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CLINICAL ARTICLE

Endovascular treatment of complex intracranial aneurysms using intra/extra-aneurysmal stent

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Abstract
Background Intra/extra-aneurysmal stent placement for treatment of complex and wide-necked bifurcation aneurysms has been previously described. However, this technique has been rarely reported in the treatment of dissecting aneurysms with incorporated vessels. We assess the feasibility and effectiveness of intra/extra-aneurysmal stent-assisted coil embolization in the treatment of those complex intracranial aneurysms.
Methods Between January 2009 and April 2010, nine consecutive patients with wide-necked or dissecting aneurysms with incorporated vessels underwent endovascular treatment using intra/extra-aneurysmal stent-assisted coiling at our institution. We assessed the clinical history, morphologic features of the aneurysms, treatment results, and follow-up.
Results All Neuroform stents were successfully deployed in this series. Of the nine aneurysms treated with stent-assisted embolization, complete occlusion was achieved in seven aneurysms, nearly complete in one, and incomplete was present in one. There was no procedure-related complication in this series. Angiographic follow-up results of eight patients (mean, 8.6 months) showed continued obliteration of the aneurysms in six patients, incomplete occlusion in two patients, and the two patients received second treatment. On the modified Rankin Scale applied in follow-up, all patients were assessed as functionally improved or of stable clinical status.
Conclusions Intra/extra-aneurysmal stent placement and subsequent coil embolization may be effective for the treatment of selected patients with complex intracranial aneurysms. Short-term follow-up data indicate good durability of stent-assisted aneurysm occlusion. However, further study with longer follow-up and larger case series is necessary for validation of the efficacy of this treatment modality.

Keywords Neuroform stent · Endovascular · Complex · Wide-necked aneurysm · Dissecting

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Introduction

Endovascular treatment with stent placement or stent-assisted coiling has recently been applied to intracranial aneurysms [2–5, 8, 9, 23]. Under most conditions, extra-aneurysmal stents are placed within the parent vessel to cover the aneurysm neck. The stent serves as a mechanical scaffold for coiling embolization of wide-necked aneurysms. For wide-necked aneurysms located at bifurcations, such as middle cerebral artery or basilar artery apex, Y-configuration stent placement is often used for coiling embolization [6, 20–22]. However, increased thrombotic potential is a major problem for a Y-stent technique due to double-stent placement. If possible, a single stent instead of double stent, aiming at protecting both incorporated branches, is considered. In addition, aneurysms with branch vessels arising from the neck offer significant technical challenges. Sometimes, a stent cannot be inserted into the incorporated branch because of its small size and/or acute angulation to the parent artery. Therefore, the waffle-cone technique is preferred [12], aiming to protect incorporated branches with intra/extra-aneurysmal stent deployment.

Intra/extra-aneurysmal stent placement for treatment of complex and wide-necked bifurcation aneurysms, the so-called waffle-cone technique, has been previously described [10, 12, 24]. However, this technique has been rarely reported in the treatment of dissecting aneurysms with incorporated vessels. Moreover, the small number of former series and the lack of follow-up prevent evaluating potential for recanalization. Here we report our experience with intra/extra-aneurysmal stent placement for endovascular treatment of those complex aneurysms and treatment durability at short-term follow-up.

Materials and methods

Patient population

Between January 2009 and April 2010, nine consecutive patients with complex intracranial aneurysms underwent endovascular treatment using intra/extra-aneurysmal stent-assisted coiling at our institution. All patients were evaluated by two neurosurgeons (Y. G. and D. S.) and two neuroradiologists (Y. T. and B. L.). There were three men and six women in the study group, with age ranging from 29 to 62 years (mean age, 52.1 years). Demographic and clinical presentation data of the patient population are shown in Table 1. Among them were one wide-necked aneurysm at anterior communicating artery (AComA) involving the A2 segment of the anterior cerebral artery (ACA), four wide-necked aneurysms located at basilar apex involving the posterior cerebella artery (PCA), and four dissecting aneurysms of the intracranial vertebral artery (VA) involving the posterior inferior cerebella artery (PICA). At presentation, two patients had acute subarachnoid hemorrhage (SAH), four had ischemic symptoms, two had headache, and one with accidental finding.

