Stent-Assisted Coil Embolization of Wide-Necked Intracranial Aneurysms Using a Semi-Deployment Technique: Angiographic and Clinical Outcomes in 31 Consecutive Patients

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Keywords: intracranial aneurysm, stent, endovascular embolization, therapeutic

Summary

We describe a modified stent-assisted coiling technique, named the semi-deployment technique, in the endovascular treatment of wide-neck aneurysms. Thirty-one consecutive patients with 31 wide-necked or fusiform intracranial aneurysms were treated with the semi-deployment technique. The technical feasibility of the procedure, procedure-related complications, angiographic results, clinical outcome and follow-up angiography were evaluated. In every case, the semi-deployment technique was successfully deployed. Immediate angiography demonstrated complete occlusion in 24 cases (77.4%), neck remnant in four cases (12.9%), and incomplete occlusion in three cases (9.7%). Procedural-related morbidity occurred in one patient (3.2%) but no procedural-related mortality. A favorable clinical outcome (Modified Ran-kin Scale score 0-2) was observed in 90.3% of the patients (average follow-up time, 23.1 months). No rehemorrhage of treated aneurysms occurred. Angiography follow-up was obtained in 22 cases (71.0 %). Three aneurysms (13.6 % of the follow-up angiograms) demonstrated recanalization. No delayed coil or stent migration was found. One patient had in-stent stenosis as a delayed complication. We found that the semi-deployment technique was helpful in the treatment of wide-neck aneurysms.

Introduction

Wide-necked aneurysms (>4 mm or dome-to-neck ratio <2) without a well-defined neck

remain a therapeutic challenge both surgically and endovascularly. Despite significant advances in coil design (e.g. three-dimensional shaped coils) as well as the development of modified techniques of coiling (e.g. balloon-assisted coiling) there remains a substantial number of aneurysms that either cannot be treated successfully with coiling or that, when treated, recur at a high incidence¹⁻³. Stent-assisted coiling has recently emerged as a complement or even as an alternative to balloon remodeling to treat such difficult lesions. Up to now, different stent techniques have been deployed⁴⁻⁸, among which the semi-deployment technique is a novel method and less frequently reported in the literature⁹. This technique combines the flexibility of balloon-assisted coil embolization and the long-term durability of stent-assisted embolization. This report describes this modified stent-assisted coiling technique, a semi-deployment technique, used successfully to occlude wide-necked aneurysms with a self-expandable stent (non-retrievable stent included) and coils. The technical efficacy and safety related to the method are reported.

Patients and Methods

Patients and general information

From October 2006 to December 2009, 31 patients (11 men, 20 women; age range, 35-74 years; mean age, 55.8 years) with 31 wide-neck intracranial aneurysms (mean diameter 7.8 mm; mean neck width 5.6 mm) were treated with the semi-deployment technique. Twenty-

