).

Methods: Over a 3-year period, a total of 70 patients with 87 unruptured VSAs of the ICA were managed by FD. There were 54 men and 16 women, with a mean age of 57 (range, 41–75) years. We retrospectively assessed the clinical data, aneurysm characteristics, and angiographic as well as clinical outcomes of patients treated by FD and compared with larger aneurysms.

Results: Fifty aneurysms (58%) were located in the supraclinoid ICA, followed by paraclinoid ICA (n = 31, 36%) and cavernous ICA (n = 6, 7%). Most aneurysms (n = 72, 83%) were between 2 and 3 mm in size. The mean aneurysm size was 2.3 mm (range, 1.5–3 mm). Follow-up angiographic data (mean, 13 months) were available in 54 patients with 68 aneurysms. Successful FD deployment in an ideal position to bride aneurysm was achieved in 86 of 87 aneurysms (99%). Complete obliteration (CO) was achieved in 63 aneurysms (93%). Compared with larger aneurysms (>3 mm), VSAs had the tendency to achieve CO ($p < 0.05$) in a midterm follow-up. Two patients (2.8%) had intraprocedural complications, including in-stent thrombosis (n = 1) and distal embolism (n = 1). One patient (1.4%) suffered from mild limb weakness.

Conclusion: The use of FD to manage VSA was technically feasible, and the procedure was simpler than those of larger aneurysms. FD stenting of VSAs was confirmed to be effective and safe and had higher CO rate than those in larger aneurysms in a midterm angiographic follow-up.

Keywords: Embolization; Flow diverter; Internal carotid artery; Very small aneurysm

1. INTRODUCTION

Endovascular coiling of intracranial aneurysms has been accepted as a treatment modality with promising results.[1–3] However, coiling of very small aneurysms (VSAs) is controversial because of the benign nature of VSAs and inherent limitations of endovascular coiling related to the difficulty of aneurysm catheterization and relative risks of aneurysm coiling.[4,5] Flow diverters (FD) have better metallic surface coverage than traditional stents, were initially designed to manage wide-necked big and giant aneurysms, and provided durable angiographic outcomes. Recently, the use of FD to manage intracranial aneurysms has been reported to be safe and effective angiographic outcomes. However, the selection of FDs to manage VSA has not well been evaluated.

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This study aimed to report our experience of using FD to manage 70 patients with 87 unruptured VSAs of the internal carotid arteries (ICAs) and to report immediate and midterm angiographic outcomes. Outcomes were also compared with those of larger aneurysms (>3 mm).

2. METHODS

From October 2018 to July 2020, at two institutions, a series of 198 consecutive patients with 253 intracranial unruptured aneurysms underwent endovascular FD performed by a major operator. Of these patient data, 70 patients with 87 asymptomatic VSAs of the ICAs were treated by FD. There were 16 men (23%) and 54 women (77%) aged 41–75 (mean, 57) years. The indications of FD management for VSAs were as follows: (1) multiple VSAs (n = 39, 56%), (2) multiple aneurysm with irregular VSA (n = 3, 4%), (3) family history of ruptured aneurysms (n = 18, 26%), and (4) previously ruptured aneurysms (n = 10, 14%). Before initiation, this study was approved by the Institutional Review Board of our institute. Informed consent was obtained from the patients or their family.

Data including sex, age distribution, clinical manifestations, and characteristics of aneurysms are summarized in Table 1. The sizes of the aneurysms varied from 1.5 to 3 mm in their maximal dimension (mean, 2.3 mm). Aneurysms were located in the supraclinoid (n = 50, 58%), paraclinoid

Table 1

Summary of demography and characteristics of 70 patients with 87 VSAs of ICAs managed by FD

	Value (percentage)
No of patients	70
No of aneurysms	87
Mean age (years)	57 (range 41–75)
Gender, n (%)	
Female	54 (77)
Male	16 (23)
Patient indication of FD to treat VSA, n (%)	
Multiple aneurysms	39 (56)
Multiple aneurysms with irregular VSA	3 (4)
Family history of ruptured aneurysm	18 (26)
History of previously ruptured aneurysm	10 (14)
Location and number of 87 aneurysms in ICA, n (%)	
Supraclinoid	50 (58)
Paraclinoid	31 (36)
Cavernous	6 (7)
Size and number of aneurysms of 87 aneurysms, n (%)	
2–3 mm	72 (83)
<2 mm	15 (17)
Mean size of aneurysms	2.3 mm (range 1.5–3 mm)

FD = flow diverter; ICA = internal carotid artery; VSA = very small aneurysms.

