Original Article

J Chin Med Assoc
2003;66:460-466

Stent-assisted Embolization of Internal Carotid Artery Aneurysms

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Key Words
aneurysm;
embolization;
intracranial stenting

Background. Endovascular embolization of wide neck aneurysm often results in incomplete occlusion or aneurysm recurrence. The purpose of this study is to assess the efficacy and safety of stent-assisted embolization of wide neck aneurysms of the internal carotid artery (ICA).

Methods. A series of 10 patients with ICA aneurysms attempted treatment by stent-assisted Guglielmi detachable coil (GDC) embolization (n = 9) or by stent alone (n = 1). There were 3 men and 7 women ranging in age from 21 to 78 years, with a mean of 51 years. The indications of stenting were wide neck aneurysms (n = 9) and herniation of detached coils from aneurysmal sac into parent artery (n = 1).

Results. Endovascular stent placement was technically successful in 8 cases. In one case with a cervical big ICA aneurysm, a stent was placed across the neck of aneurysm without deposition of embolic material into the aneurysmal sac. The initial control angiogram revealed residual aneurysm; however, complete obliteration of aneurysmal sac was achieved as observed on angiograms in 8 months. Six cases of wide neck aneurysms were successfully treated by stent-assisted GDC embolization. One case had prolapse of coil loops into parent artery after coils detached; the coil loops were successfully pushed back to aneurysm after stent placement. Two patients had difficulties to navigate the stents across the aneurysm necks because of tortuous parent arteries; in one of them, the stent partially covered the neck of aneurysm, which made the success of subsequent GDC embolization; in the other one, advancement of the stent to the targeted site was abortive, and the aneurysm was eventually loose packing. No significant procedure-related complication was found. One patient had asymptomatic dissection of the parent artery after stent placement. One patient had a transient ischemic attack and returned to normal baseline neurological conditions later. Clinical follow-up for these patients was 0.5 to 36 months, with a mean of 14 months.

Conclusions. Stent-assisted embolization is a treatment of choice for wide neck aneurysms or for patient with herniation of coil loops to parent artery after coil detached. It was proven both safe and effective over a relatively long follow-up.

The outcome or success of endovascular embolization of cerebral aneurysms depends largely on the size of the neck of aneurysms. The occlusion rate of narrow neck aneurysms with Guglielmi detachable coil (GDC, Target Therapeutic/Boston Scientific Corporation, CA, USA) is relatively good. Eighty-five percent of aneurysms with neck size smaller than 4 mm showed complete aneurysm thrombosis. However, there were significantly different results in the wide-necked group; only 15% of aneurysms with a neck larger than 4mm showed complete occlusion.[1] Attempts to occlude the wide neck aneurysm carry a high risk of coils herniation into the parent artery, with consequent vessel thrombosis or coil migration. Endovascular treatment of those wide neck aneurysms is always a challenge for neuro-endovascular therapists. Various coils or techniques such as two- or three-dimension GDC, balloon remodeling and the double microcatheter technique have been

Received: January 20, 2003.
Accepted: May 15, 2003.

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Table 1. Clinical data and outcome of ICA aneurysms treated by stenting and/or GDC

Case No.	Sex/Age	Aneurysm location	Indication for treatment	Embolic agents	Complications	Outcome	Follow-up (months)
1	F/58	Termination of ICA	SAH	Stent, GDC	None	Fair	8
2	F/72	ICA-PCoA junction	SAH	Stent, GDC	TIAs	Good	13
3	F/78	ICA-PCoA junction	Decrease visual acuity	Stent, GDC	None	Good	24
4	M/25	Cavernous ICA	Ptosis	Stent, GDC	Arterial dissection	Good	9
5	F/58	Cavernous ICA	Ptosis and TIAs	Stent, GDC	None	Good	12
6	M/31	ICA-PCoA junction	SAH	Stent, GDC	None	Died	0.5
7	M/21	Cavernous ICA	Ptosis	Stent, GDC	None	Good	6
8	F/35	Cervical ICA	TIAs, pulsatile mass	Stent	None	Good	36
9	F/57	ICA-PCoA junction	SAH, herniation of coil loops to ICA	Stent, GDC	None	Good	15
10	F/76	ICA-PCoA junction	SAH	GDC	None	Good	12