Procedures

Patients with unruptured aneurysms were given antiplatelet agents (75 mg/day of clopidogrel and 300 mg/day aspirin) for 3 days before the procedure. These patients received systemic heparinization after placement of the sheath. The activated clotting time was maintained at two to three times the baseline throughout the procedure. For patients with acutely ruptured aneurysms, no antiplatelet regimen was given. The patients received systemic heparinization after stent placement. Low molecular weight heparin (40 mg, every 12 h, hypodermic injection) was administered immediately after the procedure for 3 days. All patients were kept on a regimen of aspirin and clopidogrel postoperatively for 3 months, after which clopidogrel was no longer given.

All procedures were performed with the patient under general anesthesia and via the transfemoral approach. A 5- or 6-Fr Envoy guiding catheter (Cordis, Miami Lakers, FL, USA) was placed in the distal vertebral artery of internal carotid artery. With the help of a microcatheter (Prowler 14; Cordis, Johnson and Johnson Medical), a microguidewire (Transcend 0.014-in. wire; Boston Scientific-Target, Fremont, CA, USA) was introduced into the parent artery. The Neuroform stent (Boston Scientific-Target) was advanced over a Transcend 0.014-in. wire. The diameter of stent was decided by the size of the aneurysm neck and the proximal diameter of the parent artery. The stent was deployed and released with appropriate length of distal stent end in the fundus of the aneurysm. The coil microcatheter was then positioned into the aneurysm through the stent. Finally, the aneurysm was sequentially coiled using detachable coils.

Table 1 Summary of clinical characteristics of nine patients with complex aneurysms

Patient no.	Age (years) /sex	Clinical presentations	HH	mRS	Aneurysm location	Types	Aneurysm size (mm)
1	57/M	SAH	1	3	AComA	Saccular	7×9
2	62/F	Headache	0	1	Basilar apex	Saccular	9×5
3	47/M	Ischemia	0	0	Basilar apex	Saccular	10×10
4	62/F	Incidental	0	0	Basilar apex	Saccular	8×7
5	57/F	Headache	0	1	Basilar apex	Saccular	27×24
6	29/F	Ischemia (CN V deficits)	0	3	R-VA-PICA	Dissecting	8×4
7	53/M	Ischemia	0	0	L-VA-PICA	Dissecting	8×6
8	51/F	Ischemia	0	1	R-VA-PICA	Dissecting	8×6
9	61/F	SAH	3	4	L-VA-PICA	Dissecting	6×6

AComA anterior communicating artery, *HH* Hunt and Hess, *L* left, *mRS* modified Rankin Scale, *R* right, *SAH* subarachnoid hemorrhage, *VA* vertebral artery, *PICA* posterior inferior cerebellar artery

For dissecting aneurysm of the vertebral artery, balloon test occlusion (BTO) was performed to assess the feasibility of internal trapping of a dissected segment, for an occlusion time of 20 min [13].

Evaluations and follow-up

The technical feasibility of stent-assisted coiling procedure and occlusion of aneurysms after stent placement was evaluated [1]. The grades of aneurismal occlusion subsequent to coiling procedure were divided as complete (100% occlude), nearly complete (≥95% occluded), and incomplete (<95% occluded). These grades were determined independently by two authors (B. L. and D.S.).

The safety of this procedure was evaluated by the incidence of any procedure-related complications, including rupture of the aneurysm or parent vessel, and a thromboembolic or a hemorrhagic event during the procedure or within 30 days after the procedure. Follow-up was determined by physical examinations, and modified Rankin score (mRS) was assigned. Overall outcomes were defined as excellent, mRS 0 to 1; good, mRS 2; poor, mRS 3 to 4; or death, mRS 5. Follow-up angiography was also recommended, including 3-month MR angiography and 6-month digital subtraction angiography (DSA).