Table 1 Patient and aneurysm characteristics and follow-up results

Patient no.	Age(yrs)/sex	Presentation	HH grade	Location	Size (mm)	Neck size (mm)	Embolization results	Complications	Angio-graphic follow-up	mRS follow-up
1	56/F	CN palsy	0	PcomA	7.0	4.0	Class 1		Class 1	0
2	35/F	Incidental	0	Para-clinoid ICA	10.3	8.5	Class 1		Class 1	0
3	60/M	SAH	1	PcomA	5.0	3.0	Class 1			0
4	38/F	CN palsy	0	PcomA	6.5	4.0	Class 1		Class 1	1
5	68/F	Headache	0	Para-clinoid ICA	12.0	10.0	Class 1		Class 2	0
6	49/M	SAH	1	PcomA	3.0	2.8	Class 1		Class 1	0
7	61/M	SAH	2	Ophthalmic	5.2	4.0	Class 1		Class 1	0
8	70/F	Incidental	0	ICA bifurcation	6.0	4.5	Class 2	Intra-procedural rupture	Class 2	2
9	40/F	Previous SAH	0	PcomA	11.0	7.0	Class 1		Class 1	0
10	65/M	SAH	1	PcomA	15.7	8.0	Class 1		Class 1	0
11	54/F	SAH	1	ICA bifurcation	4.8	4.0	Class 1		Class 1	0
12	39/M	SAH	4	Basilar tip	3.5	2.5	Class 2	Groin hematoma		4
13	55/F	SAH	1	PcomA	6.1	4.5	Class 1		Class 1	0
14	57/F	Headache	0	Para-clinoid ICA	5.5	4.2	Class 1			0
15	60/F	Visual deficit	0	Ophthalmic	16.0	10.0	Class 2		Class 3	1
16	69/F	SAH	2	Ophthalmic	9.4	8.0	Class 1		Class 2	0
17	56/M	CN palsy	0	Basilar trunk	15.0	N/A	Class 3		Class 3	0
18	49/F	CN palsy	0	PcomA	4.8	4.5	Class 1			0
19	51/F	Previous SAH	0	AchoA	5.2	5.0	Class 1		Class 1	0
20	62//F	SAH	1	Basilar tip	5.8	4.9	Class 1	Thrombo-embolism	Class 1	0
21	66/M	Headache	0	VB junction	7.0	4.0	Class 1		Class 1	0
22	56/M	SAH	4	PcomA	7.2	6.5	Class 2			5
23	48/F	Incidental	0	VB junction	5.9	5.9	Class 1			0
24	37/F	CN palsy	0	V4	5.5	N/A	Class 3		Class 2	0
25	44/F	Previous SAH	0	ICA bifurcation	4.8	4.2	Class 1			0
26	56/M	TIA	0	V4	6.9	N/A	Class 1		Class 1	0
27	74/F	SAH	1	Para-clinoid ICA	3.8	3.5	Class 1		Class 1	2
28	58/M	SAH	2	PcomA	5.5	5.0	Class 1		Class 1	0
29	63/F	CN palsy	0	PcomA	26.0	14.8	Class 3	Thrombo-embolism	Class 3	1
30	64/F	Headache	0	Basilar trunk	7.1	7.0	Class 1			0
31	71/M	SAH	3	PcomA	5.2	3.8	Class 1			3

Note: PcomA, posterior communicating artery; AcomA, anterior communicating artery; Acho: anterior choroidal artery; ICA, internal carotid artery; VB, vertebrobasilar; CN, cranial nerve; TIA, transient ischemic attack; SAH, subarachnoid hemorrhage.

Figure 1 Schematic illustration of semi-deployment technique. A) After a microcatheter was introduced into the aneurysm, the stent was partially deployed to narrow the aneurysm neck. B) Homogeneous coil framing was achieved without coil prolapse by the limitation of the partially-deployed stent. C) The stent was fully deployed and coiling continued using traditional jailing technique if necessary.

four aneurysms were located in the anterior circulation and seven in the posterior circulation. Patient and aneurysm characteristics are shown in Table 1. Informed consent from the patients and institutional review board approval were obtained. The medical records, radiographic studies and endovascular procedure reports were reviewed. All procedures were performed under general anesthesia. Patients having unruptured aneurysms were premedicated with antiplatelet therapy consisting of aspirin 300 mg and clopidogrel 75 mg for three days before the procedure. Patients with ruptured aneurysms were loaded with aspirin 300 mg and clopidogrel 225 mg via nasogastric tube after general anesthesia. All patients received systemic heparinization to raise the activated clotting time (ACT) to about 300 seconds and continuous intravenous administration of nimodipine by micro-in-

fusion pump at a speed of 2mg/hour to prevent vasospasm during the procedure. In patients with unruptured aneurysms, heparinization was started before puncture, and in patients who presented with acute SAH, heparinization was started after aneurysm catheterization. A full three- or four-vessel cerebral angiogram was performed to evaluate the aneurysm fully, measure the aneurysm neck, width, and height, and measure the parent artery proximal and distal to the aneurysm.