ICA = Internal carotid artery; GDC = Guglielmi detachable coil; PcoA = posterior communicating artery; TIA = transient ischemic attack; SAH = subarachnoid hemorrhage.

described.[2-5] Due to the increasing inherent complexity, these methods are not always successful or risk-free. The use of stent-assisted embolization (SAE) for the treatment of experimental wide neck aneurysms in canine and swine was first reported in 1994 by Szikora *et al.*[6] and Turjman *et al.*[7] One year later, Massound *et al.*[8] demonstrated the validity of this technique for the treatment of experimental fusiform aneurysms in swine. However, the clinical use of this technique was restricted by the difficulty associated with the endovascular navigation of stents to the cerebral vasculature. The purpose of this study is to present our experience of managing 10 patients with internal carotid artery (ICA) aneurysms by the use of stent and to assess the role, efficacy and safety of SAE for patients with wide neck ICA aneurysms.

METHODS

From 1996 to 2002, we treated 106 cerebral aneurysms by GDC embolizations. Ten of them were difficult to occlude by the two- or three-dimension GDC because of repeated protruding of coils into the lumen of the parent arteries. Embolization of these aneurysms was attempted by the stent alone (n = 1) or by SAE (n = 8) in combination with the use of GDC. In 1 case, the stent was applied for reconstruction of patency of the parent artery because of prolapse of coil loops into the lumen of the parent artery. Individual data of patients are summarized in Table 1.

There were 3 men and 7 women aged from 21 to 78 years with a mean age of 51 years. The indications for stenting included 9 patients with wide neck aneurysms at the junction of ICA- posterior communicating artery (PCoA, n = 4), cavernous ICA (n = 3), termination of the ICA (n = 1), cervical ICA (n = 1) and one patient with herniation coil loops from aneurysmal sac to parent artery after coils detached into ICA-PCoA aneurysm.

With the patients under general anesthesia, the femoral arteries were catheterized by means of a percutaneous technique. Angiographies of bilateral carotid and vertebrobasilar arteries were assessed for the size, neck and neck to dome ratio of aneurysms. All but 1 patients met the criteria of wide neck aneurysm including neck width more than 4 mm (n = 7) or unfavorable neck to dome ratio of greater than 1 (n = 2). The calibers of nearby parent arteries were calculated as the reference of stent selection. Then a 7- to 9- French guiding catheter was positioned into the targeted artery. Next, all patients received intravenous administration of a heparin bolus (70-100 U/Kg) to obtain an activated clotting time of 2 to 2.5 of baseline. A continuous heparin infusion of 15 to 20 U/Kg/h was then used. In 1 patient with a big cervical ICA aneurysm, progressive thrombosis was expected af-

