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INTERVENTIONAL NEURORADIOLOGY

Modified protection using far proximal portion of self-expandable closed-cell stents for embolization of wide-necked intracranial aneurysms

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Abstract
Introduction Stent-assisted embolization is sometimes limited in wide-necked aneurysms involving the acute-angled origins of tortuous branching arteries, and occasionally, Y-shaped stenting is required to remedy the sweeping effects of a broad aneurysmal neck on arterial branches. Described herein is a modified stent-assisted coil embolization technique entailing strategic placement of far proximal stent ("distal stenting") as an alternate approach in such scenarios.
Methods For this particular technique, stent placement is confined to a branch artery, allowing far proximal stent to cover aneurysmal neck, with no bridge to parent artery. Kinking of stents deployed in tortuous arteries is thereby avoided, and better coverage of aneurysmal neck is achieved, compared with traditional stent protection. Records of 12 consecutive patients with wide-necked aneurysms, all treated by coil embolization with distal stenting between January 2009 and February 2014, were retrieved from a prospective data repository at our institution. Outcomes were analyzed in terms of morphologic features and clinical status.
Results This modified technique was largely applied to aneurysms of middle cerebral artery, followed by posterior communicating artery and anterior communicating artery sites. With one exception, all aneurysms treated were successfully occluded. There were no complications directly related to distal stenting. At final follow-up (mean interval, 16.8± 9.7 months), complete aneurysmal occlusion was sustained in 81.8 %. Delayed stent migration was observed in one patient (8.3 %).
Conclusion Our study suggests that distal stenting in wide-necked aneurysms is a reasonable alternative to traditional stent protection, despite the potential for delayed stent migration.

Keywords Aneurysm · Coil · Embolization · Stent

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Introduction

Wide-necked aneurysms pose a technical challenge for endovascular treatment [1–3]. However, stent utilization in coil embolization procedures has steadily increased, validating this approach as a practical and effective therapeutic strategy [2–4]. Various stent systems have continued to evolve as a result, broadening the scope of endovascular therapy considerably in this setting [4–8]. Occasionally, stenting is of limited use in wide-necked aneurysms situated at and involving origins of acutely angulated branches, and dual Y-shaped stenting may be required if both branches of bifurcation aneurysms are incorporated to a major extent. Despite the extensive supportive data available on Y-shaped stents, safety and long-term durability concerns linger, including issues with thromboembolism, flow disturbance, or difficulty of re-embolization. Subsequently, we have developed a novel modified technique for stent protection, capitalizing on the flaring proximal end of an Enterprise™ stent (Codman, Raynham, MA, USA) (so-called distal stenting). This approach offers an

alternate means of treating wide-necked aneurysms at entries of acutely angulated and tortuous branching vessels.

For the present study, selective coil embolization with proximal stent assistance was prospectively evaluated in terms of feasibility, safety, and durability. This procedural modification was elected in 12 consecutive patients, each harboring an intracranial wide-necked aneurysm with arterial branch origins at aneurysmal neck.

Materials and methods

Population

Between January 2009 and February 2014, 1,932 patients with 2,230 aneurysms were treated by coil embolization at our institution, including 629 lesions where stents were used. Of these, 12 aneurysms (females, 8; males, 4; mean age, 57.2±10.0 years) with clinical and radiographic features as shown in Table 1 were subjected to our distal stenting method. All aneurysms were unruptured wide-necked lesions (depth-to-neck ratios <1.5), three of which were recanalized (25 %). After thorough evaluation, perceived risks, benefits, and treatment options (including aneurysm clipping) were discussed with each patient and family, who then granted informed consent. Therapeutic alternatives were formulated by neurosurgical and neurointerventional teams in a multidisciplinary decision-making process. This study was conducted with the approval of the Institutional Review Board of our hospital.

Therapeutic strategy

Our stepwise technique was as follows: (1) A microcatheter for stent delivery was navigated into a distal branch, (2) a second microcatheter for coil delivery was positioned in the aneurysmal sac, (3) the first frame coil was partially or fully inserted into the sac, (4) the proximal flared end of the stent was deployed as a cover for aneurysmal neck, without bridging of parent artery, and (5) any remaining frame coil and additional filling coils were inserted under stent protection. An overview of the technique is depicted in Fig. 1. It is our contention that stent deployment should follow partial or full insertion of the frame coil to avoid internal injury to the aneurysm by the flaring stent segment. Furthermore, this technique is not advocated as a first option. If traditional stent protection is feasible, by placing stent proportionately between parent and branch arteries, then distal stenting is not needed for the coiling procedure.