A unifemoral guiding catheter (Johnson & Johnson) was used. After the procedure, the patient was moved to the neurosurgery intensive care unit for monitoring and received low-molecular weight heparin calcium 4000IU/12h for the next 48 hours. Clopidogrel 75 mg each day was orally taken for an additional 30 days, and aspirin 100 mg for six months. For each patient,

A

B

C

D

the pre- and postembolization and follow-up (if possible) angiograms were reviewed and compared by two senior endovascular neurosurgeons not involved in the procedure for initial and follow-up occlusion grade, which was classified as class 1: complete occlusion (no contrast filling the aneurysmal sac); class 2: neck remnant (residual contrast filling the aneurysmal neck); class 3: residual flow (residual contrast

filling the aneurysmal body)⁶. Clinical outcome was graded according to modified Rankin score (mRS), as follows: excellent (mRS 0-1), good (mRS 2), poor (mRS 3-4) and death (mRS 5).

Description of the semi-deployment technique

The semi-deployment technique is a variation of the parallel technique. It consists of the delivery the microcatheter into the aneurysm

Figure 2 A large aneurysm of posterior communicating artery was treated with the semi-deployment technique (Patient 9). Lateral angiogram (A) shows a posterior communicating artery aneurysm. The Neuroform stent delivery system was brought up over the exchange microguidewire to cross the aneurysm neck. Then a microcatheter over a pre-shaped microguidewire was introduced into the aneurysm (B). The stent was partly deployed to narrow the aneurysm neck (C). After the first coil was placed, the stent was fully deployed (D). Postprocedure angiogram (E) reveals complete occlusion. The 12 months follow-up angiogram (F, G) remains unchanged.

sac and navigating a self-expandable stent into the parent vessel, and subsequently partially deploying (approximate 50%-60% of its opening) the stent, which covers the distal part of the aneurysm to narrow the neck and leaves room to modify the coil delivery microcatheter position during embolization. After a homogeneous coil framing or complete embolization is achieved, the stent is fully deployed. If neces-

sary, coiling can be continued using the traditional jailing technique to obtain circulatory exclusion of the lesion.

A sketch of the whole semi-deployment technique is shown in Figure 1, and a representative case is shown in Figure 2.

In our series, two types of stents were used, including the Neuroform stent and the Enterprise stent.

Statistical analysis

SPSS 11.0 software (SPSS, Inc, Chicago, IL, USA) was used for statistical analysis. A chi-square test was used to compare the incidences of complete occlusion and procedure-related complication in Hong's and our series.

Results

Technical feasibility and complications

The semi-deployment technique was successful in all cases. The stent was deployed to the intended location, and the wide neck of the aneurysm was accurately and completely covered in all patients. No arterial dissection/rupture, or vasospasm occurred. Immediate angiography demonstrated class 1 occlusion in 24 cases (77.4%), class 2 in four cases (12.9%), and class 3 in three cases (9.7%).

Procedural-related morbidity occurred in one patient (3.2%), with aneurysm perforation by the microcatheter resulting in subarachnoid hemorrhage (Patient 8). This event may be related to the extremely tortuous parent artery, which might have led to an increased tension. The patient developed residual mild neurological deficit and independent daily activity. Two thromboembolic events occurred. The patients were managed with local intra-arterial administration of abciximab or urokinase and mechanical disruption of clot with microwire immediately. Complete or nearly complete vessel recanalization was achieved in these cases, and these two patients recovered without any neurological deficit. One patient (Patient 12) had a puncture site hematoma, which was perhaps caused by the use of powerful anticoagulation and antiplatelet agents.