Results

Endovascular treatments are summarized in Table 2. Overall, nine Neuroform stents were implanted partially within the aneurysm lumen and the parent vessel lumen. Stent release and positioning were considered optimal in eight (88.9%) patients and suboptimal in one. There was no procedure-related complication in this series, including rupture of the aneurysm or parent vessel, and a thromboembolic or a hemorrhagic event during the procedure.

Patients with wide-necked saccular aneurysm

In five patients with saccular aneurysm, immediate angiographic outcomes were complete occlusion (three patients), nearly complete occlusion (one patient), and incomplete occlusion (one patient). Angiographic follow-up ranging from 4 to 12 months was available in all five patients. Follow-up angiograms of these patients showed complete occlusion (three patients) and incomplete occlusion (two patients), and there was no evidence of in-stent stenosis. In these two patients, retreatment was performed using additional coils embolization. Postembolization angiographic results showed aneurysm occlusion in patient 2. In patient 5, despite of sequential coil embolization, it was unable to achieve compact coil packing of the neck.

One patient with ischemic stroke had excellent outcomes (mRS, 0) without no new neurologic deficits during the follow-up period of 12 months. One patient with accidental finding had excellent outcomes (mRS, 0), and another patient with SAH also had excellent outcomes (mRS, 0). In the remaining two patients with headache, no aneurysm bled regardless of incomplete occlusion. However, these patients still suffered headache (mRS, 1).

Patients with VA-PICA dissecting aneurysm

To determine the feasibility of internal trapping of a dissected segment, BTO of the affected parent VA was performed. During a 20-min occlusion, these patients with VA-PICA dissecting aneurysm suffered no neurologic manifestation of ischemia. Therefore, we performed internal trapping of the dissected site with revascularization of the PICA by the waffle-cone technique. In all four patients with VA-PICA dissecting aneurysm, immediate angiographic outcomes were complete occlusion (four patients). Angiographic follow-up ranging from 5 to 15 months was available in three patients. One patient was lost to follow-up because of address change. All these aneurysms and

Table 2 Summary of treatment options, complication, and follow-up outcomes

Patient no.	Stent (mm)	Immediate results	Complication	Follow-up (months)	Angiographic result	Follow-up mRS
1	NF 4.0/15	Complete	None	12, DSA	Complete	0
2	NF 4.5/15	Nearly complete	None	4, DSA	Incomplete	1
3	NF 4.5/20	Complete	None	12, DSA	Complete	0
4	NF 4.5/15	Complete	None	9, DSA	Complete	0
5	NF 4.5/20	Incomplete	None	4, DSA	Incomplete	1
6	NF 4.0/15	Complete	None	8, DSA	Complete	2
7	NF 4.5/15	Complete	None	5, DSA	Complete	0
8	NF 4.5/20	Complete	None	15, DSA	Complete	0
9	NF 3.0/15	Complete	None	NA	NA	NA

NF Neuroform, *mRS* modified Rankin Scale occluded arterial segments remained occluded on follow-up angiograms, and the PICA was preserved well.

One patient with facial numbness and left limb numbness was unable to carry out all previous activities but was able to look after her own affairs without assistance (mRS, 2). In two patients with ischemic stroke, there were no instances of postprocedural ischemic attacks, new neurologic deficits, or minor or major strokes (mRS, 0) during the follow-up periods of 5 to 15 months. One patient with SAH was disabled at admission (mRS, 4) but had improved functional ability at discharge (mRS, 2). However, the patient was lost to follow-up because of address change.

