Chapter 13

Complications and Adverse Events Associated with Stent-Assisted Coiling of Wide-Neck Intracranial Aneurysms

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Additional information is available at the end of the chapter

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1. Introduction

Endovascular treatment of intracranial aneurysm has been increasingly performed worldwide. The recent publication of a multiple center randomized trial showing improved safety and clinical outcome of patients treated with endovascular methods as compared with open clipping is encouraging to endovascular neurosurgeons and accelerates this trend. [1] Stent-assisted coil embolization, which is earliest reported by Higashida in 1997 [2] and now widely accepted, has expanded the treatment possibilities. It allows for adequate coil placement, prevents coil protrusion into the parent vessel, and also helps prevent aneurysm recanalization. In the last decade, the development of intracranial stents has increased the options for the treatment of wide-necked aneurysms. Successful experiences of the stent-assisted coiling have been reported by many teams in endovascular neurosurgery centers throughout the world. However, most of the reported complications involved a limited number of patients and varied among reports.[3,4] There has been no systematic report of a relatively larger number of patients treated at a single institution, to provide an overview of these complications. The purposes of this article are to systematically document and analyze the periprocedural and follow-up complications of stent-assisted coiling of cerebral aneurysms at our institution and to tentatively answer the following question: is the incidence of complications with stent-assisted coiling acceptable, compared with the benefits?

2. Patients and methods

2.1. Patient population

Between Jul 2003 and Dec 2009, 232 consecutive patients with 239 wide-neck aneurysms underwent stent-assisted coil embolization at our institution. Therapeutic alternatives were discussed between neurosurgical and neurointerventional teams. Informed consent from the patients and institutional review board approval was obtained. The medical records, radiographic studies and endovascular procedure reports were reviewed. Patient and aneurysm characteristics are summarized in table 1.

No. of patients	232
Age (y)	
Mean	55.1
Range	18-81
Gender	
Female	142
Male	90
Ruptured aneurysms (%)	129 (54.0)
Hunt and Hess grade	
I	39
II	46
III	34
IV	7
V	3
Unruptured aneurysms (%)	110 (46.0)
Headache	35
Previous SAH	29
Incidental	22
CN paisy	13
TIA	11
Aneurysm location (%)	
Anterior Circulation	195 (81.6)
PcomA	49
AcomA	12
Paraclinoid ICA	41
Cavernous ICA	20
Ophthalmic	37
ICA bifurcation	14
AchoA	17
A1 segment of ACA	5
Posterior Circulation	44 (18.4)
BA	18
VA	12
VB junction	9
PICA	5
Aneurysm size (%)	
Small	164(68.6)
Large	43(18.0)
Giant	32(13.4)
Neck size (mm)	
Mean	5.9
Range	2-24

Note: SAH, subarachnoid hemorrhage; TIA, transient ischemic attack; PcomA, posterior communicating artery; AcomA, anterior communicating artery; Acho: anterior choroidal artery; ICA, internal carotid artery; ACA , anterior cerebral artery; BA, basilar artery; VA, vertebral artery; VB, vertebrobasilar; PICA, posterior inferior cerebellar artery, small, <10 mm; large, >10-25 mm; giant, >25 mm.

Table 1. Patient and aneurysm characteristics

2.2. Treatment procedures

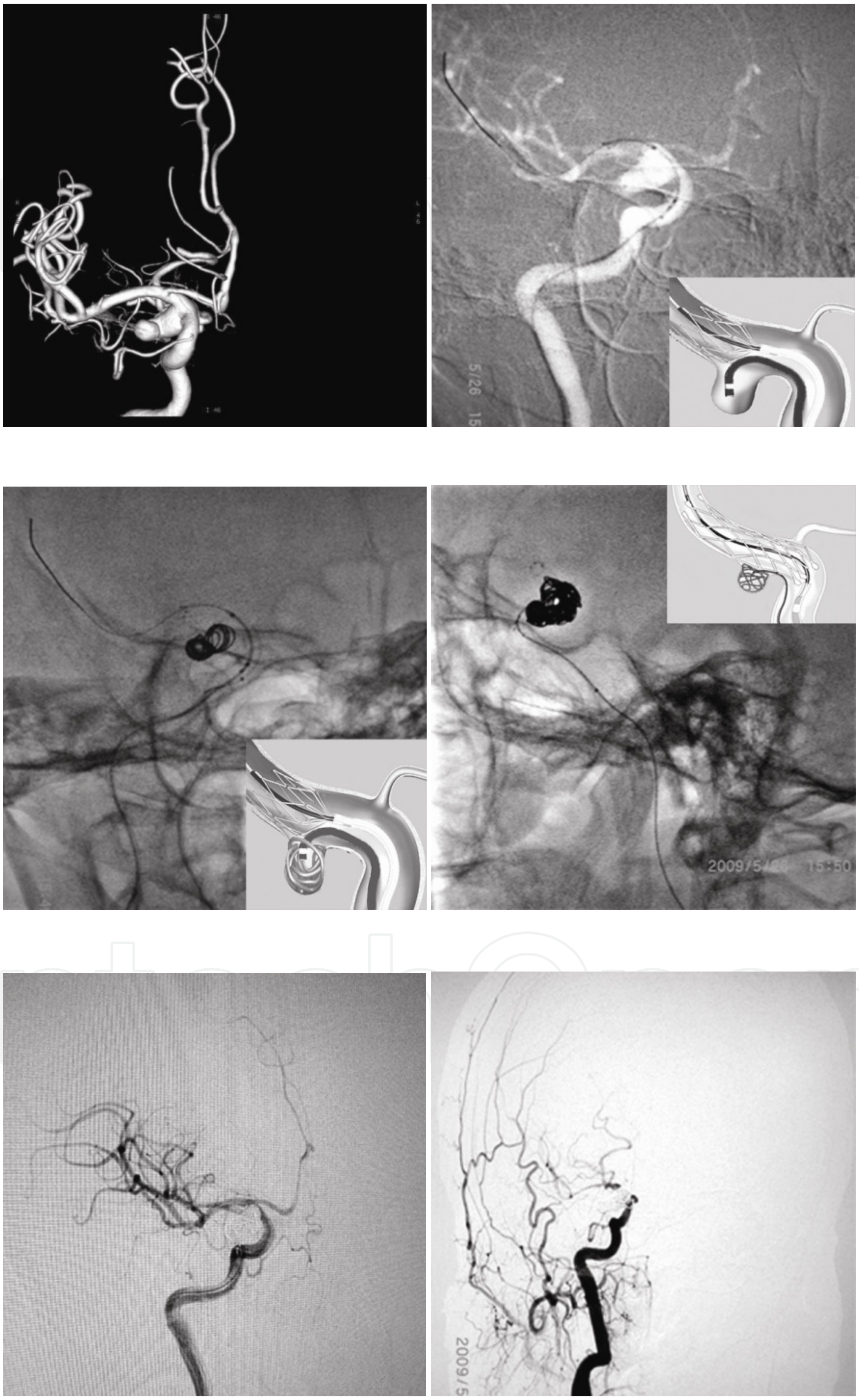
All procedures were performed under general anesthesia. Patients having unruptured aneurysms were premedicated with antiplatelet therapy consisting of aspirin 300 mg and clopidogrel 75 mg for 3 days before the procedure. Patients with SAH were loaded with aspirin 300 mg and clopidogrel 225 mg via nasogastric tube after general anesthesia. All patients received systemic heparinization to raise the activated clotting time (ACT) at about 300 seconds and continuous intravenous infusion of Nimodipine, 2mg/hour to prevent vasospasm during the procedure. In patients with ruptured aneurysms, heparinization started before puncture, and in patients who presented with acute SAH, heparinization started after aneurysm catheterization. A full three- or four-vessel cerebral angiogram was performed to permit a complete evaluation of the aneurysm, measure the aneurysm neck, width, and height, and measure the parent artery proximal and distal to the aneurysm. A 6F or 8F sheath was introduced in the right femoral artery following a standard Seldinger puncture. A 6F or 8F Envoy guiding catheter (Johnson & Johnson) was then guided into either the cervical internal carotid or vertebral artery, depending on the location of the aneurysm. The microcatheters were Prowler series (Johnson & Johnson), Excelsior SL-10, or Excelsior 1018 (Boston Scientific/Target Therapeutics). In all cases, embolization was completed by packing the aneurysm sac with a variety of commercially available coils. 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 6 months.