(n = 31, 36%), and cavernous (n = 6, 7%) internal carotid artery (ICA). Regarding pretreatment medication, clopidogrel 75 mg and aspirin 200 mg were given daily for 6 days before embolization.

2.1. Angiography protocol and endovascular procedure

Under general anesthesia, ultrasound-guided puncture, and an 8-F long femoral artery sheath was placed into the abdominal aorta. Conventional digital subtraction angiography (DSA) of the parent artery and rotational and three-dimensional reconstruction DSA were routinely performed to evaluate the angioarchitecture of the aneurysm and parent artery. An intravenous bolus (3000 units) of heparin was routinely administered after the guiding catheter was placed into the parent artery, and an activated clotting time was maintained to twice the baseline throughout the procedure. The 8-F guiding catheter was introduced and navigated into the proximal cervical ICA, and an 6-F intermediate catheter was coaxially placed to the cavernous ICA. A 2.7-F microcatheter was navigated to the distal parent artery or its branch. A self-expandable Pipeline flex (n = 18, Medtronic, Irvine, CA) or flow redirection endoluminal device (n = 52, Microvention, Tustin, CA) FD of appropriate size and length was selected and deployed into the parent artery to bridge the aneurysm neck. The stent length was chosen to provide at least a 3–4 mm landing zone beyond the aneurysm neck on the proximal and distal parent arteries. The stent size was equal to or 0.2 mm greater than the caliber of the parent vessel at the targeted landing zone. No adjunctive aneurysm coiling was performed in all VSAs.

Postembolization DSA, Dyna-computed tomography of the brain, and stent-apposition vessel-wall images were routinely obtained to assess the hemodynamic alteration of the aneurysm sac, patency of the parent artery and its intracranial branches, as well as apposition of the FDs. We gave clopidogrel 75 mg and 200 mg aspirin daily for 6 months, followed by clopidogrel 75 mg and aspirin 100 mg daily for the next 6 months. DSA was performed in 54 patients with 68 aneurysms in a mean 13 months (range from 4 to 18 months). Clinical follow-up data after 3 months (mean, 18) were obtained in all 70 patients.

2.2. Angiographic outcome evaluation

These DSA findings and treatment outcomes of 87 VSAs and 166 aneurysms >3 mm were evaluated independently by two experienced interventional neuroradiologists using the same workstation to evaluate the angioarchitectures and treatment outcomes, with emphasis on the location, number of aneurysms, adjunctive aneurysm coiling, complication, and CO of the aneurysm sac. Any discrepancy in the angiographic findings of these two interventional neuroradiologists was resolved through reassessment and discussion to reach an agreement.

2.3. Statistical analysis

The SPSS statistical software package (version 20) was used for all statistical analyses. In two groups of patients with VSAs and larger aneurysms (>3 mm), correlations between age, gender, DSA findings, aneurysm size, adjunctive aneurysm coiling, periprocedural complication, and CO of the aneurysm were analyzed using the chi-square test for categorical variables. Continuous variables (e.g., age and aneurysm size) were analyzed using one-way analysis of variance, p value <0.05 was considered to indicate a significant difference.

3. RESULTS

A summary of the data on the immediate treatment outcomes, procedure-related complications, follow-up DSA, and clinical outcomes are presented in Tables 2 and 3. Successful deployment of FDs to an ideal location with coverage of the aneurysm neck was observed in 86 of 87 patients, resulting in a deployment success rate of 99%. In one patient with multiple aneurysms associated with failure of VSA coverage of the aneurysm neck, further intervention was not attempted because of the small size of the aneurysm. Regarding immediate hemodynamic alteration of the aneurysm sac, immediate change in aneurysm hemodynamics was observed in 62 aneurysms (71%) by delayed washout of the contrast material in the aneurysm sac. Prompt CO was observed in one aneurysm (1%); the other 24 aneurysms (28%) showed no obvious hemodynamic change. Periprocedural complication occurred in 2 (2.8%) patients, including in-stent thrombosis (n = 1) or distal embolism (n = 1), which were