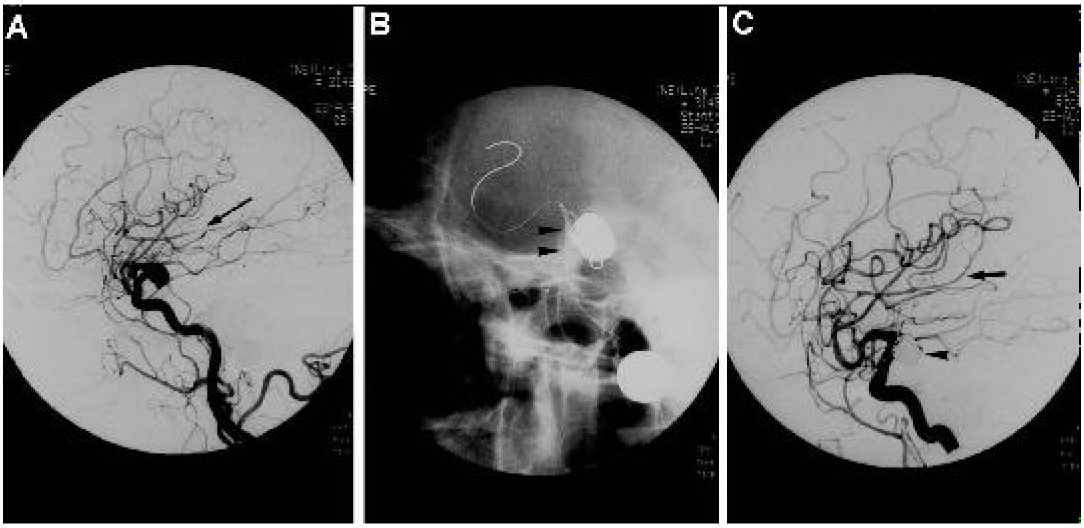

Fig. 1. A 58-year-old female presented with subarachnoid hemorrhage. (**A**) Initial carotid angiogram revealed a wide neck aneurysm near termination of right ICA. Spontaneous occlusion of branch of right middle cerebral artery (MCA) was found incidentally (black arrow); (**B**) Stent was advanced across aneurysm neck (black arrow heads), followed by GDC embolization of aneurysm; finally the stent was deployed; (**C**) Control angiograms showed almost total occlusion of aneurysm (black arrowhead) without compromise of the ICA flow; recanalization of occlusive branch of right MCA was achieved after thrombolytic treatment (black arrow). Patient had permanent neurological deficits.

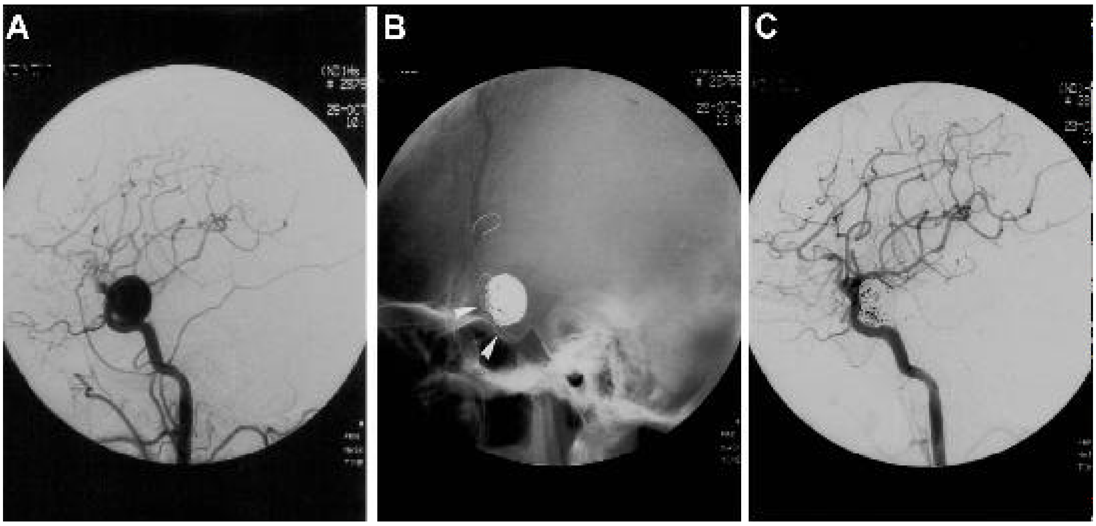

Fig.2. A 78-year-old female complained of decreased visual acuity. (**A**) Right carotid angiogram demonstrated a wide neck big aneurysm at the supraclinoid region; (**B**) Intracranial stent was navigated vigorously but just partially covered and narrowed the neck (white arrowheads), which facilitated GDC embolization subsequently. (**C**) Control angiograms revealed subtotal occlusion of aneurysm with preservation of the ICA flow. Patient had a recurrent aneurysm at 16 months follow-up angiograms because of coils compaction; she received a second GDC embolization with almost total occlusion of the recurrent aneurysm.