2.3. Stenting strategies

Stent deployment was successful in 237 of 239 aneurysms, and failed in two aneurysms. Strategies used regarding the sequence of stenting and coiling in 237 treated aneurysms were the following:

1. Stents were delivered before coiling in 205 of 237 aneurysms (86.5%).

a. Stenting before coiling in the same session in 191 aneurysms (80.6%). In 67 of 191 aneurysms, the sequential technique was used, by which the microcatheter was introduced into the sac through the struts of the stent. In 93 of 191 aneurysms, the jailing technique was used, by which the coiling catheter was "jailed" between the vessel wall and the stent. Other 31 of 191 aneurysms were treated using the semi-deployment technique. It consisted of the delivery microcatheter into the aneurysm sac and navigating a self-expandable stent into the parent vessel, and subsequently partially deploying (approximate 50%-60% of its opening) the stent, which covered 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 was fully deployed. If necessary, coiling could be continued using traditional jailing technique to obtain circulatory exclusion of the lesion. A illustrated case of the whole semi-deployment technique is shown in Figure 1.



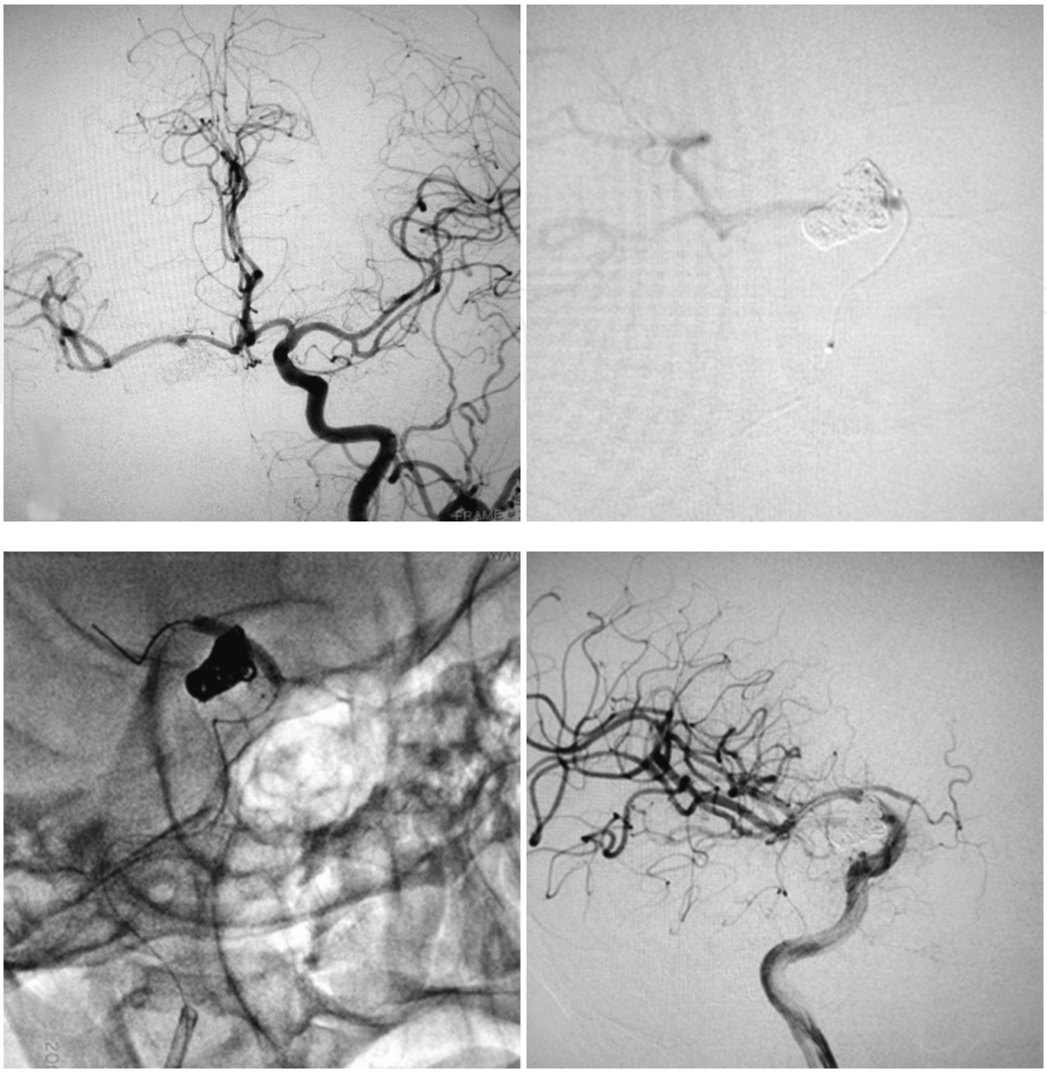


Figure 1. Three dimensional reconstruction (A) of the right ICA in anteroposterior view demonstrated a posterior communicating artery aneurysm. The Neuroform stent delivery system was brought up over the exchange microguidewire to cross the aneurysm neck. The stent was partly deployed to narrow the aneurysm neck after aneurysm catheterization (B). Homogeneous coil framing was achieved without coil prolapse by the limitation of the partially-deployed stent. (C). After several coils were placed, the stent was fully deployed and coiling continued using traditional jailing technique (D). Postprocedure angiogram (E) revealed complete occlusion. 13 months follow-up right common carotd artery angiogram (F) revealed high-grade stenosis within the stented segments of right ICA. Collateralisation was seen over the anterior communicating artery from the left side (G). Superselective angiogram (H) demonstrated that right ICA was not completely occluded. Then, balloon angioplasty of the right ICA was performed (I). Postangioplasty control angiography demonstrated substantial improvement in the caliber, but flow to right cerebral anterior artery was still delayed (J).

b. Stenting before coiling in a second session in 14 aneurysms (5.9%). The main reason for using this option was the difficulties of accessing the aneurysm for coiling after initial stent placement, especially when the parent artery was tortuous, or the aneurysm was small. The coiling procedure was usually performed from 1 to 2 months after the stenting procedure.

2. Stents were delivered after coiling in 31 of 237 aneurysms (13.1%).
   a. Stenting after coiling with balloon remodeling technique in 24 aneurysms. The choice of this option was to decrease the risk of thromboembolism complications in some partially thrombosed aneurysms.
   b. Bail-out stenting in 7 aneurysms. In these cases, the deployment of the stent was not planned in advance. Trapping of an extruded coil or coil mass by means of stent placement could prevent parent vessel closure and obviate the need for coil removal.
3. Stent was delivered alone in one aneurysm (0.4%). A 38-year-old woman with a basilar aneurysm was planned to treat with sequential technique. Because trans-stent aneurysm catheterization was difficult and caused stent movement, coil embolization was postponed to a second session. Fortunately, intraaneurysmal spontaneous thrombosis was noted by angiography 3 months later, and coiling was no more an option for her. Complete occlusion was observed at 1-year follow-up angiography (Figure 2).