Table 2

DSA and clinical outcomes of 70 patients of 86 VSAs successfully managed by FD

	Number (percentage)
Immediately DSA outcomes (70 patients, 86 aneurysms), n (%)	
CO of aneurysm	1 (1)
Delayed washout of contrast in the aneurysm	62 (71)
Unchanged of hemodynamic of aneurysm	24 (28)
Follow-up DSA in 48 patients of 68 aneurysms (mean time of follow-up)	13 mos
Obliteration of aneurysm, n (%)	
Raymond class I	63 (93)
Raymond class II	3 (4)
Raymond class III	2 (3)
Procedural-related complication (n = 2, 2.9%), n (%)	
In-stent thrombosis	1 (1.4)
Distal thrombosis	1 (1.4)
Neurologic outcomes of 70 patients (mean follow-up time), n (%)	15 mos
mRS 0	69 (99)
mRS 1	1 (1)

DSA = digital subtraction angiography; FD = flow diverter; mRS = modified Rankin scale (>3 months after discharge); VSA = very small aneurysm.

Table 3

Comparison of demography and outcomes of FD managing 87 VSAs and 166 larger aneurysms of ICAs

	VSAs (≤3 mm)	Larger aneurysms (>3 mm)	*p*
No of patients	70	128	
No of aneurysms	87	166	
No. of patients/aneurysms FU by DSA	54/68	89/116	
Age (y) (mean)	57	52	0.875
Gender			
Men	16 (23%)	35 (27%)	0.894
Women	54 (77%)	93 (73%)	0.894
Mean size of aneurysm (mm)	2.3	7.8	0.042
Successful FD deployment for aneurysm	86 (99%)	163 (98%)	1.000
Alter aneurysm hemodynamic after FD	62 (71%)	124 (75%)	0.661
Adjunctive aneurysm coiling	0 (0%)	28 (17%)	<0.001
Periprocedural complications	2 (2.9%)	6 (4.9%)	1.000
Mena DSA follow-up time (mo)	13	15	0.893
CO of aneurysm	63/68 (93%)	88/116 (76%)	0.008
Mean clinical follow-up time (mo)	18	16	0.951

CO = complete obliteration; DSA = digital subtraction angiography; FD = flow diverter; FU = follow-up; VSA = very small aneurysm.

treated by the administration of glycoprotein IIb/IIIa inhibitor. Clinical follow-up data of >3 months were available in all 70 patients; follow-up ranged from 5 to 23 (mean, 18) months. During the follow-up period, late hemorrhage or ischemic stroke was not observed. Fifty-four patients with 68 aneurysms had follow-up DSA, and CO of the aneurysm (Raymond class I) was observed in 63 aneurysms (93%, Figs. 1–3), subtotal occlusion with small neck remnant (Raymond class II) in three aneurysms (4%), and partial obliteration of aneurysms (class III) with residual sac in two (3%). Neurologic outcomes >3 months after discharge were stable in 69 patients. One patient had mRS 1 resulting from an in-stent thrombosis.

4. DISCUSSION

Endovascular embolization by coiling has become a standard technique to manage intracranial aneurysm. To achieve aneurysm coiling with maintained flow of the parent artery, the microcatheter should be successfully navigated into the aneurysm sac, followed by an uneventful aneurysm coiling. The advent of self-expandable intracranial stents for assisting aneurysm coiling has increased the treatment options for geometrically difficult aneurysms, particularly in those aneurysms with wide neck, unfavorable neck-to-dome ratios, or even fusiform aneurysms.[2,3]

VSA is referred to as an aneurysm sac size ≤3 mm. The indication for the treatment of intracranial unruptured VSA remains controversial. Previous studies have shown that the risk of aneurysm rupture from a small unruptured aneurysm is exceedingly low, unless the patient had a history of rupture of another aneurysm or had high-risk aneurysm morphology with irregular or false aneurysm sac. An annual rupture rate of 0.14% was reported for paraclinoid ICA aneurysms measuring 3–4 mm in a Japanese cohort.[6] Therefore, as an aggressive intervention to manage VSAs, the operator should balance the benign history of VSA and periprocedural risk. In this series, we treated VSAs in patients with relatively high-risk aneurysm rupture, such as patients with a family history of ruptured aneurysm or history of previously ruptured aneurysm in other location or territory or irregular shape of the VSAs. However, in this series, most VSAs do not have an immediate risk of rupture; we simultaneously treated VSAs in patients with multiple aneurysms in one segment of the parent artery.