Clinical outcome

One patient (Patient 22) with SAH (Hunt-Hess grade IV) died because of the severity of his initial hemorrhage during hospitalization. Another 30 patients were clinically evaluated. Clinical follow-up was obtained from three to 43 months with a mean of 23.1 months. The mRS score was excellent in 26 patients, good in two and poor in two patients at the last follow-up. No rehemorrhage of treated aneurysms occurred.

Follow-up outcome

Follow-up angiography was performed in 22 cases. Angiographic follow-up was obtained from six to 38 months, with a mean of 20.7

months. In 20 cases, the degree of aneurysm occlusion was either stable or improved. Three aneurysms (13.6 % of the follow-up angiograms) demonstrated recanalization. Two of these aneurysms underwent successful re-embolization (Patient 5 and Patient 15). The other patient's (Patient 16) angiogram showed an increasing remnant neck on the six-month follow-up examination, but the subsequent follow-up angiogram showed a stable appearance. Therefore, re-embolization was not a treatment option for her. No procedural complications were seen in the retreatment.

In these 22 follow-up patients, no delayed coil or stent migration was found. However one delayed complication occurred. In-stent stenosis was confirmed in a 65-year-old male patient (Patient 10) by follow-up angiography 13 months after the procedure. The 4.5 mm×15 mm Neuroform stent was deployed in the paraclinoid and communicating segments of the right ICA to treat a PcomA aneurysm. High-grade stenosis within the stented segments of the right ICA was noted. He suffered from a mild left hemiparesis. In view of the severity of the stenosis and symptoms while on aspirin, balloon angioplasty of the right ICA was performed. Postangioplasty control angiography demonstrated a substantial improvement in the caliber and the patient recovered fully.

Discussion

Endovascular and surgical treatment of wide-neck and fusiform intracranial aneurysms has remained technically challenging. Stent-assisted aneurysm embolization is a new tool in the treatment of intracranial aneurysms and maybe particularly useful in the case of wide-necked or dissecting aneurysm. The earliest clinical report of stent-assisted coiling of an intracranial ruptured cerebral aneurysm is by Higashida et al. in 1997⁷. Since then, with improvements in microstent technology, more studies from various centers describing the experimental and clinical use of different stents for embolization assistance have reported good results in the literature¹¹⁻¹⁵. More recently, series of patients treated with self-expandable stents devoted to intracranial aneurysms such as the Neuroform stent, the Enterprise stent, the Leo stent or the Solitaire AB stent have been reported¹⁶⁻¹⁹. The stent can provide a permanent scaffold across the aneurysm neck, which may prevent coil prolapse into

the parent artery and allow for safer packing of the aneurysm with a denser coil mesh. In addition, the stent may help prevent recanalization by hemodynamic changes and stent endothelialization.

For the stent-assisted coiling technique, Two main options are deployed: 1) the stent can be placed first, then a coiling microcatheter is placed into the aneurysm through the struts of the stent (sequential technique); 2) the coiling catheter can be placed first within the aneurysm sac, then the stent is positioned and immediately deployed across the aneurysm neck, which may cage the catheter between the vessel wall and stent (jailed technique or parallel technique). The sequential technique has been reported to have difficulties accessing the aneurysm for coiling after initial stent placement sometimes, which leads to potential hazard of rupturing the aneurysm, especially when the parent artery is tortuous, the aneurysm is small, or the closed-cell stent is used. Furthermore, if the microcatheter is forced out of the aneurysm during coiling, re-entry through the stent struts may also be challenging and hazardous. Although the conventional parallel technique avoids some of the drawbacks of the sequential technique, it does not offer the possibility of modifying the microcatheter position within the aneurysm sac, further limiting the operator's ability to appropriately address complex aneurysms.