Distal stenting was our resort in the following circumstances: (1) acute-angled origination of stented branch, with vascular tortuosity (to avoid kinking or ovalization of a closed-cell stent), (2) disproportionate incorporation of branch orifice by aneurysm, rather than symmetric branch

Table 1 Summary of the patients' data

No.	Age	Sex	An status	Size of An (mm)	D/N ratio	Location	Degree of occlusion	Comment	Complication	Follow-up	GOS
1	53	F	I	6.6	1.0	MCAB	NR		None	Minor recanalization at 6 mo	5
2	52	F	I	6.0	0.5	MCAB	NR		Delayed infarction at 2 mo	Complete occlusion at 6 mo	5
3	58	M	R	R	0.8	AcomA	NR	A1 fenestration	None	Complete occlusion at 18 mo	5
4	72	F	I	8.1	0.9	MCAB	NR		None	Complete occlusion at 12 mo	5
5	52	F	I	5.5	0.8	MCAB	RS		None	Minor recanalization at 18 mo	5
6	44	M	R	R	0.7	MCAB	NR		None	Complete occlusion at 12 mo	5
7	44	M	R	R	0.5	PcomA	NR		None	Complete occlusion at 30 mo	5
8	50	M	I	5.0	1.2	MCAB	NR		None	Complete occlusion at 18 mo	5
9	66	F	I	6.6	1.0	MCAB	NR		None	Complete occlusion at 12 mo	5
10	71	F	I	5.4	0.6	PcomA	NR		Asymptomatic thrombus	Complete occlusion at 36 mo	5
11	55	F	I	6.7	0.9	MCAB	NR		None	No follow-up, pontine ICH	1
12	69	F	I	3.3	0.8	MCAB	NR		None	Complete occlusion at 36 mo	5

GOS Glasgow outcome scale, *An* aneurysm, *D/N* depth to neck width, *I* initial, *R* recanalized, *AcomA* anterior communicating artery, *MCAB* middle cerebral artery bifurcation, *PcomA* posterior communicating artery, *NR* neck remnant, *RS* residual sac, *ICH* intracerebral hemorrhage, *mo* months

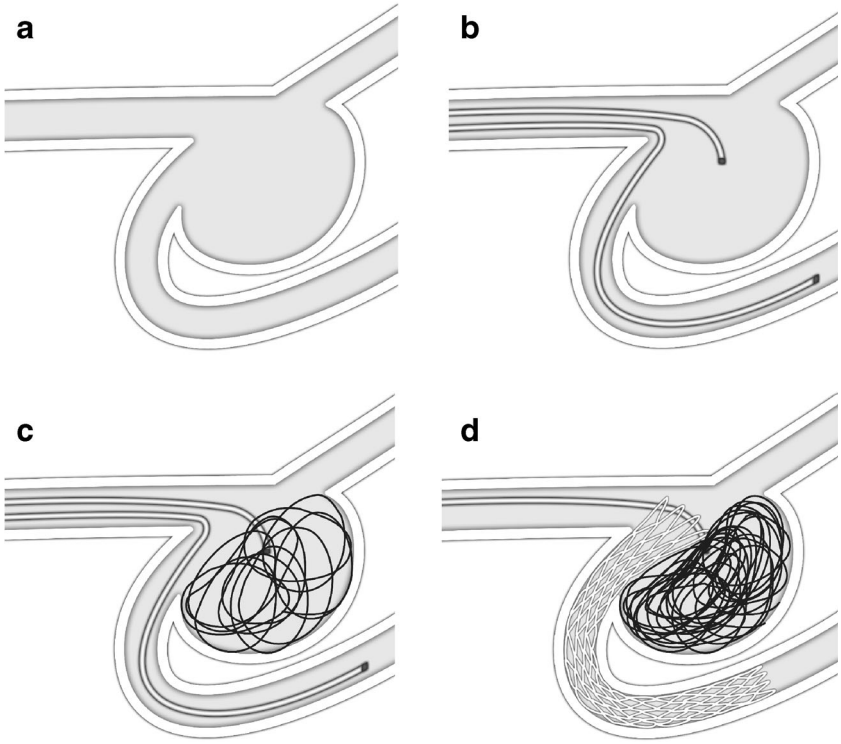

Fig. 1 **a** Wide-necked aneurysm of MCA bifurcation incorporating orifice of tortuous inferior division. **b** Separate microcatheters delivering coil to sac of aneurysm and stent (for protection) to inferior division. **c** Proximal stent coverage of aneurysmal neck (without bridging of parent artery) after partial or full insertion of first frame coil into sac. **d** Coil insertion completed under stent protection

involvement, and (3) fenestration or stenosis of proximal parent artery targeted for stenting.