Previous studies have demonstrated that the periprocedural risk of coiling VSA is not negligible because of a combined morbidity and mortality rate of 4.6%.[4,5,7–9] In the technical aspect, coiling VSAs is more difficult and challenging than those of larger aneurysms. A VSA restricts the free movement of the microcatheter and provides less support of the microguidewire system for microcatheterization, and the microcatheter was unstable inside the aneurysm. Coiling protruding into the parent artery is not uncommon because of the small and limited space in VSAs. Furthermore, a little expected forward movement of the microcatheter and coil may lead to aneurysm rupture in the small confined space of the VSA. Although some published data demonstrated that endovascular coiling of the VSA is feasible and did not lead to increased overall morbidity and mortality rates, procedural rupture was significantly more frequent in VSAs than in larger aneurysms (7.7% vs 3.6%).[7] Nguyen et al[10] reported a 5-fold increase in the incidence of aneurysm rupture during embolization in 3-mm aneurysms when compared with larger aneurysms. Dalfino et al[4] reported coiling of 20 VSAs and concluded that it was a safe procedure; however, residual neck or partial embolization occurred in 50% of the aneurysms.

FD was designed as a single-stent treatment option for intracranial aneurysms by endoluminal reconstruction instead of endosaccular coiling. Most FDs have denser metallic surface coverage with smaller porosity than traditional stents, and the metallic surface coverage coverage of FDs varied from 30% to 35%.[11] FDs take advantage of changing the parent artery/aneurysm sac interface, altering in-flow and out-flow hemodynamics, to promote aneurysm thrombosis. Subsequent neointimal

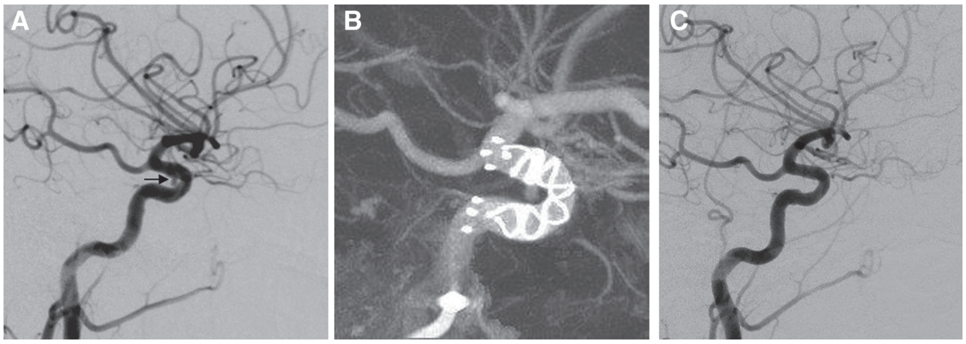

Fig. 1 The patient was a 65-year-old woman who had a family history of rupture aneurysm. A, Right lateral carotid DSA showed an asymptomatic VSA at the right supraclinoid internal carotid artery (arrow). B, The patient underwent FD to manage this VSA. C, CO (raymond I) of the aneurysm was observed in a 12-month DSA follow-up. CO = complete obliteration; DSA = digital subtraction angiography; FD = flow diverter; VSA = very small aneurysm.

