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# Stent-assisted coiling of intracranial carotid ophthalmic segment aneurysm segment aneurysms: Long-term follow-up from a single center

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ABSTRACT

*Background:* To evaluate the efficacy of stent-assisted coiling (SAC) for the treatment of carotid ophthalmic segment aneurysm segment aneurysms (OSAs) of the internal carotid artery (ICA) through detailed long-term follow-up of a large patient cohort.

*Methods:* We retrospectively analyzed 88 consecutive patients with OSAs between January 2009 and January 2020 at our center. Angiographic results were evaluated using the modified Raymond grading system and clinical outcomes were evaluated using the mRS scale. The primary endpoints were major aneurysm recurrence and poor clinical outcomes for at least 18 months of follow-up. The patients were asked to attend clinical follow-up assessments and possibly undergo DSA or MR via telephone.

*Results:* We enrolled 88 patients with 99 OSAs treated with coiling, of whom 76 were treated with SAC. The coiling procedures were successful in all 88 patients. Overall, complications occurred in 8 patients (9.1%). No procedure-related mortality was observed. 67 (76.1%) experienced immediate aneurysm occlusion at the end of the procedure. Long-term angiographic follow-up (18 months) was available in 45/88 aneurysms (51%) (average 18.7 $\pm$ 5.2 months). Four patients continued their follow-up for 5 years after initial aneurysm treatment. After a clinical follow-up time of 28.7 months (range, 12–51 months), 85 patients (95.5%) achieved favorable clinical outcomes (mRS scores of 0–2).

*Conclusions:* This study indicates that SAC treatment is a safe and effective therapeutic alternative for ruptured and unruptured OSAs. The procedural risks are low with relatively long-term effectiveness.

## 1. Introduction

Approximately 5–11% of all intracranial aneurysms arise in the ophthalmic segment of the internal carotid artery (ICA).[1–3] Aneurysms arising from the ICA distal to the cavernous sinus and proximal to the posterior communicating artery were first described by Drake in 1968.[4] The segment of the proximal ICA have different names, such as carotid-ophthalmic, proximal carotid, paraclinoid, and ophthalmic artery aneurysms. It was classified by Bouthillier et al.[5] as an ophthalmic segment in 1996, and became known as the Bouthillier classification.

Of primary importance is the fact that carotid ophthalmic segment aneurysms are often large and extremely close to highly delicate or complex structures. Craniotomy for clipping can be challenging and usually requires extensive drilling of the clinoid process and mobilization of the optic nerve for adequate proximal control and safe exposure. Furthermore, intraluminal thrombus, atherosclerosis, and calcification at

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the neck can hamper the accurate placement of an aneurysm clip, and bone dust in the intradural compartment after clinoidectomy can result in chronic headaches.[6]

Previous surgical studies[7,8] have reported higher treatment morbidity and mortality rates than those for other anterior circulation lesions. Endovascular treatment (EVT) has become the predominant approach for ophthalmic segment aneurysm segment aneurysms (OSAs) at many centers.[9,10] However, coil embolization of OSAs continues to be associated with a lower rate of complete occlusion and more frequent recurrence,[11] and detailed long-term outcome data and technical aspects for the management of OSAs are still lacking. Hence, this study aimed to further understand the clinical outcomes and treatment techniques for stent-assisted coil (SAC) embolization of OSAs.

## 2. Methods

Clinical records of patients who presented for SAC treatment for OSA between January 2009 and January 2020 under the auspices of the Institutional Review Board of our hospital. Informed consent was obtained from each patient before the study was conducted. Each patient underwent cerebral angiography to determine aneurysm size, shape, and configuration. The feasibility of SAC treatment was assessed by the primary authors (M. H. L. and B. X. G.) and an endovascular team including neurointerventionalists and neurosurgeons.