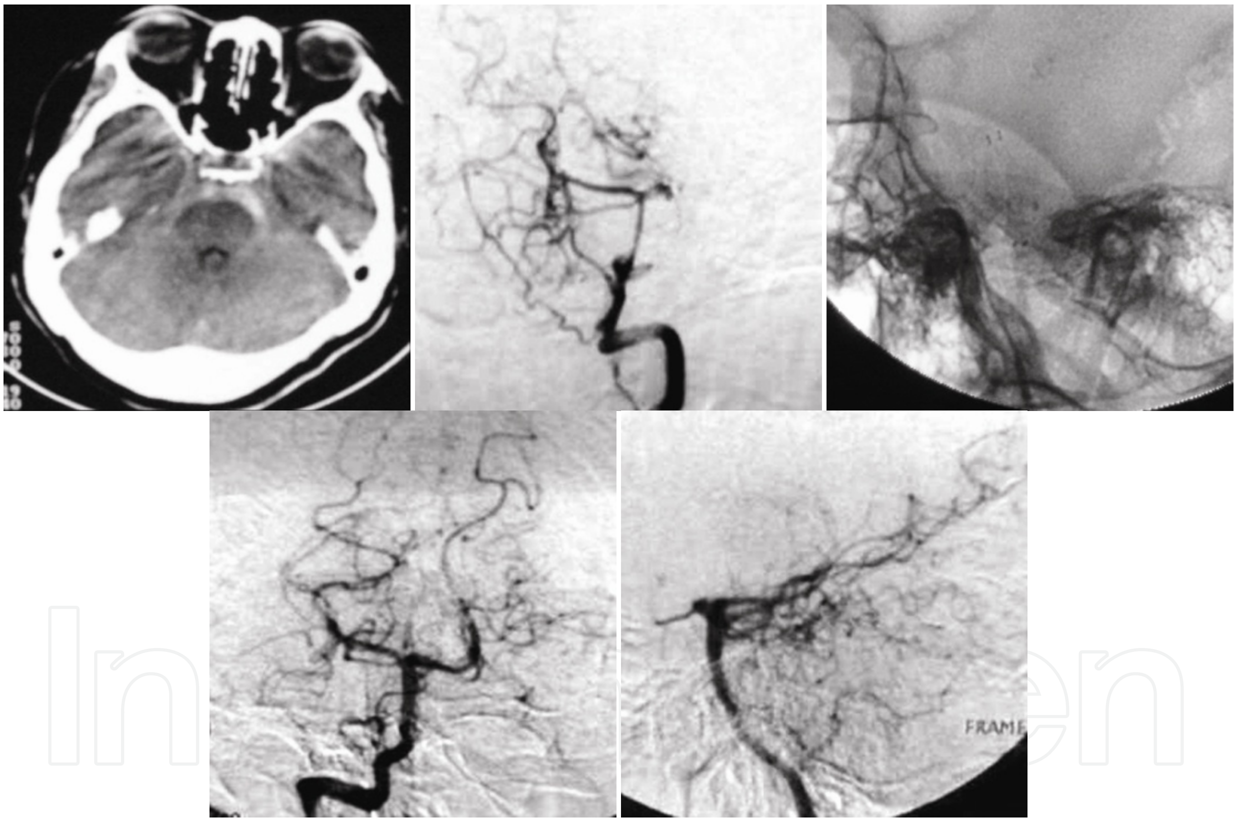


Figure 2. Angiography demonstrated a basilar trunk aneurysm in a 38-year-old woman with SAH (A B). A Neuroform stent (4.5 × 20 mm) was deployed across the aneurysm neck, and coil embolization was postponed to a second session due to difficulty in trans-stent aneurysm catheterization (C). One-year follow-up angiography demonstrated complete occlusion (D E).

2.4. Data collection

All patients underwent CT scanning within 6 hours after the procedure. During the hospital stays, physicians performed neurological examinations of the patients once each day. After discharge, clinical follow-up data were collected by clinic visitation, follow-up angiography, or telephone interview. 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). For each patient, 6 months, 1 year, 3 year and 5 year follow-up angiogram were recommended. The pre-embolization, post-embolization and follow-up (if possible) angiograms were reviewed and compared by 2 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). [5] Recanalization was defined as more than 10 % increase in contrast filling of the aneurysm; less than 10 % increased filling was defined as unchanged. [6]

Angiographic results and clinical outcome were evaluated. Cases with complications were analyzed, including radiological findings, clinical presentations, management experience and clinical sequelae.

2.5. Statistical analysis

SPSS 11.0 software (SPSS, Inc, Chicago, IL) was used for statistical analysis. A chi-square test was used to compare the incidences of intraprocedural rupture and thromboembolic complications between ruptured unruptured aneurysms and to compare the incidences of complete occlusion rate between different stenting strategies.

3. Results

3.1. Angiographic results

Immediate angiographic results of the 236 aneurysms treated with stent-assited coiling are summarized in Table 2.

		class 1	class 2	class 3
Overall	236	162	45	29
Small	162	128	21	13
Large	41	22	11	8
Giant	33	12	13	8
Ruptured	128	82	26	18
Unruptured	108	80	19	11
Overall (%)	236	162(68.6)	45(19.1)	29(12.3)

Table 2. Immediate angiographic occlusion classification

Aneurysm occlusion rate was analyzed in relation to different stenting techniques, bail-out stenting cases excluded. Stenting before coiling was performed in 205 aneurysms and angiographic results showed class 1 occlusion in 142 (69.3%) aneurysms, class 2 in 39

(19.0%) aneurysms, and class 3 in 24 (11.7%) aneurysms. Stenting after balloon-assisted coiling was performed in 24 aneurysms and angiographic results showed class 1 occlusion in 19 (79.2%) aneurysms, class 2 in 3 (12.5%) aneurysms, and class 3 in 2 (8.3%) aneurysms. On comparative analysis of stenting before coiling versus stenting after balloon-assisted coiling, the complete occlusion rate did not show statistical difference (P=0.315, χ^2 test).