In some instances, our technique helped avoid dual Y-shaped stenting, because the extent of aneurysmal neck coverage achieved exceeded that of traditional single stenting, conferring better protection during embolization (Fig. 2).

Endovascular procedure

All procedures were performed under general anesthesia. Aneurysmal configuration and arterial architecture were evaluated via the Integris V (Philips Medical System, the Netherlands) and Innova IGS 630 (GE Healthcare, USA) biplane system, incorporating 3D rotational angiography. The largest dimension in 3D view was recorded as size of aneurysm. Aneurysmal neck size and depth-to-neck ratio were measured on a working projection of digital subtraction angiography. All patients were given 75 mg of clopidogrel and 100 mg of aspirin for a minimum of 5 days before the procedure, or they received loading doses of clopidogrel and aspirin (300 mg each) 1 day prior to the procedure and were supplemented (clopidogrel, 75 mg; aspirin, 100 mg) on the morning of the procedure. In patients showing poor response to clopidogrel, cilostazol was added. A bolus of heparin (3,000 IU) was administered after femoral arterial sheath placement and thereafter at hourly intervals (1,000 IU/h) or as needed to maintain activated clotting time at 250 to 300 s. Dual antiplatelet medication was also recommended to be maintained for at least 1 month after the procedure, and a single agent was to be maintained for at least 1 year.

Procedural and follow-up outcomes

The degree of aneurysmal occlusion was assessed by completion angiography with a 3-point Raymond scale: complete occlusion (no residual filling of contrast medium in the aneurysms), residual neck (a small amount of residual contrast filling at the base of the aneurysm), and residual aneurysm (any contrast filling in the aneurysmal sac) [9].

In patients with unruptured aneurysms, MR angiography and/or plain radiography were recommended at 6, 12, 24, and 36 months after coil embolization. Conventional angiography was recommended at the 12-month follow-up visit if post-treatment MR angiography was not feasible (due to stent-induced artifact) or if recanalization of an aneurysm was suspected by noninvasive diagnostics (i.e., MR angiography or plain radiography), so that further intervention could be contemplated.

Clinical outcomes were assessed via the Glasgow outcome scale (GOS). Anatomical follow-up results were categorized as follows: complete occlusion (no residual filling of contrast medium in the aneurysms), minor recanalization (a small amount of residual contrast filling at the base of the aneurysm), or major recanalization (any contrast filling in the

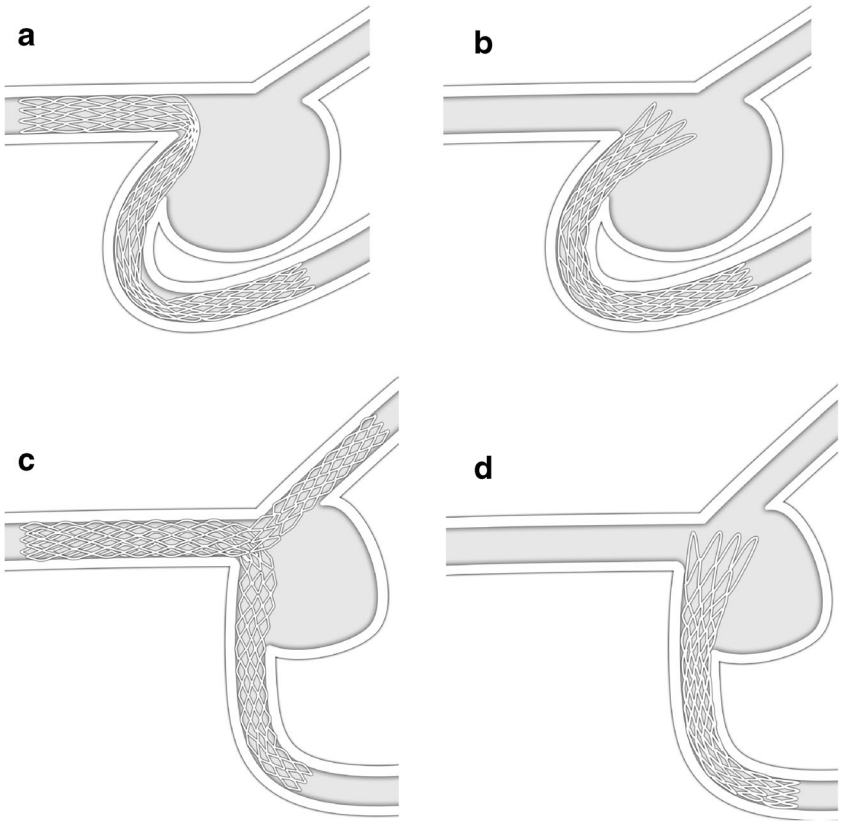

Fig. 2 **a** Tendency for kinking or ovalization (narrowing) of closed-cell stents traditionally deployed (i.e., placed symmetrically between parent and branch arteries) at points of curvature in tortuous acute-angled vessels. **b** Problematic kinks preventable by distal stenting, with better coverage of aneurysmal neck than achieved traditionally. **c** Occasionally needed dual Y-shaped stenting for coil embolization. **d** Distal stenting may instead suffice (dual stenting unnecessary)

aneurysmal sac). Repeat embolization was recommended in instances of major recanalization.