In this retrospective study, we used the modified Bouthillier nomenclature[5] for carotid segments. The ophthalmic segment was defined as the intracranial ICA extending from the distal dural ring covering the ICA at the anterior clinoid process to the origin of the posterior communicating artery, which represents the segment from the ophthalmic artery to the posterior communicating artery in DSA.[5] OSAs were then classified into 3 types according to where the sac arose: type Ia comprised aneurysms originating from the superior ophthalmic segment of the ICA in proximity to the ophthalmic artery, projected superiorly; type Ib comprised aneurysms originating from the superior ophthalmic segment of the ICA with no ophthalmic artery involvement, projected superiorly; type II aneurysms arose from the ventral ophthalmic segment of the ICA and had no collateral branch, projected inferiorly; type IIIa aneurysms arose from the medial ophthalmic or clinoidal segment of the ICA, and type IIIb aneurysms arose from the lateral ophthalmic ICA.[5,12,13] Fundus sizes were classified as very small (<5 mm), small (5–9 mm), large (10–25 mm), or giant (>25 mm). The necks were defined as narrow (<4 mm) or wide (<4 mm).

In our series, the indications for treatment were surgical difficulties, ruptured aneurysms, symptomatic unruptured aneurysms, and unruptured aneurysms with irregular shapes. Patients with severe stroke or new ischemic events within three months were excluded. Preoperative management and EVT techniques were similar to those described previously.[14,15] Postoperative follow-up angiography was performed in all patients and was independently reviewed by a neuroradiologist (W·W.). All patients were asked to attend the clinical follow-up assessments and undergo DSA or MR via telephone. Any neck remnants were classified according to the modified Raymond-Roy Classification scale.1 Perioperative complications and GOS scores were recorded retrospectively. A soft-tip microguidewire was used to catheterize the aneurysm sac using Echelon 10 (EV3, Irvine, CA, USA) and Excelsior SL-10 (Stryker Neurovascular, Fremont, CA, USA) microcatheters. A second microcatheter was navigated, and the neck of the aneurysm was crossed to deploy a stent. Three types of coils were used: GDC (Stryker Neurovascular, Fremont, CA, USA); Helicoil, Microplex, and Hydrocoil (Microvention Inc., Aliso Viejo, CA, USA); and Nexus and Axium (EV3, Irvine, CA, USA) coils. Three types of stents were used: Neuroform (Stryker Neurovascular, Fremont, CA, USA), Solataire AB (EV3, Irvine, CA, USA), and Enterprise (Codman and Shurtleff, Raynham, MA, USA). Intravenous heparin (usually 50 U/kg as an initial bolus) was administered to achieve an activated clotting time of 200–300 s immediately after femoral puncture for all aneurysms. Heparinization was discontinued after the procedure. All unruptured patients started dual antiplatelet therapy with 75 mg clopidogrel and 100 mg aspirin at least three days before the operation. All patients who underwent SAC embolization were administered aspirin (100 mg) and clopidogrel (75 mg) postoperatively and maintained on aspirin (100 mg daily) and clopidogrel (75 mg daily) for 4 weeks, followed by aspirin alone (100 mg daily) indefinitely; however, preloading with aspirin and clopidogrel was not performed because of the risk of rebleeding.

### 2.1. Statistical analysis

Statistical analyses were performed using SPSS (version 21.0; SPSS Inc., Chicago, Illinois, USA). An independent *t*-test was performed for continuous variables, and a $\chi 2$ test was used to assess correlations between the categorical variables. Continuous variables are presented as mean ± standard deviation (SD), and categorical variables are shown as frequency (n) and percentage (%), where appropriate. Descriptive analyses were performed for baseline demographics, aneurysm and treatment characteristics, and patient outcomes. Statistical significance was set at $p < 0.05$. significant.