3.2. Procedure-related complications

Of the total of 239 procedures for 232 patients, 34 procedural complications occurred, of which 26 were in the anterior circulation and 8 in the posterior circulation. Table 3 summarizes the procedural complications. Procedure-related morbidity and mortality were 4.2% and 1.3%, respectively.

Complication	No sequela	Morbidity	Mortality	Total	Incidence(%)
Thomboembolism	8	4	1	13	5.4
Intraprocedural rupture	3	3	2	8	3.3
Coil protrusion	5	0	0	5	2.1
New mass effect	1	2	0	3	1.3
Vessel injury	2	1	0	3	1.3
Stent dislodgement	2	0	0	2	0.8
Total	21	10	3	34	14.2

Note: Results include patients with more than one complication.

Table 3. Procedure-related complications in aneurysms

3.2.1. Thomboembolism

Thirteen periprocedual thromboembolic events occurred; 9 were in ruptured aneurysms and 4 in unruptured ones. Nine thromboembolic complications were evident during the procedure, and four were clinically and angiographically noted after the procedure. Complete or partial recanalization was achieved in 9 cases by local or systemic administration of abciximab or urokinase and mechanical disruption of clot with microwire immediately. On last follow-up, eight patients completely recovered, two patients developed residual mild neurological deficit and independent daily activity, and two patients developed hemiplegia and became dependent. A 68-year-old woman with ruptured PcomA aneurysm (Hunt-Hess grade Ⅰ) developed right hemiparesis six hours after the procedure. A thrombus in the distal stent segment of right ICA was confirmed by angiography and the left cerebral hemisphere infarction was noted by MRI. She developed severe brain herniation eventually, and decompressive craniotomy failed to save her life.

3.2.2. Intraprocedural rupture

Intraprocedural aneurysmal rupture occurred in eight aneurysms due to coil extrusion (n=2), microcatheter protrusion (n=5), or inflation of the balloon (n=1): three in the PcomA, two in the ophthalmic artery, one in the AComA, one in the AchoA, and one in the basilar tip. All eight ruptures occurred during embolization of acutely ruptured small aneurysms, four of which occurred when coiling microcatheter accessed the aneurysm through the struts of the stent. All intraprocedural ruptures were managed with a protamine injection for heparin reversal and further coil embolization. External ventricular drainage (EVD) surgery was preformed in four cases with postprocedural Fisher grades of Ⅲ or Ⅳ. Five of these ruptures resulted in adverse outcome (3 neurological sequelae, 2 death).