ter stent was placed across the aneurysmal neck, but there was no deposition of embolic material into aneurysmal sac. For SAE of intracranial aneurysms in the other 9 patients, the stent delivery catheter was advanced through a 300 cm, 0.014 inch length exchange guidewire and the appropriate coronary stent was tried to navigated across the neck of the aneurysms (Fig. 1). Before the stent was deployed, a microcatheter was placed into aneurysmal sac through the neck of aneurysm, and the appropriate size and number of GDCs were subsequently

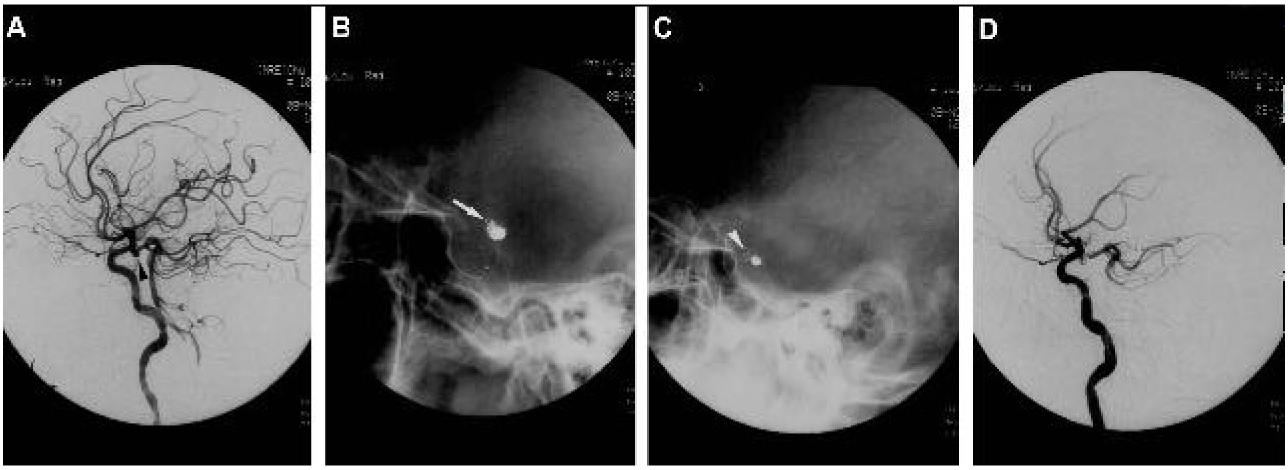

Fig. 3. A 57-year-old female presented with subarachnoid hemorrhage. (**A**) Right carotid angiogram documented a small aneurysm at the junction of the ICA-PcoA (black arrow head). (**B**) GDC embolization was undergone, unfortunately, prolapse of detached coil loops into ICA (white arrow) was depicted during the procedure; (**C**) A intracranial stent (white arrow head) was advanced across the aneurysmal neck and protruding coil loops were push back to the aneurysm; (**D**) Control angiograms revealed total occlusion of aneurysm with preservation of the ICA flow.

placed in the aneurysmal sacs. Following GDC embolization, the stent was deployed. In 2 aged patients, we had a difficulty to navigate the stents across the aneurysmal neck because of the tortuous ICA. One of them had the stent partially covering the neck of the aneurysm (Fig. 2), while the other one, failed in navigating the stent to the targeted site, even though GDC embolizations were preceded. In one patient, stent was not intended to use, however, after 3 GDCs were detached into the aneurysm, herniation coil loops to the parent artery were found (Fig. 3). Because of potential risk of thromboembolic event, a stent was deployed across the neck of an eurysm for reconstruction of patency of the parent artery. After completion of the procedure, a control angiogram of the ICA was performed in each patient to evaluate the treatment result and to exclude a thromboembolic branch occlusion. Clinical or angiographic follow-up for these patients was 0.5 to 36 months, with a mean of 14 months.