Biondi et al. predominantly used stenting after coiling with balloon remodeling technique⁸. In this method, the role of the stent was coil mass stabilization and the prevention of aneurysm recanalization⁸. The major advantage is that the microcatheter can be repositioned during intermittent deflation of the balloon. However, the balloon remodeling technique has some drawbacks according to our experience (a possible bias). Coil mass herniation is sometimes a limitation of balloon-assisted coiling once the balloon is deflated or removed. Repeated inflation and deflation of the balloon may cause intimal damage²⁰, which has occurred in our practice. Furthermore, balloon inflation, which results in complete blood flow arrest in the parent artery, can increase the risk of thromboembolic events^{21,22}, although this is still controversial.

Compared to the previous techniques, the semi-deployment technique has several advantages. First, it increases the maneuverability of the coiling catheter, allowing more controlled

coil positioning. Second, the coil basket can be optimized and there is less likelihood for coil migration when the aneurysm neck is narrowed by the partially deployed stent. Lastly, it decreases the risk of the stent herniating into the aneurysm in the treatment of large or giant aneurysms. The recent introduction of a retractable stent makes this technique safer and more effective. The actual aneurysm neck size can be altered by changing the stent deployment degree during the procedure depending on other factors such as the selected coil size and the coil mass stability.

This article describes our experience using a semi-deployment technique for stent-assisted coiling of wide-necked and fusiform aneurysms. Technical success was achieved in all 31 cases with no periprocedural morbidity and 90.3% complete occlusion or neck remnant. This technique was also reported by Hong et al. They used only a retrievable stent, whereas, in our series, the non-retrievable stent (Neuroform stent) was predominantly used. A comparison between Hong et al.'s and our series demonstrates the incidences of complete occlusion and procedure-related complication are not statistically significant ($P>0.05$). This finding may advocate for broader stent options for the semi-deployment technique.

We do not believe that this technique has higher risk of procedure-related complications than the conventional stenting technique. As our series shows, procedural complications rarely occurred. In fact, the procedural-related morbidity complication is not believed to be directly related to the technique. Usually, thromboembolism is the main cause of procedure-related adverse events²³. In previous studies, the reported rates of thromboembolism in patients undergoing stent-assisted coiling and balloon-assisted coiling were between 0% and 20%^{5,24,25}. In our series, two thromboembolic events occurred, with no permanent neurological deficits, which was acceptable compared with most publications. Besides enough heparinization, dual pre- and postoperative antiplatelet therapy, shorter duration of endovascular manipulation, and sufficient prevention from injection of embolus into circulation, the use of bioactive coils (e.g. Matrix coil) in conjunction with the stent should be avoided. Once thromboembolism was noted, local intra-arterial administration of abciximab or urokinase and mechanical disruption of the clot with microwire are necessary. Delayed ischemic neuro-

logical deficit associated with vasospasm is a major cause of morbidity and mortality in patients with SAH. Symptomatic vasospasm is reported in 22-40% of patients with SAH, resulting in 34% morbidity and 30% mortality rates²⁶⁻³⁰. According to our experience, simultaneous manipulation of two microcatheters may carry the risk of instrument-related mechanical vasospasm. Thus, we use nimodipine infusion in all patients throughout the procedure to prevent potential vasospasm. No adverse event occurred with this medication with continuous monitoring of blood pressure in our series. However, the overall study number is small, and there may still be theoretically increased thromboembolic risk with this technique from the two microcatheters and partially deployed stent in the parent artery during coiling, particularly in a small parent vessel. In addition, another potential disadvantage is that coils have a greater chance to protrude into the parent artery during this technique than traditional stent-assisted coiling. At this early stage, this disadvantage also remains theoretical.

ticularly in a small parent vessel. In addition, another potential disadvantage is that coils have a greater chance to protrude into the parent artery during this technique than traditional stent-assisted coiling. At this early stage, this disadvantage also remains theoretical.

Conclusion

The semi-deployment technique is feasible and safe in treating complex aneurysm with comparable incidences of morbidity and mortality. A non-retrievable stent can also be used for this technique.

Nevertheless, further experience is necessary to determine the complication rate and suitable selection of patients.

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