Illustrative cases

Case 1

A 57-year-old man (patient 1) presented with sudden headache 2 days ago. Computed tomography (CT) scan revealed acute subarachnoid hemorrhage. DSA showed a 7-mm aneurysm with incorporation of the A2 segment of the right ACA. Moreover, acute angle between AComA and A2 segment of right ACA was defined (Fig. 1a). The procedure was performed under general anesthesia and no antiplatelet regimen. A 6-Fr guiding catheter was placed into the left internal carotid artery. A Neuroform stent (4.0×15 mm) was placed partially within the fundus of the aneurysm and proximal end anchored in the left A1 segment of ACA (Fig. 1b). Full heparinization (activated clotting time >250 s) was instituted after stent placement. The aneurysm was then sequentially coiled to complete obliteration, despite of slight compromise of distal flow (Fig. 1c). The patient suffered no posttreatment complications and was discharged 14 days later. The 12-month follow-up angiography showed no recurrence of the aneurysm (Fig. 1d).

Case 2

A 47-year-old man (patient 3) presented with vertebrobasilar insufficiency for 3 months. CT and MRI scan revealed posterior circulation cerebral aneurysms. Angiography showed a 10-mm basilar apex aneurysm that incorporated

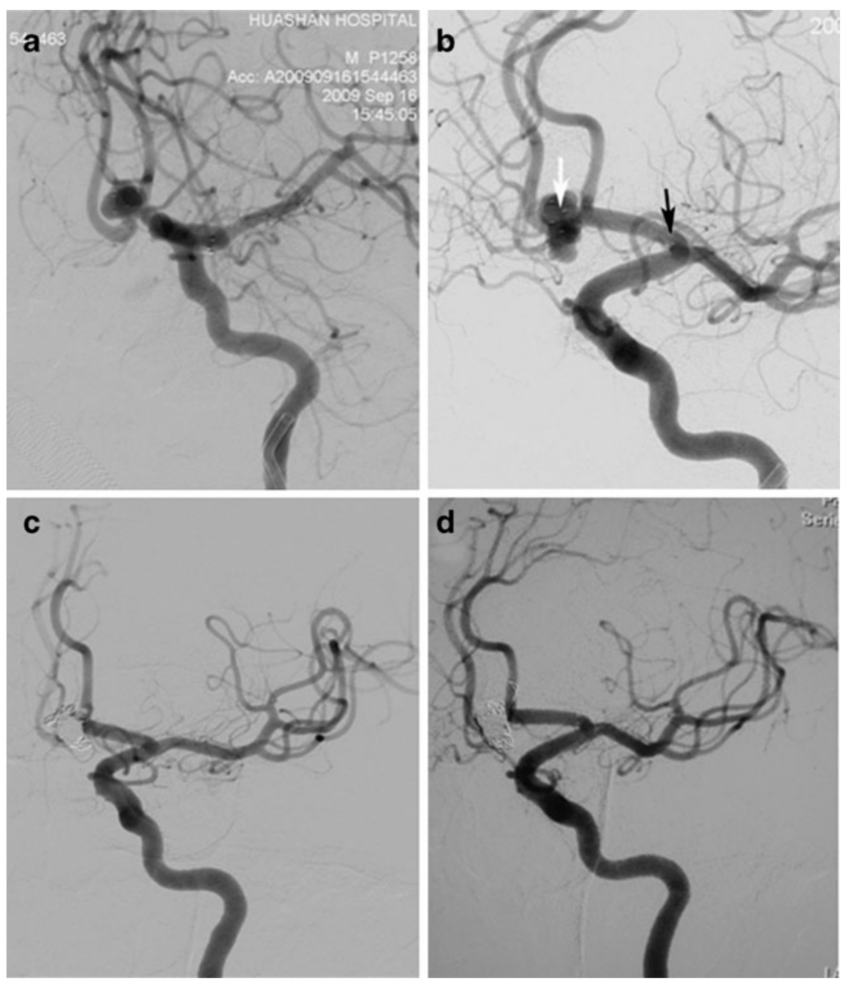

Fig. 1 **a** Left ICA angiogram in oblique view showing a wide-necked AComA aneurysm with incorporation of the A2 segment of the right ACA; **b** Neuroform stent markers in proximal fundus (*white arrowhead*) and left A1 (*black arrowhead*); **c** the aneurysms was coiled to complete obliteration; **d** the 12-month follow-up angiography showing no recurrence