3.2.3. Coil protrusion

Coil protrusion occurred in five procedures, in four of which the last several loops of a small coil (diameter 2 mm) in part protruded through the interstice after detachment, and in one of which the coil was unraveled when a second stent-assisted coiling was performed on a 71-year-old female with bilateral PComA aneurysms. During positioning of the third coil (3 mm × 6 cm), the microcatheter was repelled from the aneurysm from the aneurysm into the parent vessel, and it was noted that the trailing end of the coil was unraveled, with several loops in the parent vessel, which affected the blood flow. After attempts to pull back the coil or to replace the coil failed, a balloon catheter was introduced into the guiding catheter, and the trailing end of the coil was caged in the guiding catheter by inflation of the balloon. Then the coil was stretched into the aorta. Fortunately, none of these patients had sequela.

3.2.4. New mass effect

Cranial nerve III palsy occurred in three large PComA aneurysms, which thought to be the result of the compressive effect of a coiled aneurysm. Only one patient recovered under steroid therapy.

3.2.5. Vessel injury

Vessel injury occurred in three procedures. Two cases of small vessel dissections developed during balloon manipulations. Each involved the carotid siphon. Both dissections spontaneous healed on angiographic follow-up, with no clinical consequence. One case of intracranial hematoma was noted in a 67-year-old woman with a ruptured right PcomA aneurysm (Hunt-Hess grade II). She developed conscious disturbance about one hour after treatment. Intracranial CT showed 30 ml hematoma in the right ipsilateral fissure, most probably due to MCA injury with the microguidewire used for stent introducement. Surgical evacuation was performed and she discharged with mild hemiparesis.

3.2.6. Stent dislodgement

Stent dislodgement during treatment occurred in two procedures: one caused by aneurysm catheterization through the stent struts and the other caused by retrieving the coiling catheter jailed between the stent and vessel wall. In the former case, the stent still covered the aneurysm neck and embolization was completed successfully. In the latter case, the coil mass partially herniated to the parent artery, which blocked the blood flow, during treatment for a left paraclinoid ICA aneurysm. Fortunately, we did not pull back the exchange microwire over which the stent delivery system was brought up. Another Neuroform stent (4.5 × 30 mm) was advanced through that exchange microwire and successfully deployed across the aneurysm neck. The herniated coil mass was pushed back against the vessel wall, and complete flow recanalization was achieved, with no clinical consequence (Figure 3).

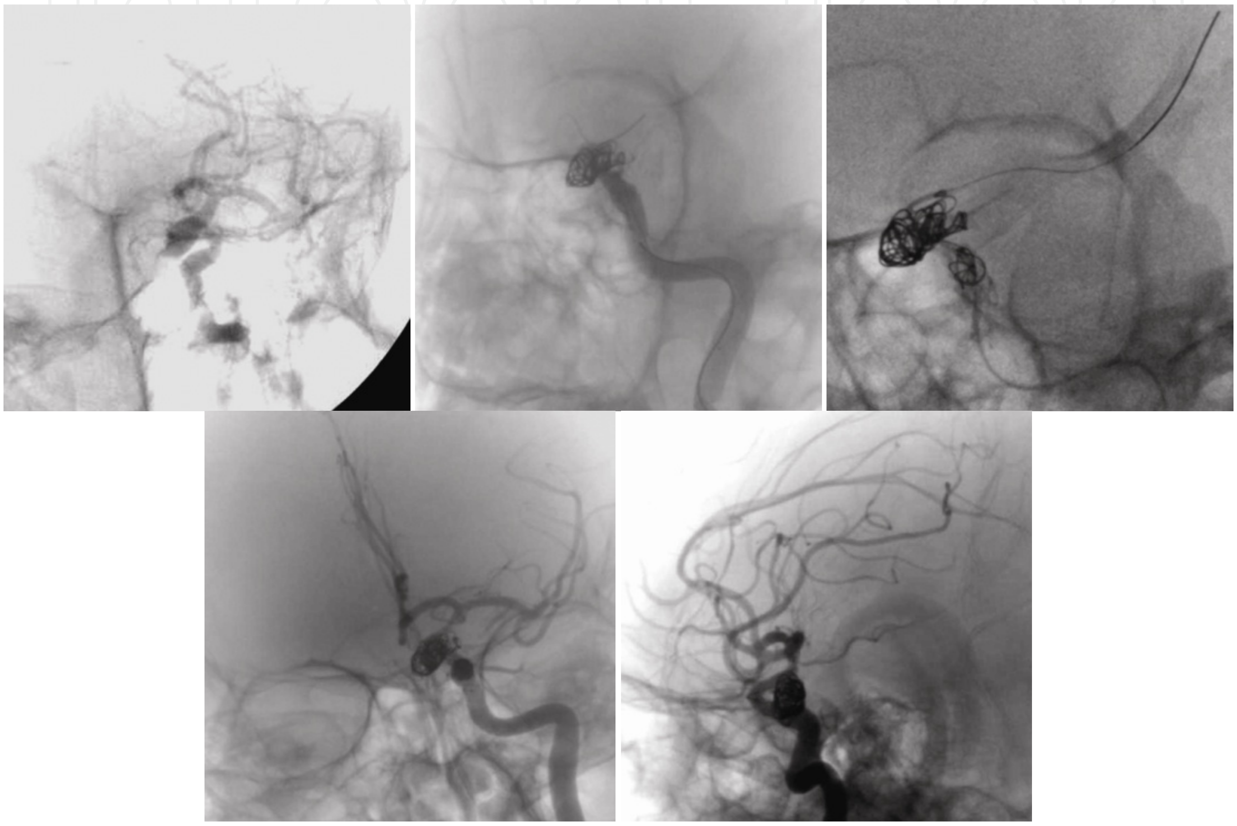


Figure 3. Angiography showed a left paraclinoid ICA aneurysm in a 62-year-female (A). Retrieving the coiling catheter jailed between the stent and vessel wall caused Enterprise stent dislodgement and the coil mass partially herniated to the parent artery, which blocked the blood flow (B). A Neuroform stent (4.5 × 30 mm) was advanced through the exchange microwire and successfully deployed across the aneurysm neck to push back the coil mass against the vessel wall (C). Frontal and lateral angiogram (D E) showed complete flow recanalization of the parent artery and class2 occlusion of the aneurysm.