RESULTS

The results and follow-up findings are listed in Table 1. In 1 case with a cervical big ICA aneurysm, a stent was placed across the neck of aneurysm without deposition of embolic material into the aneurysmal sac. The initial control angiogram revealed residual aneurysm; however, complete obliteration of aneurysmal sac was achieved on follow-up angiograms in 8 months. For 8 patients with SAE of intracranial wide neck aneurysms in combination with GDC, technical success was achieved in 6 (Fig. 1); 2 patients had difficulties to navigate the stents across the aneurysmal neck because of tortuous parent arteries as we mentioned before. One of them, had the stent partially covering the neck of aneurysm to reduce the size of neck from 7 mm to 3 mm, which made the success of subsequent GDC embolization (Fig. 2). The other one, failed to advance the stent to the targeted site, the aneurysm was eventually loose packing. In 1 patient with prolapse of detached coil loops into parent artery, the coil loops were successfully pushed back to the aneurysmal sac with preservation of the ICA flow (Fig. 3). One patient had spontaneous occlusion of one branch of middle cerebral artery before embolization. Recanalization was achieved by intra-arterial thrombolysis (Fig. 1A, C); however, the patient had permanent neurological deficits. Asymptomatic stent-related minor dissection of the ICA was found in one patient, and spontaneous healing was documented on 6-month angiography. One patient experienced transit ischemic attacks and returned to baseline neurological conditions later. One patient died after the procedure 2 weeks later, from the presumed consequence of subarachnoid hemorrhage. There was no procedure-related permanent neurological deficit or mortality. Coil compaction with recurrent aneurysm was documented in 1 patient in 16 month follow-up, who received secondary embolization with total obliteration of aneurysmal sac. The clinical and/or angiographic follow-up was 0.5 month to 36 months with a mean of 14 months.

DISCUSSION

There have been increasing reports in literature on intravascular stenting in the treatment of neurovascular disease, for example, the occlusive and aneurysmal diseases in the extracranial and intracranial carotid, vertebral and basilar arteries.[9-14] However, aneurysms with wide neck and with unfavorable ratio of neck diameter to dome continue to cast significant technical challenges for GDC embolization. Endovascular treatment of those wide neck aneurysms can lead to incomplete occlusion and aneurysm recurrence. Attempts at complete obliteration may increase the risks of coil protrusion, embolic complication, or thrombosis of the parent artery. At present, the SAE technique is considered one of the valuable techniques to treat those wide neck or fusiform aneurysms.[12-14]

The standard SAE consists of the placement of a stent in the parent artery across the aneurysm neck. A microcatheter is then navigated through the stent interstices into the aneurysmal lumen, and coils embolization is performed. The stent serves as a mechanical scaffold for the placement of intra-aneurysmal coils, preventing their prolapse into the parent artery and allowing a denser coils packing, which may reduce the likehood of future coil compaction. The stent also favorably alters the mechanical flow dynamics of aneurysm lumen by increasing high-flow resistance into the aneurysm lumen through the stent interstices, promoting intra-aneurysm stasis and thrombosis. In our series, we had 1 patient with a big cervical ICA aneurysm. Since there was no immediate risk of stroke after medication, the patient was treated by the stent alone. Progressive thrombosis of the aneurysm was observed in the series of follow-up angiograms and complete obliteration was observed in 8 months after stent placement.

The choice of stent depends on the location of aneurysm, parent vessel diameter, and aneurysm neck size. The stent may be successfully used for extracranial aneurysms such as in Case 8 of our series, whereas intracranial applications require the use of a more flexible, coronary stent. Current available stents may be too stiff to navigate to intracranial arteries; in addition, stiff stents have the potential risk of kinking and/or dissecting tortuous vessels. In our series, 1 patient had asymptomatic dissection and spontaneous healing was found in 6 months. For those patients with tortuous parent arteries, the availability of more flexible and pliable devices may alleviate this problem in the future.