both the origins of the PCA (Fig. 2a). With use of a technique similar to that used in patient 1, a 4.5×20-mm Neuroform stent was placed directly into the aneurysm with the proximal end anchored in the basilar artery trunk (Fig. 2b). The aneurysm was then sequentially coiled using Guglielmi detachable coils (Boston Scientific) in combination with Microplex coils (Microvention, USA). At the conclusion of the procedure, the aneurysm disappeared completely, and bilateral PCA were preserved well (Fig. 2c). The 12-month follow-up showed persistent occlusion of the aneurysm (Fig. 2d).

Case 3

A 29-year-old woman (patient 6) presented with right facial numbness and left limb numbness for 3 months. DSA revealed dissecting aneurysm of right vertebral artery with the right PICA originating from the neck of the aneurysm (Fig. 3a). The left vertebral artery was dominant, and the patient also received successful BTO. With use of a similar technique to that described above, a 4.0×15-mm Neuroform stent was placed partially within the aneurysm lumen with the remainder of the stent anchored in the right VA (Fig. 3b). The aneurysm and the distal vertebral artery just proximal to the aneurysm were then completely occluded, and the right PICA was preserved well (Fig. 3c). The 8-month follow-up angiography in right VA showed that dissected segment was completely occluded and the patency of PICA (Fig. 3d).

Discussion

Stent-assisted coil embolization is currently a widely used technique in the treatment for wide-necked intracranial aneurysms [2–5, 8, 9, 23]. Under traditional conditions, the stent bridged from the proximal afferent feeding artery across the neck to the distal efferent artery. The stent provides a mechanical scaffold that prevents coil herniation into the parent vessel, thus facilitating more complete aneurysm packing. Moreover, the stent may prevent aneurysm recanalization by flow redirection and facilitating the remodeling of the aneurysm neck. For wide-necked bifurcation aneurysms, such as those arising from middle cerebral artery or basilar artery apex, the Y-configuration stent placement (using two stents) could be options [6, 20–22]. However, double stent might increase thrombotic potential compared with a single stent. Additionally, a stent sometimes cannot be inserted into the incorporated branch because of its small size and/or acute angulation to the parent artery. Thus, we use an intra/extra-aneurysmal stent placement to protect incorporated branches. Moreover, in tortuous parent vessel, the stent can easily be placed into the aneurysm fundus and