## 3. Results

Eighty-eight patients with 99 OSAs were treated with SAC (76/88) or conventional coiling (12/88). The patient demographics and aneurysm characteristics are summarized in Table 1. Most patients were female (68/88, 77.3%). The mean patient age was 55.8 ± 11.1 years. Eight (9.1%) patients presented with multiple aneurysms. Approximately 44% of treated aneurysms were wide-necked. The mean aneurysm diameter was 6.8 mm (range, 2–27 mm), three (3.4%) patients had giant aneurysms, 18 (18.2%) had large aneurysms, 26 (26.3%) had small aneurysms, and 52 (52.5%) had very small aneurysms. A total of 60 patients had unruptured aneurysms. Aneurysm size was 8.2 ± 5.1 mm in the ruptured group and 6.2 ± 5.7 mm in the unruptured group ($p = 0.11$). The mean neck width was 4.28 mm (range, 2–15 mm). Aneurysm neck width did not differ between the two groups (3.9 ± 1.7 mm vs. 3.8 ± 2.2 mm; $p = 0.82$). However, a significantly higher rate of ruptured aneurysms was observed in the type III aneurysm group (Table 1).

The coiling procedures were successful in all 88 patients. The number of stents used was 1.05 per aneurysm. A single stent was used in 72 (94.7%) aneurysms, and multiple stents were used in 4 cases (Fig. 1). 26 and 61 aneurysms were treated using the jailing and post-release techniques, respectively (Fig. 2). Post-interventional ischemic events developed in three patients after SAC. Clinical outcomes at discharge improved

**Table 1**
Baseline characteristics of OSAs.

| | Ruptured cases | Unruptured cases | P value |
|---|---|---|---|
| No. of patients | 28 | 60 | |
| No. of OSAs | 28 | 71 | |
| Age(y) (mean) | 52.1 ± 12.3(29–83) | 57.5 ± 10.1(35–75) | 0.036 |
| Male/Female | 10/18 | 10/50 | 0.059 |
| Diameter | | | |
| <5 mm | 7 | 45 | 0.01 |
| 5–10 mm | 13 | 13 | 0.01 |
| 10–25 mm | 7 | 11 | 0.385 |
| >25 mm | 1 | 2 | 1.0 |
| Mean diameter | 8.2 ± 5.1 | 6.2 ± 5.7 | 0.11 |
| Neck width | | | |
| <4 mm | 14 | 42 | 0.5 |
| >4 mm | 14 | 29 | 0.5 |
| Mean neck width | 3.9 ± 1.7 | 3.8 ± 2.2 | 0.82 |
| Type of OSAs | | | |
| Type 1a | 2 | 8 | 0.42 |
| Type 1b | 6 | 7 | 0.12 |
| Type 2 | 2 | 13 | 0.44 |
| Type 3a | 16 | 36 | 0.36 |
| Type 3b | 2 | 7 | 0.51 |