3.3. Nonprocedural complications attributable to SAH

3.3.1. Vasospasm

Though all 129 patients with SAH were managed with systemic administration of Nimodipine and/or lumbar drainage of cerebrospinal fluid, twenty-four (18.6%) had systematic vasospasm, resulting in five cases of parent artery occlusion during the procedure. one aneurysm was located at AComA, Two at PcomA, and two at basilar tip. They were managed with local administration of Nimodipine 3mg and narceine 30mg immediately. Three patients resolved well after administration and had no deficit. In a 58-year-old woman with ruptured basilar tip aneurysm (Hunt-Hess grade Ⅲ), after a successful stent deployment vasospasm was noted in the basilar trunk. After immediate management, angiogram showed vasospasm completely resolved. However, she did not recover from the transient ischemia. Fellow-up MR showed infarct in the pons. Eventually, she discharged to a skilled nursing facility, not cognitively able to participate in her care. In a 70-year-old man with ruptured left paraclinoid ICA aneurysm (Hunt-Hess grade Ⅲ), vasospasm was noted in the left supraclinoid ICA during post-procedure angiography. After immediate management, angiogram showed vasospasm completely resolved. However, decreased level of consciousness occurred 24 hours later after the treatment. CT scan showed left cerebral hemisphere infarction. Cerebral angiography revealed diffuse severe bilateral anterior and posterior circulation vasospasm. An emergent decompressive craniotomy was performed. This patient had a long recovery with right hemiplegia and expressive aphasia, and then discharged to a skilled nursing facility.

3.3.2. Hydrocephalus

Of the 129 patients with SAH, nine (6.9%) had shunt-dependent hydrocephalus. All these nine patents received EVD only. One poor-grade patient died of the initial effect of SAH, and other patients recovered gradually. no patients developed chronic hydrocephalus at clinical follow-up.

3.4. Clinical outcome

Three patients died of procedure-related complications, and eight patients with acute SAH (high Hunt-Hess grade) died because of the severity of their initial hemorrhage during hospitalization. All other 221 patients were clinically evaluated. Clinical follow-up was obtained from < 1 month to 81 months with a mean of 57.7 months. The mRS score was excellent in 167 patients, good in 38 patients, and poor in 11 patients at last follow-up. Five died of other diseases. No rehemorrhage of treated aneurysm occurred.

3.5. Follow-up complications

3.5.1. Aneurysm recanalization

Follow-up angiography was obtained using DSA or MRA in 155 patients with 159 treated aneurysms. Angiographic follow-up was obtained from 3 to 62 months, with a mean of 39.2 months. 131 of the 155 patients (84.5 %) had >1 year follow-up. The main reasons that patients were lost to follow-up were the patients' refusal to return, economical problem and travel distance. In these 159 angiographic followed aneurysms, the follow-up angiograms of 23 aneurysms (14.5 % of the follow-up angiograms) demonstrated recanalization (Table 4). Of note, 8/22 (36.4 %) class 2 and class 3 aneurysms converted to class 1 on last follow-up. Seventeen of these aneurysms underwent successful re-embolization. The other six patients' angiogram showed an increasing remnant neck on the first follow-up examination, but the subsequent follow-up angiogram showed a stable appearance. Therefore, re-embolization was not a treatment option for them. No symptomatic procedural complications were seen in the retreatment.

Aneurysm size	Recanalized
Small	9/102
Large	6/31
Giant	8/26
Overall	23/159(14.5)
Immediate aneurysm result	**Recanalized (%)**
Class 1	9 /108
Class 2	9/32
Class 3	5 /19
Overall	23/159 (14.5)

Table 4. Recanalization rates

3.5.2. Chronic effect on parent artery

In-stent stenosis was confirmed in two patients by follow-up angiography. In a 45-year-old man, after stent-assisted coiling of a VB aneurysm, delayed in-stent stenosis was seen at 3-month follow-up but had resolved spontaneously at 12-month follow-up. Fortunately, he patient had no symptom. In a 65-year-old man, a 4.5 mm ×15 mm Neuroform stent was deployed in the paraclinoid and communicating segments of right ICA to treat a PcomA aneurysm. High-grade stenosis within the stented segments of right ICA was present 13 months after the procedure. 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 substantial improvement in the caliber and the patient recovered fully (Figure 1).

One patient developed ophthalmic artery occlusion 6 months after the procedure in whom the ophthalmic artery origin was bridged with the stent. Fortunately no clinical problem occurred because of the reconstruction of the ophthalmic artery via external carotid artery collaterals.

A case of Déjérine syndrome occurred in a 52-year-old woman with a VB junction aneurysm treated by stent-assisted coiling eight month after the procedure. She suffered from vertigo, bilateral deep sensory disturbance and right mild hemiparasis. Diffusion-weighted MRI demonstrated increased signal in the medial medulla. The mechanism was suggested that unusually aggressive neointimal response to the stent resulted in occlusion of a small penetrating artery from the stented segment of the vertebral artery, though direct evidence was not found by angiography. (Figure 4)

Figure 4. Frontal and lateral angiogram (A B) showed VB junction aneurysm in a 52-year-old woman. Complete occlusion was achieved by stent-assisted coiling (Neuroform 4.5mm ×30mm) (C). Diffusion-weighted MRI demonstrated increased signal in the medial medulla eight month after the procedure (D). Fowllow-up angiogram demonstrated that the stented segment of the parent artery appeared intact, with no evidence of dissection or in-stent stenosis (E F).

3.5.3. Hemorrhagic events

No rehemorrhage of treated aneurysm occurred. One 73-year-old male died of contralateral putaminal hemorrhage 7 months after discharge. Though he had a history of hypertension for nearly 20 years, posttreatment antiplatelet might be a precipitating factor.

3.6. Incidences of thromboembolism and intraprocedural rupture in ruptured vs unruptured aneurysms

All 8 intraprocedual ruptures, and 9 of 13 thromboembolic events were in the SAH group. The incidence of intraprocedural rupture and thromboembolism were 6.2% and 6.9%, respectively, in the ruptured group and 0% and 3.6%, respectively, in the unruptured group. There was a statistically significant difference in the incidence of intraprocedural rupture between two groups (P =0.008). The incidence comparison for thromboembolism between these groups, however, gave a P value of 0.256.