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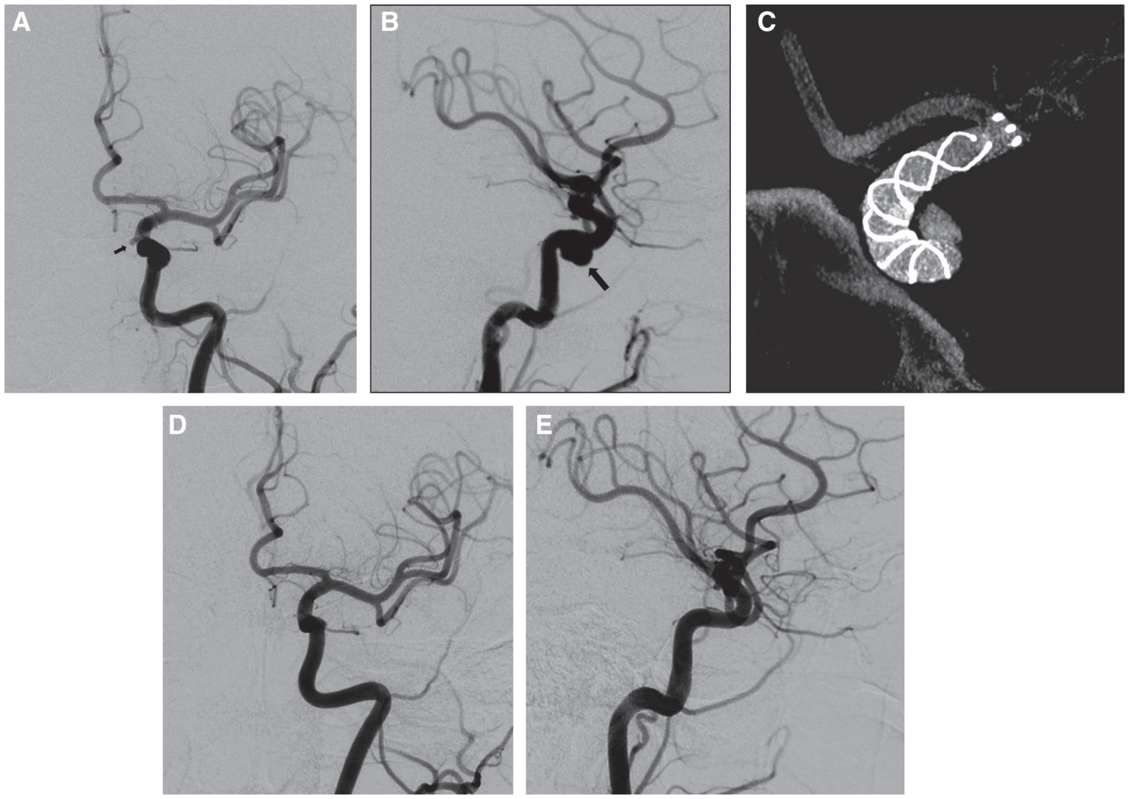

Fig. 2 The patient was a 57-year-old woman who suffered from ptosis of the right eye. A, B, In the left carotid, DSA revealed a VSA at the right medical paraclinoid ICA (small arrow) and medium-size aneurysm at the right cavernous ICA (big arrow). C, She underwent FD to manage these two aneurysms. D, E, Carotid DSA on 13-month post-FD stenting showed CO of the aneurysms; gradual resolution of her ptosis was observed. CO = complete obliteration; DSA = digital subtraction angiography; FD = flow diverter; ICA = internal carotid artery; VSA = very small aneurysm.

overgrowth covers the stent, reconstructing the parent artery, eliminating the aneurysm/parent vessel interface, and maintaining the patency of the side branch of the parent artery. As opposed to aneurysm coiling, FDs cause aneurysms to thrombose gradually rather than immediately at the end of the procedure. FDs were initially reserved to treat complex, large, giant, and fusiform aneurysms, which were less effective or difficult to manage by traditional aneurysm coiling because of insufficient treatment or aneurysm recurrence. With the growing data and relevant reports, FDs are now increasingly selected to manage small or less complex aneurysms in many institutions. Chalouhi et al[12] selected an FD to treat 100 small intracranial aneurysms with a mean size of 5.2 mm, 72% CO was achieved using 6.3-month imaging follow-up data, and symptomatic procedure-related complications occurred in 3%. Griessenauer et al[13] reported the use of FD in managing 69 small aneurysms of the paraophthalmic ICA and CO was achieved in 81.5% at a mean of 11.5 months of radiographic follow-up. Mild neurologic deficits occurred in 3% of the patients.

Theoretically, the application of an FD within the parent vessel for the treatment of VSAs has two major advantages. First, FD can shorten the procedure time because aneurysm catheterization and coiling are not required; a shorter procedure time frame is usually associated with fewer risks for periprocedural complications. Second, FDs prevent intraprocedural aneurysm rupture related to aneurysm catheterization or ischemic change resulting from coil migration or protrusion into the parent artery or its branch. The procedure of FD application in managing