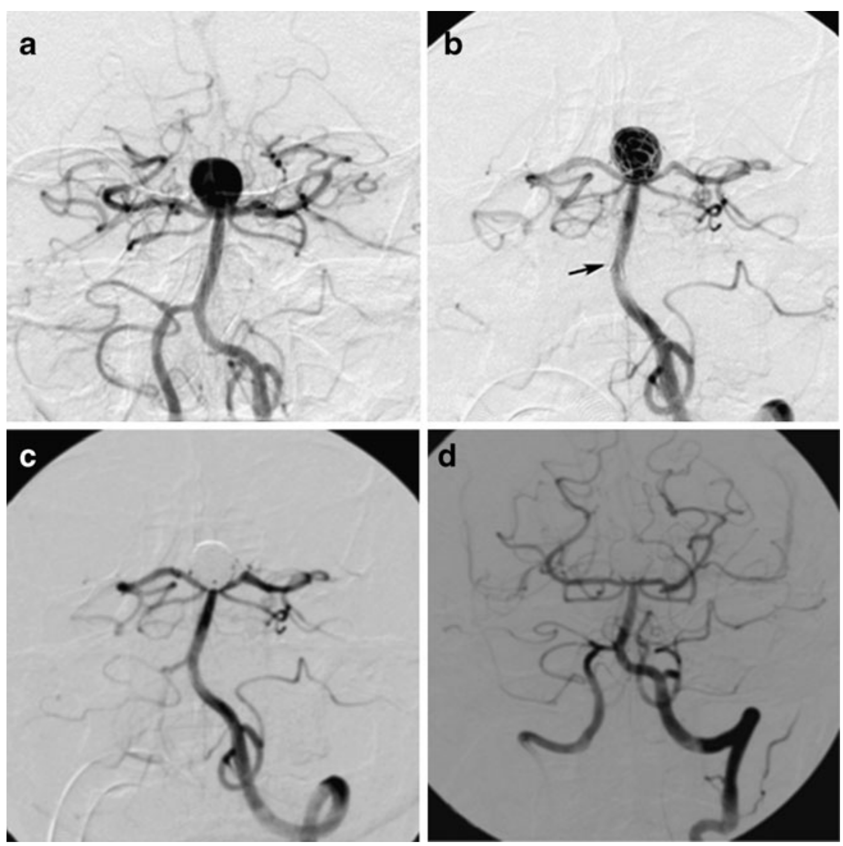

Fig. 2 **a** Left VA angiogram in anteroposterior view showing a wide-necked basilar apex aneurysms incorporating bilateral PCA; **b** Neuroform stent markers in proximal fundus and BA (*arrowheads*); **c** the aneurysms was coiled to complete obliteration, and bilateral PCA were preserved well; **d** the 12-month follow-up angiography showed no recurrence

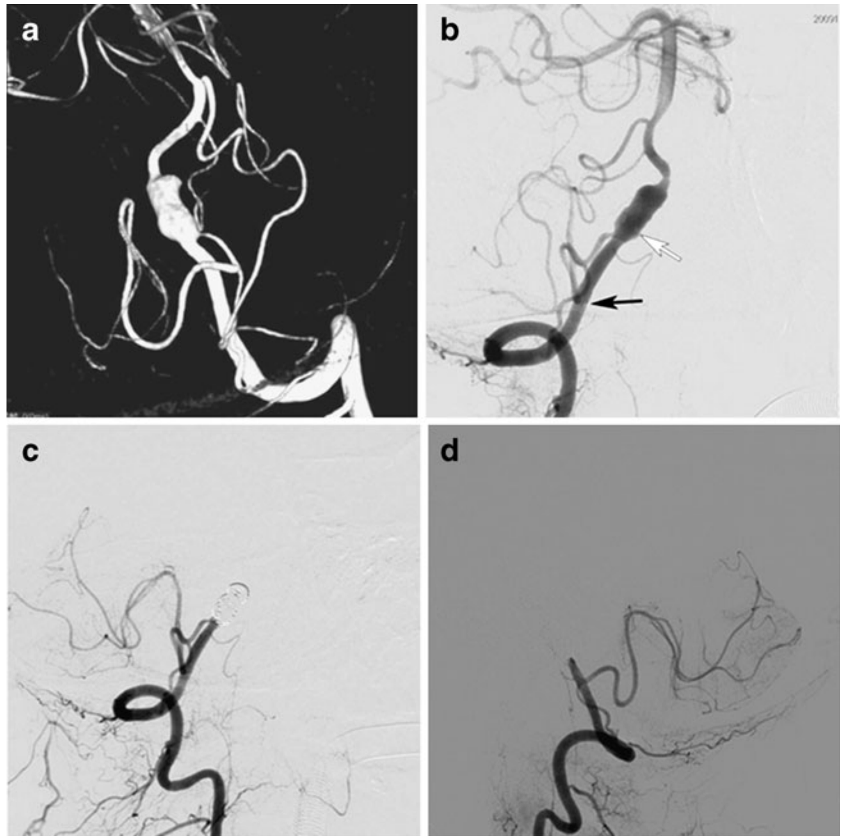

Fig. 3 **a** Three-dimensional reconstruction image in oblique view showing a right VA dissecting aneurysm involving the origin of the PICA; **b** Neuroform stent marker in proximal fundus (*white arrowheads*) and VA (*black arrowheads*); **c** the dissected segment was completely occluded by coil embolization, and right PICA was preserved; **d** the 8-month follow-up angiography in right VA showing that dissected segment was completely occluded

deployed, avoiding the risks of passing wires and stents distally. In our report, the stent was placed into the proximal fundus of the aneurysm fundus, and the proximal stent is deployed in the parent vessel lumen. Because the appearance of the stent/coil combination after treatment is like ice cream, we call it "ice-cream technique", which was also called "waffle-cone technique" [12].