4. 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 1997[2]. From then on, with improvements in microstent technology, more reports from various centers describing the experimental and clinical use of different stents for embolization assistance has reported good results in the literature.[7-13] Up till now, several literatures have demonstrated the technical feasibility, efficacy of treating complicated intracranial aneurysms. [14-17] 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. [17]However, as a new device, there is limited knowledge about the complications and the long-term effects of the stent on the cerebrovasculature.

We have found that the overall procedure-related complication, morbidity and mortality were 14.2 %, 4.2 % and 1.3 %, respectively, and that a cumulative excellent or good clinical outcome rate is 88.3 %, which reflect better outcome than open surgical series. Most of our complication cases were treated during the first half of our experience period.

4.1. Ischemic events

Ischemic event is a significant problem in periprocedural period. Usually, thromboembolism is the main cause of ischemic event. [18] Park observed nine thromboembolic events among 27 complications during coiling of 118 ruptured aneurysms.[19] The acute or subacute thrombogenicity of endovascular stents also represents an important limitation with respect to the treatment of aneurysms and appears to be the main drawback of stent-assisted coil embolization. [20-24] According to these literatures, incidence of thromboembolic event ranged from 4.2 to 17.1%. In our series, we observed a relatively low rate of thromboembolic events (5.4%), with 1.6% morbidity and 0.4% mortality. Our findings suggest stent-assisted coiling does not increase the risk of thromboemblism with proper management, which is similar to those of some reports. [18]This low rate of thromboembolic events has been achieved with enough heparinisation, dual pre- and postoperative antiplatelet therapy, shorten duration of endovascular manipulation, and sufficient prevention from injection of embolus into circulation. Additionally, the use of bioactive coils (e.g. Matrix coil) in conjunction with the stent should be avoided. Partially thrombosed aneurysms can be coiled using the balloon remodeling technique, and then the stent is delivered across the aneurysm neck at the end of the procedure. Once thromboembolism is noted, local intra-artery administration of abciximab or urokinase and mechanical disruption of clot with microwire are necessary. Sometimes mechanical dilation with balloon angioplasty can be performed.

Delayed in-stent stenosis is likely a rare event. Biondi et al [16] reported one (2.4%) asymptomatic stenosis of the parent artery at the proximal end of the stent, which was observed on follow-up angiography and successfully treated by angioplasty. Fiorella et al [25] reported a 5.8% rate (9 of 156 patients) of delayed moderate to severe (>50%) in-stent stenosis after 2 to 9 months, of which two patients needed retreatments to control ischemic symptoms. In our series, in-stent stenosis was confirmed in two patients, one of whom underwent angioplasty. The Wingspan study[26], reported a rate of in-stent stenosis of 29.7% and an additionally 4.8% of in-stent thrombosis after an average of 5.9 months on the treatment for symptomatic intracranial atheromatous disease. Endothelian disruption and denudation of the vascular wall during stenting in the absence of functional endothelium in an atheromatous vessel resulting in neointimal tissue formation may play an important role. This action is mediated by proliferation and activation of regional smooth muscle cells. It is unclear whether similar reaction is also responsible for delayed in-stent stenosis after the stent placement, which has much lower radial force, as an aneurysm neck bridging device covering the normal vessel wall. Additional follow-up will be critical to delineate the incidence of this phenomenon.

Delayed ischemic neurological 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 rates. [27-31] Murayama et al [32] reported a 23% incidence of symptomatic vasospasm after endovascular coil occlusion of acutely ruptured; this rate compares favorably with that found in conventional surgical series. Gruber et al[33], however, noted an increased incidence of vasospasm-related infarctions in patients treated endovascularly (37.7% vs. 21.6% with surgery). However, when patients with Fisher grade 4 and Hunt and Hess grade V lesions were excluded, the difference between the treatment groups was no longer significant. Other authors [19,34,35] have not found an increased risk of vasospasm with endovascular therapy as well. They concluded that the type of treatment was not associated with an increased risk of cerebral vasospasm. Rabinstein et al [36] studied 415 consecutive patients with aneurysmal SAH. Symptomatic vasospasm occurred in 39% treated with surgical clip placement and 30% treated with endovascular coil occlusion. In a univariate analysis, the incidence of vasospasm did not differ between the groups. In our study, the incidence of symptomatic vasospasm among 129 patients with SAH was 18.6%. It seems that the stent-assisted coiling does not increase the risk of symptomatic vasospasm, compared with open clipping and other endovascular techniques.

4.2. Stenting techniques

Different stategies regarding the timing of stent deployment in relation to coiling are practiced. In majority of reports, stenting was performed before coiling in the same session, including the sequential technique and the jailing technique.[9, 20-22] The strategy of stenting after balloon-assisted coiling is less frequently reported. [21, 16] In our series, several main options were practiced and the strategy of stenting before coiling was predominantly used.

On comparative analysis of stenting before coiling versus stenting after balloon-assisted coiling, the complete occlusion rate did not show significant difference ($P>0.05$, χ^2 test). However, balloon remodeling technique have some drawbacks according to our experience (maybe 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 damage[37], which has occurred in our series. Furthermore, balloon inflation, which results in complete blood flow arrest in the parent artery, can increases the risk of thromboembolic events[38, 39], although this is still controversial. In our series, a novel stent-assisted coiling technique, the semi-deployment technique, was used in 31 aneurysms. Compared to the conventional techniques, this technique has several advantages. First, it increases 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. Last, it decreases the risk of the stent herniating into the aneurysm in treatment of large or giant aneurysm. Nevertheless, further experience is necessary to determine complication rate and suitable selection of patients to different strategies.