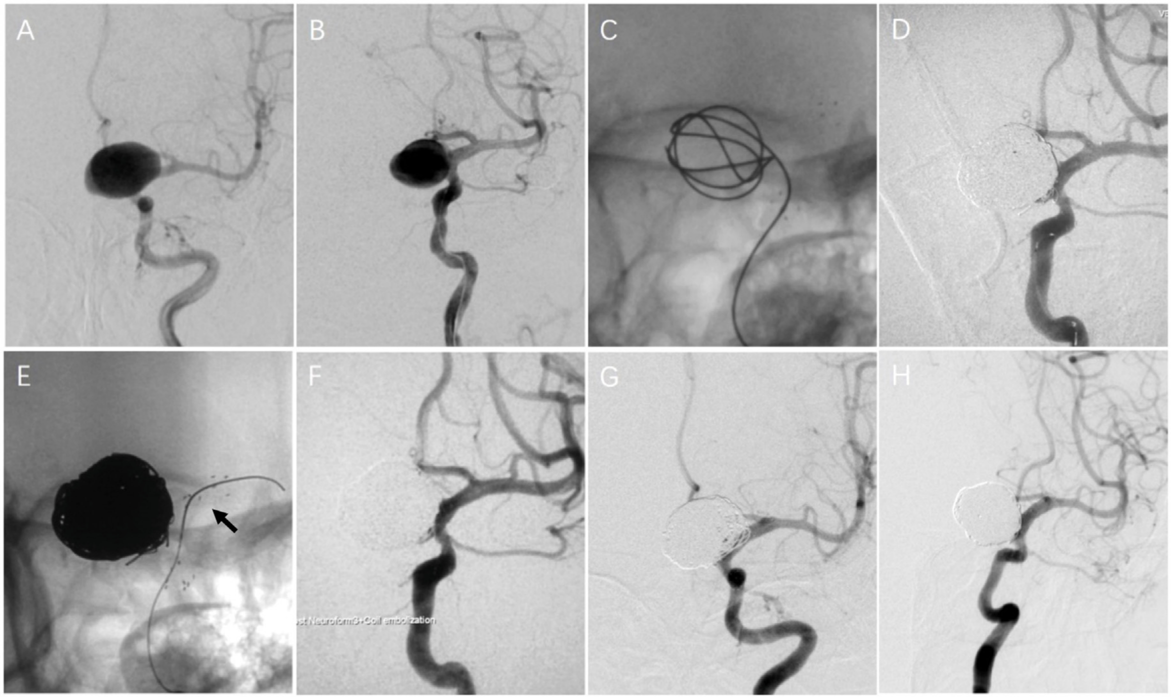


**Fig. 1.** A 56-year-old female patient suffering from vision loss. A, anterior-posterior angiograms of left ICA showing a large OSA with type IIIb. B, first Neuroform™ stent deployed. C, a microcatheter passing through the stent strut. D, neck of aneurysm failed to completely embolize. E, second Neuroform™ stent (arrow) deployed. F, immediate angiograms showing near-complete occlusion of the aneurysm. G and H, serial angiograms at the 60-month follow-up showing stable occlusion of the aneurysm.