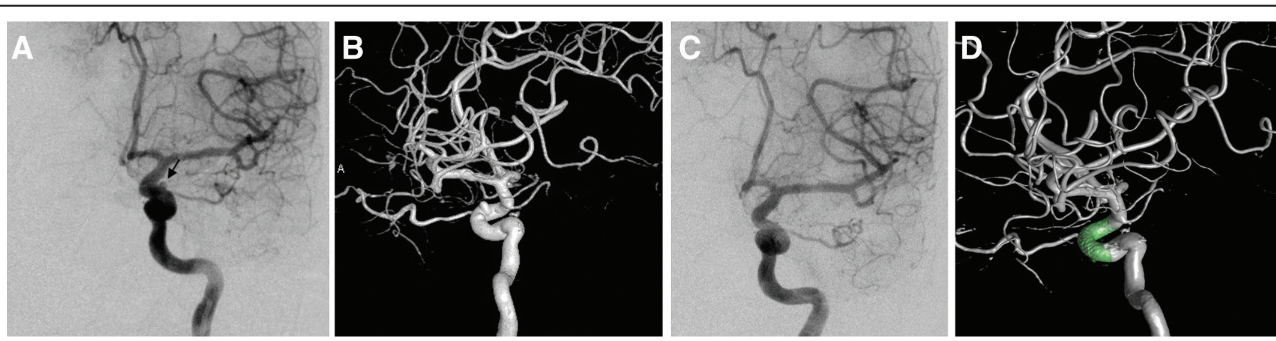

Fig. 3 The patient was a 55-year-old man. A, B, Conventional and reconstruction DSA depicted two VSAs at the left paraophthalmic ICA (arrows). C, D, He underwent FD stenting to manage these two VSAs and showed CO of the aneurysm sacs on 10-month postembolization DSA follow-up. CO = complete obliteration; DSA = digital subtraction angiography; FD = flow diverter; ICA = internal carotid artery; VSA = very small aneurysm.

VSAs is simpler and safer than those in complex larger, giant aneurysms because navigation of the microcatheter to the distal parent artery maybe difficult due to the difficult anatomy of the parent artery aneurysm and the microcatheter is usually looped in the aneurysm sac; thus, finding the distal parent artery or straightening the looping microcatheter for subsequent FD deployment is difficult. Moreover, overmanipulation catheter/guidewire system may be associated with intraprocedural hemorrhage. Moreover, to enhance the effect of the CO or to prevent late hemorrhage following FD deployment, adjunctive aneurysm coiling is usually necessary in big and giant aneurysms; this additional procedure may increase periprocedural risks of hemorrhage or of nonhemorrhagic complications.

We successfully navigated and deployed 70 FDs into the targeted locations of the parent arteries with coverage of the aneurysm neck in 69 patients (99%). Treatment of one VSA associated with multiple aneurysms using FD failed; further intervention to manage VSA was not attempted because of the small size of the aneurysm. The success rate of FD deployment in our series was comparable with those in previous series, which ranged from 95% to 99%.[11,14–17] The complication rate (3%) of FDs in the treatment of small aneurysms were reported in two published series.[12,13] These complications were nearly the same with our series of 2.9% and lower than that using FD to manage larger aneurysm with approximately 4.9%. The most common complication of FD was symptomatic ipsilateral ischemic stroke due to in-stent thrombosis or distal emboli, resulting from the poor vessel apposition of the FD or insufficient dual antiplatelet treatment because of clopidogrel resistance.[18] In our series, ischemic complications occurred in two patients (2.9%) because of poor apposition of the FDs (n = 1) or insufficient dual antiplatelet treatment (n = 1). Most cases of immediate FD-related ischemic stroke can be solved by balloon angioplasty or catheter-guided massage to improve FD apposition, plus intravascular infusion of glycoprotein IIb/IIIa to lyse early clots in the stent or distal arterial branch.

The CO rate of aneurysm after FD varied from 76% to 81.5%, depending on the aneurysm size, location, and follow-up time frame.[14–16] A report demonstrated 96% of CO in 5-year follow-up.[16] In our series, CO of aneurysms were achieved in 93% of aneurysms in a mean 13-month DSA follow-up. This midterm angiographic outcome was better than previously published data of FD in small aneurysms with CO of 72%–81.5%.[12,13] The rate of CO in our series was related to the aneurysm size, and our mean size was 2.3 mm compared with 7.8 mm of larger aneurysm (>3 mm), showing statistical significance ($p < 0.05$). In the comparison of 128 patients with 166 aneurysms managed by FD, no significance was observed in the rate of successful FD deployment, immediate alteration of the aneurysm hemodynamic, and periprocedural complications. Adjunctive aneurysm coiling of the aneurysm sac was not necessary in all VSAs; however, 17% of larger aneurysms received coiling to enhance the effect of embolization.

In conclusion, FD was proved to be both safe and effective in managing VSA. The procedure was simpler than those of larger aneurysm. The CO rate was 93% in a midterm angiographic follow-up, which was better than that in larger aneurysms of 3 mm.

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