By far, effective placement of the stent with complete crossing over the aneurysm orifice is presumed as a key to successful treatment of wide neck aneurysms.[12-14] Nevertheless, incomplete covering of the aneurysm neck does not mean technical failure. On the other hand, narrowing the neck by the use of stent to partially cover the aneurysm neck might facilitate GDC embolization subsequently. Our experience in 1 case has highlighted that GDC embolization can benefit from advancing the stent partially across the wide neck of the aneurysm.

A main drawback of the use of the standard SAE with early deployment of the stent before GDC embolization is poor intra-procedural fluoroscopic visualization of coils in relation to the parent arterial lumen, particularly when treating fusiform aneurysms.[15,16] Coil loop protrusion through the stent interstices back into the parent artery may be difficult to detect because of superimposition of coils and stent meshwork. The use of an inflated balloon in the stent during coil embolization has been suggested as a possible solution by some authors, but this might increase thromboembolic event. Additionally, the microcatheter recoil to parent artery during GDC embolization may make it difficult to place microcatheter into aneurysmal sac again through deployed stent interstices. In our series, we have modified this standard SAE in order to solve these problems by late deployment of stent (Fig. 1B) instead of early deployment as soon as it was advanced across aneurysm neck. The stent was left as a reference of parent artery lumen. Next, we placed a microcatheter into the aneurysm sac followed by GDC embolization, then the stent was finally deployed. The major advantage of this modified SAE is clear visualization of lumen of the parent artery relationship to aneurysmal sac. If coil loops protrude to parent artery, the deployed stent can push the protruding coils back to the aneurysmal sac or arterial wall with reconstruction of the patency of the parent artery. In addition, if the microcatheter recoils to parent artery during GDC embolization, it is more easily to introduce a microcatheter through wide neck aneurysm than through the stent mesh.

In this series, we also used stent to treat 1 patient with protruding coil loops occurring after coil detached. In this case, snare retrieval devices can be used, but it is also technically challenging to remove a significant coil mass, as well as potentially hazardous, with the significant risk of embolic and/or occlusive complications or vessel perforation.[17] In our experience, stent is a valuable adjunct in treating inadvertent parent vessel coil prolapse and subsequent embolic complication.

Our experiences have highlighted technique aspects of this procedure that should help the neurointerventionist achieve optimal results. However, several limitations of the SAE approach to cerebral aneurysms exist. The first is the current designs of the stent and stent delivery catheter, which restrict the use of SAE predominantly to sidewall aneurysms rather than bifurcation aneurysms, such as those encountered at the Will's circle. The second is that stents are known to induce intimal hyperplasia. Excessive neointimal proliferation after stent placement can result in hemodynamically significant stenosis, especially of the smaller intracranial branches. Concerns also exist that occlusion of the ostia of small side branches and perforating arteries by stent placement may result in ischemia or infarction in the territories of these vessels. This is the most relevant for intracranial aneurysms, in which occlusion of small but important perforating vessels may potentially result in significant morbidity. Because of the high porosity of the stent used, lateral branches such as the ophthalmic artery and anterior inferior cerebellar artery remain parent following placement of a stent across their origins. Experimentalevidence in dogs also suggests that small, lateral carotid branches, which approximate intracranial perforating vessels relative to their diameter and angle of origin, remain patent if less than 50% of the ostium diameter is covered by the stent struts.[18]

In conclusion, we report our preliminary experience with stents used alone or in combination with GDC placement for the treatment of aneurysms originating from different ICA segments and for patient with prolapse of detached coils during embolization. Our account demonstrates that modified SAE is both feasible and safe with the use of flexible intravascular stents. Thus far, we have been able to place coils satisfactorily in complex aneurysms that we would have been unable to treat without stent placement. Although the long-term effects of stents are currently unknown, we believe that stent for cerebral aneurysms holds great practical promise, especially in view of the potential for device improvements.

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