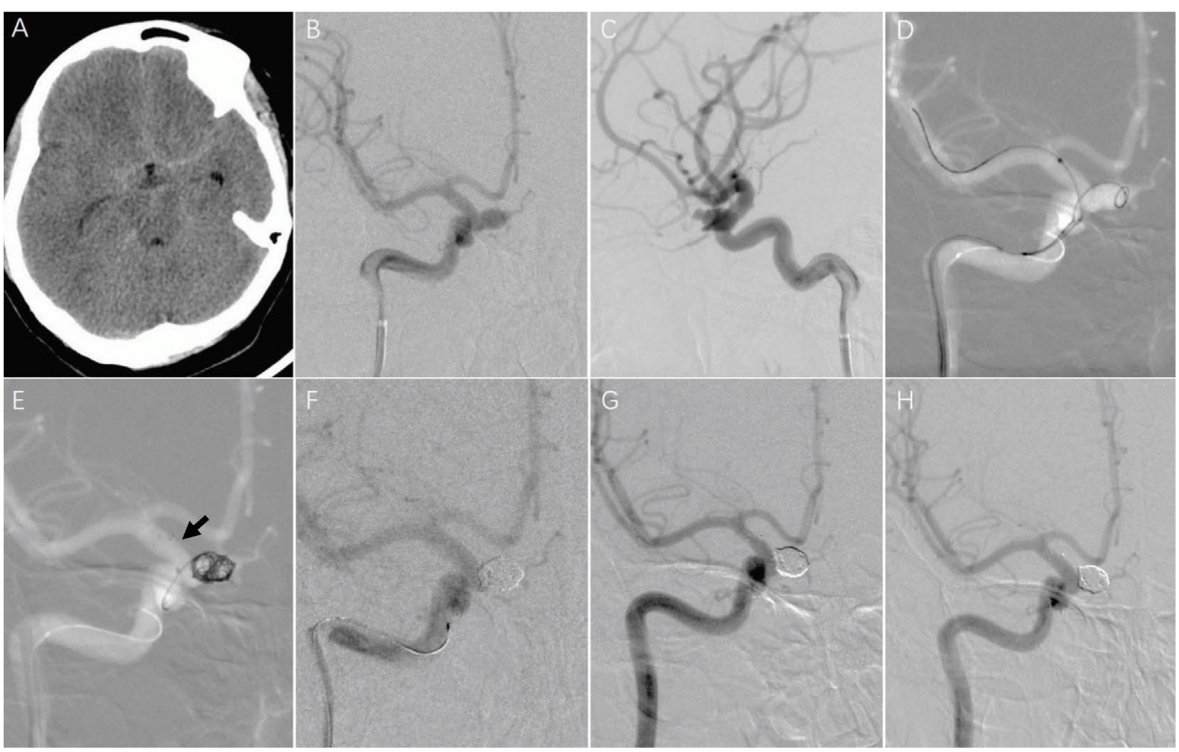


**Fig. 2.** A 30-year-old female patient with a FisherIgrade SAH. A, brain CT showing SAH. B and C, the working projection and lateral angiogram of the right ICA showing a ruptured OSA with type IIIa. D and E, roadmap showing stent-jailing technique where the Neuroform™ stent microcatheter and the coil microcatheter were placed(arrow). F, immediate angiograms showing the complete occlusion of the aneurysm. G and H, angiograms at the 6- and 24-month follow-ups showing stable occlusion.

in all patients. Of the five patients (4.5%) with technical complications, coil migration during SAC occurred in two patients (2.3%), and stent migration was encountered in three patients (2.3%) without clinical sequelae. Overall, complications occurred in 8 patients (9.1%). No procedure-related mortality was observed. After a clinical follow-up time of 28.7 months (range, 12.1–51.2 months), 85 patients (95.5%) attained favorable clinical outcomes (mRS scores of 0–2).

Angiographic follow-ups were performed in 88 patients. Of these, 67 (76.1%) patients had immediate aneurysm occlusion at the end of the procedure (Fig. 1). Of the 71 unruptured aneurysms, 35.2% were occluded immediately with SAC, and 8 of the 13 Raymond class 3 obliterated aneurysms showed progressive thrombosis occlusion during follow-up (Fig. 2) (Table 2). Of the 28 ruptured OSAs, 12 were treated without stent assistance, to reduce the need for antiplatelet therapy. A significantly higher initial Raymond class 1 neck closure rate was observed in the 16 patients with SAC than in the 12 patients without SAC (62.5% vs. 25%, $p = 0.029$), and the 12 patients without SAC showed a significantly higher class 3 remnant rate at follow-up (25% vs. 0%, $p = 0.024$) (Table 3).

## 4. Discussion

Due to their rarity, to the best of our knowledge, there is still a dearth of studies reporting on the SAC management of OSAs compared to the number of other intracranial aneurysms. However, aneurysms in this region are equally complex, commonly multiple and frequently large. The treatment of these aneurysms represents a tremendous technical challenge to neurosurgeons and neuroradiologists.[7] This report summarizes 11 years of experience with patients with OSAs treated with the SAC technique at our institutions. Earlier investigations of EVT have yet to fully address the technical considerations, including treatment options and microcatheter shaping. Nevertheless, this series summarizes the results in a relatively homogeneous group (treated only with SAC) and provides a single-center's operative experience over a recent 11-year period, indicating that SAC is safe and clinically effective in treating these aneurysms.