Selection of stent

In our series, we preferred the Neuroform self-expanding stent for the treatment of complex intracranial aneurysms. Because of its open-cell design, the distal aspect of the stent within the aneurysm fundus acts to capture and restrain the initial coils, holding them within the aneurysm and allowing for neck reconstruction. Although the Enterprise stent is another stent with better navigability and flexibility [11], its close-cell design limited its use in our series. During coiling embolization of aneurysms, the stent cannot reconstruct the aneurysm neck, which resulted in neck remnants.

The diameter of the stent was decided by the location of incorporated vessels arising from the aneurysm neck. In our opinion, the diameter of the stent would better be large enough to protect incorporated branches. If the distance between incorporated vessels and the neck exceeded the diameter of the stent, this technique might be ineffective. In patient 5, the giant basilar apex aneurysm was 27 mm in diameter. Although the stent was placed into the fundus of the aneurysm and sufficiently released, it could not effectively cover bilateral initial segment of the PCA. However, the aneurysm sac protruded toward the anterior direction, the angle between the sac and neck, was formed. Thus, the stent only provided vertical protection after placement. Despite of sequential coil embolization, it was unable to achieve compact coil packing of the neck.

Selection of aneurysm morphology

In our series, the waffle-cone technique was used in two types of intracranial aneurysms, including saccular and dissecting. Although protecting neck devices such as remodeling balloons or self-expandable stents are used in the treatment of wide-necked saccular aneurysms, these techniques may be limited in treatment aneurysms with an incorporated branch [15, 16]. When a balloon or a stent cannot be inserted into the corporated branch because of its small size or acute angulation to the parent artery, catheter-supported technique may be used [15]. However, post-embolization angiography revealed that mostly of them were nearly completely occluded. In our experience, the waffle-cone technique may be effective for selected complex aneurysms. For saccular aneurysms with regular morphology, the diameter of the aneurysm would better exceed 5 mm. If with irregular morphology, subject configuration of the aneurysm should be round or oval shape. Meanwhile, there were enough spaces between the neck and the roof of the aneurysm, so that the stent could open within the aneurysm fundus. However, as above mentioned, if the distance between incorporated vessels and the neck exceeded the diameter of the stent, this technique might be ineffective. Since the stent acts as a flow diverter, this technique risks directing blood flow into the sac of the saccular aneurysms.

To date, dissecting aneurysms of the VA that involve the PICA represent a significant challenge. In patients who had dominant vertebral dissecting aneurysms with poor collaterals, internal coil trapping cannot be applied. Double stents, multiple overlapping stents, or diverting stents may be effective for obliteration of a dissecting aneurysm than a single stent [1, 17]. If the contralateral vertebral artery is equal or greater in caliber, proximal occlusion of the parent artery is an option, but this technique does not protect from rebleeding because of retrograde flow to the dissected segment [19]. Internal coiling trapping including the PICA origin may also be considered. However, previous studies demonstrated lateral medullary and cerebellar infarction due to PICA occlusion [18]. Thus, the ideal method treatment, if possible, is complete isolation of the dissected segment by trapping, with revascularization of the PICA by endovascular procedures as VA to PICA stenting [7]. However, a stent sometimes cannot be inserted into the PICA because of its small size and/or acute angulation to the VA. Therefore, we use this technique not only to protect the PICA but also occlude the dissecting segment.

Stent-assisted coil embolization

Although we experienced no complications, it is likely to cause aneurysm rupture during placing the stent into the aneurysm, especially with freshly ruptured aneurysms. Therefore, we should prevent the stent from puncturing the roof the aneurysm during intra-aneurysmal segment placement.