4.3. Dual antiplatelet regimen

There are controversial reports about benefit of the dual antiplatelet therapy. [40, 41] The optimal regimen has not yet been defined. It is intuitive that the aneurysms are fragile and parent vessels are less healthy in patients in the acute phase of SAH. A meta-analysis of published reports, from retrospective data has also suggested the risk of intraprocedure rupture is significantly higher in patients with ruptured aneurysms. Our data suggest that the incidence of intraprocedual rupture is significantly higher in patients with ruptured aneurysm ($P<0.01$), and the incidence of thromboembolism between those with and without ruptured aneurysms is not statistically significant. This finding may advocate for a more cautious preprocedural antiplatelet treatment for patients with ruptured aneurysms. Katsaridis V has reported a very low thromboembolic complication rate (1.8%) in the Neuroform2 stent-assisted embolization of 54 aneurysms without antiplatelet pretreatment.[40] In our practice, it is after general anesthesia that dual antiplatelet treatment (aspirin 300 mg and clopidogrel 225 mg via nasogastric tube) initiates for accurately ruptured aneurysms.

Because of a prolonged posttreatment antiplatelet regimen, if there is any evidence that the patient will need EVD surgery due to SAH, this should be done before interventional therapy. On the basis of our experience, this might not only prevent fatal increase of intracranial pressure, but might also reduce subsequent bleeding complications if the patient is on a strong anticoagulation and antiplatelet regimen. However, in our series, a total of seven patients underwent additional emergent surgical treatment after interventional therapy. Five patients received EVD and two patients underwent decompressive craniotomy. Protamine chloride and minirin were used to reverse the anticoagulation and antiplatelet drugs before surgery. Fortunately, there were no surgical complications or special difficulties due to abnormal intraoperative bleeding during the operation. Taking into account relatively more ischemic events, a more aggressive anticoagulation and antiplatelet therapy should be used after the procedure.

In our opinion, the risk of periprocedual antiplatelet therapy should be weighed against the potential benefit and that antiplatelet and anticoagulation therapy should be tailored according to the results of ongoing researches.

4.4. Aneurysm recanalization

The goal of aneurysm treatment should be permanent exclusion of the aneurysm from the circulatory system to prevent rupture or rerupture. Aneurysm recanalization must be acknowledged as a failure to achieve this goal. However, not a single one of treated aneurysms experienced rehemorrhage during the follow-up time, in our series, despite incomplete occlusion and recanalization. Lylyk et al reported that follow-up was obtained in 63% of their patients and stressed that there were no cases of repeated hemorrhage.[21] Biondi et al [16] also reported that no aneurysm bled after stent-assisted coiling during the follow-up period, though complete or subtotal aneurysm occlusion was not always obtained. Based on these results, we therefore conclude that the risk of rupture after occlusion of aneurysms may be substantially reduced. Aneurysm follow-up angiography and reembolization, if necessary, still should be done, though. Fiorella et al [22] reported initial (3-6 mo) angiographic follow-up in 58% of aneurysms treated with Stent-assisted coiling showing progressive thrombosis in 52% of patients, recanalization in 23%, and no change in 25%. In the series of Biondi et al [16], recanalization was observed in 13% of wide-neck aneurysms treated with stent-assisted coiling. We observed 23 cases (14.5%) of aneurysm recanalization on follow-up angiograms, which was acceptable compared with most publications. In our experience, the recanalization rate of none-stented wide-neck aneurysms is high. Murayama et al reported that the overall recanalization rate of coiling without stenting was 20.9%.[6] A stent placed across the aneurysm neck may prevent recanalization because of the hemodynamic changes and stent endothelialization. The stent is used not only to assist in coil delivery, but also to prevent recanalization. In our series 60.9% (14/23) of the recanalized aneurysms were not initially completely occluded (class2 or class3) and no recanalization occurred in small aneurysms which was completely occluded. Therefore, sequential follow-up angiograms are mandatory, especially for those aneurysms showing incomplete occlusion. In our series, no adverse events were shown on follow-up angiograms or occurred during retreatment with detachable coils. Recently, Renowden et al [42] and Henkes et al [43] reported complication rates of 2% to 3% in their large series of retreatment of previously embolized aneurysms. Follow-up procedures can be done safely, and the risk from retreatment with detachable coils does not negate the advantages of initial use of coil embolization. During initial treatment discussions, patients should aware that wide-neck aneurysms, especially large and giant ones, may require multiple treatment and will certainly require a significant course of long-term follow-up.

5. Conclusion

Our study indicates that stent-assisted coil embolization of intracranial aneurysm is a safe technique with low morbidity and mortality rates. Our results are consistent with those reported in the literature (Table 5). The main cause of morbidity and mortality is thromboembolism (38.2% of all procedure-related complications are thromboembolic in our study). In our hand, this technique does not increase the risk of symptomatic vasospasm, compared with open clipping and other endovascular techniques. The recanalization rate is relatively low. The delayed in-stent stenosis seems a rare complication, compared to stent deployment in atherosclerotic lesions. Nevertheless, additional, large series with long-term follow-up are necessary to determine the durability of these promising results.

Series (ref no)	No of patients (aneurysms)	Rate
Fiorella et al. 2004 (15)	19 (22)	10.5% thromboembolism rate (10.5% thromboembolic morbidity)
dos Santos et al. 2005(17)	18 (17)	23.5% technical complication rate (5.8% morbidity)
Lee et al. 2005(23)	22 (23)	9.1% procedure-related complication rate
Akpek et al. 2005(20)	32 (35)	25% adverse event rate, 9.3% morbidity, 3.1% mortality
Lylyk et al. 2005(21)	50 (50)	8.6% morbidity, 2.1% mortality
Katsaridis et al. 2006(38)	44 (54)	4% stent-related complication rate
Biondi et al. 2007(16)	42 (46)	4.3% procedural morbidity, 2.2% procedural mortality
Yahia et al. 2008 (3)	67(67)	7.4% procedure-related complication rate
Mordasini et al. 2008 (44)	18(18)	22.2% thromboembolism rate(no morbidity and mortality)
Wajnberg et al. 2009 (24)	24 (24)	4.2% procedure-related thromboembolism rate
Seadt J et al. 2009 (45)	42(42)	2.4% procedural morbidity

Table 5. Published complication rates for Neuroform stent-assisted coiling of intracranial aneurysms

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