In our report, the appearance of 94.9% of Class 1 and 2 aneurysm occlusion at the latest follow-up was higher than the reported 44.0–82.9% occlusion rate of endovascularly reported in the literature.[11,16] Meanwhile, 60% of cases showed total angiographic occlusion at the last follow-up. In addition, we did not observe any intraoperative aneurysm rupture. Different types of OSAs may also have different rates of total occlusion, as suggested by our results. In our study, Types II (100%) and III (83.6%) had higher initial total and near-total occlusion rates than Type I (52.2%), which might have been due to better microcatheter stability associated with these inferior aneurysmal projections during embolization. In a previous study, simple embolization alone achieved complete occlusion in only 20% of anterior wall or ophthalmic aneurysms, whereas 85% of posterior wall aneurysms were completely occluded.[1] Sherif et al.[17] also recommended endovascular embolization for inferior or medial projections of small and narrow-necked OSAs. In another study, the occlusion rates of superiorly projecting aneurysms after direct surgery were significantly better than after EVT.[18]

However, aneurysms with superior projections may also have favorable hemodynamic factors for EVT. Our study suggested that type I OSAs may be subjected to lower wall shear stress or more favorable blood flow patterns than OSAs at other sites, which are associated with a reduced coil compression rate and facilitated thrombus formation in the sac.[19–21] Interestingly, the total occlusion rates at the latest follow-up were 73.9%, 60%, and 55.7% for types I, II, and III, respectively. Furthermore, progressive intra-aneurysm thrombosis was noted in one patient with type I OSA.

It should be pointed out that the low reintervention rate after SAC was also due to progressive intra-aneurysm thrombosis. Lawson et al.[22] reported an 89% complete occlusion rate for the SAC group compared to only 40% in the non-stented group, with a much lower recanalization rate (8% vs. 38%). The 4%(4/99) recurrence rate in our report is comparable with that reported in previous SAC-treated OSA series.[23] All recanalized cases were treated with SAC, and three showed total occlusion at the latest follow-up.

**Table 2**
Immediate and last angiographic results of EVT for OSAs.

| Immediate (%) | Ruptured OSAs | | | Unruptured OSAs | | |
|---|---|---|---|---|---|---|
| | Class 1 | Class 2 | Class 3 | Class 1 | Class 2 | Class 3 |
| Type Ia | 100 (2/2) | 0 | 0 | 37.5 (3/8) | 37.5 (3/8) | 25 (2/8) |
| Ib | 66.7 (4/6) | 33.3 (2/6) | 0 | 42.9 (3/7) | 42.9 (3/7) | 14.3 (1/7) |
| Type II | 0 | 100 (2/2) | 0 | 38.5 (5/13) | 61.5 (8/13) | 0 |
| Type IIIa | 43.8 (7/16) | 56.3 (9/16) | 0 | 33.3 (12/36) | 38.9 (14/36) | 27.8 (10/36) |
| IIIb | 0 | 100 (2/2) | 0 | 28.6 (2/7) | 71.4 (5/7) | 0 |
| Last (%) | Class 1 | Class 2 | Class 3 | Class 1 | Class 2 | Class 3 |
| Type Ia | 100 (2/2) | 0 | 0 | 62.5 (5/8) | 37.5 (3/8) | 0 |
| Ib | 83.3 (5/6) | 16.7 (1/6) | 0 | 71.4 (5/7) | 14.3 (1/7) | 14.3 (1/7) |
| Type II | 50 (1/2) | 50 (1/2) | 0 | 61.5 (8/13) | 38.5 (5/13) | 0 |
| Type IIIa | 56.3 (9/16) | 43.7 (7/16) | 0 | 58.3 (21/36) | 30.6 (11/36) | 11.1 (4/36) |
| IIIb | 50 (1/2) | 50 (1/2) | 0 | 42.9 (3/7) | 57.1 (4/7) | 0 |

**Table 3**
Initial and last follow-up results for 28 ruptured cases treated with and without stent assistance.

| | Techniques | | p value |
|---|---|---|---|
| | Stent | Non-stent | |
| Immediate immediate angiographic results(%) rowhead | | | |
| Class 1 | 62.5(10/16) | 25(3/12) | 0.029 |
| Class 2 | 37.5(6/16) | 75(9/12) | 0.067 |
| Class 3 | 0 | 0 | – |
| 3–6 months follow up(%) rowhead | | | |
| Class 1 | 62.5(10/16) | 25(3/12) | 0.067 |
| Class 2 | 37.5(6/16) | 41.7(5/12) | 1 |
| Class 3 | 0 | 33.3(4/12) | 0.024 |
| Last follow up(%) rowhead | | | |
| Class 1 | 65(13/20) | 62.5(5/8) | 1 |
| Class 2 | 35(7/20) | 37.5(3/8) | 1 |
| Class 3 | 0 | 0 | – |