Results

The Enterprise stent was deployed in all patients as the distal stenting device of choice, applied primarily for aneurysms of middle cerebral artery (MCA) bifurcation (n=9), followed by posterior communicating artery (n=2) and anterior communicating artery (n=1) lesions. Stents were successfully deployed by this technique in all instances, without malposition. In addition to distal stenting, three patients required other techniques (multiple microcatheters, 2; microcatheter protection, 1). Aneurysmal occlusion was achieved in ten patients, leaving two with residual sacs. One patient developed an asymptomatic thrombus, which resolved with intra-arterial tirofiban infusion. No other procedure-related adverse events were encountered. All patients were neurologically intact (GOS 5) at the time of discharge.

During follow-up (mean interval, 16.8±9.7 months), 9 of 11 patients evaluated at >6 months by magnetic resonance angiography and/or digital subtraction angiography showed complete occlusion of treated aneurysms. Minor recanalization was evident in two patients remaining. None of them showed major recanalization. Conventional angiography was also performed in eight patients, revealing delayed stent migration in one subject (12.5 %), without clinical signs or symptoms. None displayed significant in-stent stenosis. One patient who discontinued antiplatelet maintenance for thyroid cancer surgery suffered delayed infarction, without permanent neurologic sequelae (GOS 5). One patient expired 8 months after treatment, from hypertensive pontine hemorrhage unrelated to coil embolization.

Illustrative case

Patient 5

This 52-year-old female was admitted for endovascular treatment of a right-sided aneurysm at MCA bifurcation. By conventional angiography, a wide-necked aneurysm incorporated the orifice of inferior division, with inferior division arising from an acute-angled and tortuous parent artery. Distal stenting was elected to prevent kinking of a traditionally placed stent and to avoid dual Y-shaped stenting. A 6-Fr guiding catheter was first positioned in cervical segment of left internal carotid artery. After a microcatheter was passed for stent delivery to the inferior division, another microcatheter for coil delivery was inserted into the aneurysmal sac, and the frame coil was partially introduced. Distal stenting was then implemented to protect parent artery from coil protrusion, deploying the

proximal flared end of an Enterprise stent as a cover for aneurysmal neck. Thereafter, framing by first coil continued under stent protection and was satisfactorily configured. The entire sac ultimately was filled with additional coil, successfully occluding the aneurysm (Fig. 3). The patient was discharged the next day, without complication.

Discussion

Once the Neuroform™ stent (Stryker Neurovascular, Fremont, CA, USA) emerged for treating intracranial aneurysms, the scope of coil embolization broadened considerably, and thanks to various state-of-the-art self-expandable stents, many aneurysms previously viewed as unsuitable for such devices are no longer off-limits [10]. The choice of stent now depends on morphologic attributes of aneurysms and parent arteries [11]. However, some angio-anatomic configurations are still problematic, limiting the use of stents or necessitating dual Y-shaped stenting. In these instances, the protection derived from the far proximal end of a stent (so-called distal stenting) constitutes a promising alternative. This preliminary study of a small population suggests that wide-necked aneurysms involving origins of acute-angled and tortuous branching arteries may be safely and effectively treated by distal stenting, although delayed stent migration is a minor drawback of no apparent clinical consequence.

Among the self-expandable stents that are commercially available, the Enterprise was used by us exclusively. It is a nonbraided laser-cut nitinol stent of closed-cell design that is retrievable and shortens minimally during stent deployment. These features facilitate accurate stent placement. Because the Neuroform device is a nonretrievable open-cell stent and the Solitaire stent has a tapered proximal end, they were unacceptable for our purposes. Although wire-braided closed-cell stents are similar to the Enterprise stent and seem satisfactory for distal stenting, proximal shortening during deployment may be excessive.

Accurate stent placement is critical for distal stenting, demanding precision in two-handed control. The microcatheter shaft is gripped by the left hand near the connecting hub of the guidance system to adjust its tension, while the right hand regulates stent advancement at the pushing terminus [12]. The Enterprise stent shortens minimally during stent deployment, so the proximal end may be inserted a bit closer to the target point prior to actual deployment. To avoid injuring the aneurysm internally, the frame coil should be partially or fully inserted before stent deployment.