The location of the distal stent within the aneurysm lumen was depended on the distance between incorporated vessels and the aneurysm neck. Once the distal aspect of the stent opened in the lumen of the aneurysm, it should cover the incorporated vessels against coil extravasation. If the distal end of the stent within the aneurysm lumen is too long, the neck remnants usually occurred. On the other hand, if the intra-aneurysmal segment is too short, it provided no protection. In patient 2, displacement of the stent during deployment resulted in long length of the distal aspect of the stent within the aneurysm lumen and residual aneurysm neck after coil embolization.

During subsequent embolization, the microcatheter entered the aneurysm through intracavity of the stent. We suggested advancing the microcatheter tip further above the tip of the stent. In such position, coils looped from the roof of the aneurysm to the neck, in favor of remodeling of the aneurysm neck during coil delivery. We often select 3D coil as the first coil. The diameter of the coil was close to the aneurysm fundus and larger than the neck.

Antiplatelet strategies

For unruptured aneurysms, patients should be pretreated with aspirin and clopidogrel. Heparin should also be used at the earliest possible moment. However, the protocol of pretreatment with antiplatelet agents for patients with acutely ruptured aneurysms is still controversial. Although some researchers suggested antiplatelet treatment very shortly before stent placement considering of the thrombogenicity of endovascular stents [4–6], we gave no antiplatelet regimen. During procedure, the patients only received systemic heparinization after stent placement. Previous studies have demonstrated that stent-assisted coiling without any pretreatment is safe in ruptured aneurysms [14]. Similar with that, we observed no device-related thromboembolic complications in our series. However, further study is needed to assess the risk of thrombogenicity for different therapy.

Conclusions

Intra/extra-aneurysmal stent placement and subsequent coil embolization may be effective for the treatment of selected patients with complex intracranial aneurysms. By deploying intra/extra-aneurysmal stent, complete coil embolization of some complex lesions can be achieved, while preserving incorporated branches. Long-term durability of this technique remains to be defined. Further study with longer follow-up and larger case series is necessary for validation of the efficacy of this treatment modality.

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Conflicts of interest None.

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Comment

The authors treated nine patients from January 2009 to April 2010 using intra/extra-aneurysmal stent-assisted coiling technique (i.e., "waffle-cone technique"). There were three men and six women, from ages 29 to 62 years. Aneurysms treated were one anterior communicating, four basilar apex, and four intracranial vertebral artery (VA) dissecting aneurysms. There were two patients who presented with subarachnoid hemorrhages, four with ischemic symptoms, two with headaches, and one with an incidental finding. The technique used was placement of the distal end of the Neuroform stent into the fundus of the aneurysm and then coiling of the aneurysm through a microcatheter placed through the stent. The Neuroform stent is an open-cell, self-expanding stent that allows for capture and restrain of initial coils and allows for neck reconstruction. Two patients with saccular aneurysms had incomplete occlusion on follow-up, and retreatment with further coils was performed. Four patients had VA-posterior inferior cerebellar artery dissecting aneurysms that were treated by sacrificing the artery with coil occlusion using the waffle-cone technique. Follow-up showed complete occlusion. All patients received heparin during treatment, but only the patients with nonruptured aneurysms were treated with antiplatelet therapy.

This paper is the largest series reported with use of the waffle-cone technique. The follow-up ranged from 4 to 12 months—the longest follow-up reported in any of the case series on waffle-cone technique. The discussion was very complete and the authors explained the reasons why they chose the specific aneurysms in their series and used the Neuroform stent. They also discussed the reason for the incomplete occlusion; the diameter of the vessels and neck exceeded the stent diameter. The risks of the technique, which are flow diversion into the aneurysm increasing risk of rupture and risk of the stent placement causing aneurysm rupture, were also discussed. The small size of the incorporated branches was discussed as the main reason for choosing the technique.

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