Microcatheter shaping requires considerable expertise. Sustained microcatheter stability is essential for coil placement. In our experience, simple cobra or pigtail microcatheter shaping is generally used for ventral OSA (Type II). Some authors recommend that an anti-S shape is effective for Type I and II OSA, and a simple cobra or 2D pigtail figure is effective for Type III.[24] In superiorly directed OSA, S-figured and straight microcatheters are generally used, whereas straight microcatheters are particularly helpful in aneurysms more proximally situated at the carotid siphon. Considering that 43.4% of the OSAs in our study were wide-necked, large, and irregularly shaped, they could be particularly difficult to obliterate.

In our institute, SAC is more frequently used to treat ruptured OSAs because, in our experience, it can facilitate a more stable aneurysm neck sealing. Both open- and closed-cell stents were used to treat aneurysms at this site. A closed-cell stent with a smaller cell size may be effective in treating small aneurysms in the vessel curvature of the ophthalmic segment to prevent coil herniation. When the passage of a microcatheter through the stent wall was considered challenging because of the tortuosity of the ophthalmic segment, the jailing technique was chosen to prevent stent motion or migration.[25,26] The two cases of coil shift observed in the study were mainly because the ending coils failed to wind well with the previous coils.

The overall complication rate was 9.1%, with a mortality of 0%, respectively. These findings are within the range of morbidity (0.8–21%) and mortality (0–2.2%) reported for SAC-treated OSAs in the literature.[11,27] No ophthalmic artery occlusion or delayed optic ischemia occurred. We observed no rebleeding, which may have resulted from dense coil occlusion of the aneurysmal orifice achieved using the SAC technique. Recent studies.[28] have suggested negligible rates of early and midterm rebleeding, implying that with increasing experience and improved devices, the rate of early rebleeding after coil embolization may decrease.

Based on our institutional data, at least 60% of the treated unruptured OSAs were less than 5 mm in diameter. Currently, there are no uniform recommendations for the management of asymptomatic, unruptured OSAs. Fusiform dissecting aneurysms are the most difficult OSAs to treat. Li et al.[29] reported an intracranially covered stent that could navigate through tortuous vascular segments at the skull base. One patient in our series was treated with a covered stent because of the challenging morphology of a blood-blister-like aneurysm, which was totally occluded. The clinical application of the flow-diverting device is an effective alternative technique for treating OSAs in recent years.[30] Our series will also serve as a baseline for comparison with FDDs technologies.

### *4.1. Limitation*

Our study has several limitations. The present study was a retrospective study of ICA OSAs treated using the SAC approach, and the treatment strategy was chosen based on experience. Second, variable imaging modalities affect the sensitivity and specificity of occlusion status evaluation.

## 5. Conclusions

This study included a large number of ICA SAs and provided detailed clinical and radiological outcomes as well as technical considerations. An appropriately shaped microcatheter is mandatory and can facilitate safe entry and sustained stability for the SAC treatment of OSAs. Our experience indicates that SAC treatment is a safe and effective therapeutic alternative for ruptured and unruptured OSAs. However, the procedural risks are low, with relatively long-term effectiveness.

## Declaration of interest

MingHua Li is Editor-in-chief for Journal of Interventional Medicine and was not involved in the editorial review or the decision to publish this article. All authors declare that there are no competing interests. This study was supported by grants from the National Natural Science Foundation of China, grant no. 81370041, 81771233, 81671655, the Outstanding Clinical Discipline Project of Shanghai Pudong, grant no. PWYgy2018-04.

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