In tortuous and acutely angled arteries that curl back and forth regularly, closed-cell stents may undergo kinking at points of curvature (see Fig. 2) when placed traditionally

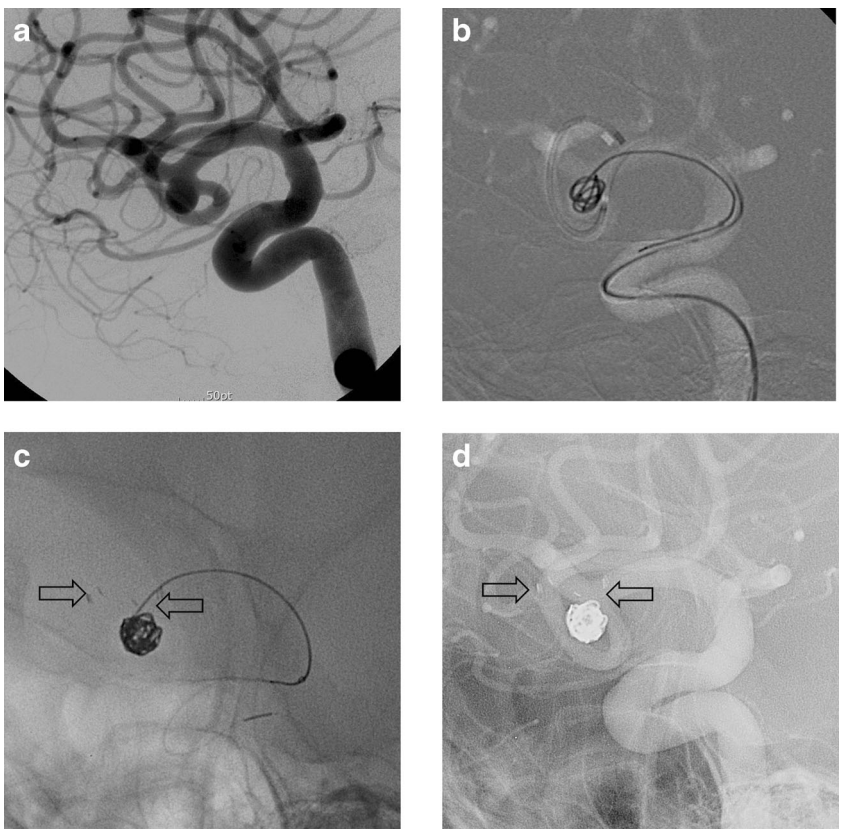

Fig. 3 **a** Wide-necked aneurysm of right MCA bifurcation incorporating orifice of tortuous inferior division by conventional angiography. **b** Separate microcatheters in inferior division of MCA and in the aneurysmal sac and frame coil partially inserted into the aneurysmal sac. **c** Additional coil inserted after distal stenting. **d** Small residual neck documented by completion angiography (*arrows* indicate both ends of the stent)

(i.e., positioned symmetrically between parent and branch arteries). Distal stenting lowers the risk of stent-induced flow disturbance by preventing such problems. Compared with traditionally used single stents, distal stenting also provides broader coverage of aneurysmal neck, ensuring excellent protection against coil protrusion (see Fig. 2).

In some instances, the enhanced neck coverage achieved by proximal flaring of a single stent may help avoid the need for dual Y-shaped stenting. Our experience with nonoverlapping Y-shaped stents deployed in wide-necked aneurysms of basilar tip was detailed in an earlier report [12]. Although overlapped Y-shaped stenting with various devices was amply discussed elsewhere, we were troubled by safety and durability issues. The previous study indicated that applying the flared end of an Enterprise stent to the neck of an aneurysm was technically feasible and did guard the parent artery from protruding coil. Likewise, Yashar et al. [13] described the horizontal deployment of a nonretrievable Neuroform stent as a one-time effort via antegrade approach, in a manner similar to distal stenting, although follow-up results were not reported. Lubicz [14] also reported linear stent-assisted coiling using dual Leo devices in a modified Y configuration. Both sources further corroborate the viability of distal stenting. Compared with traditional stenting, it is also much easier to select aneurysms with microcatheters through proximal stent cells.

There are drawbacks to distal stenting. At first, delayed migration may occur, albeit without apparent clinical consequence. Proximal migration is generally more common with traditional closed-cell stenting, based on factors such as disparate parent/branch arterial size, stented arterial angle change, and gravitational or motion effects [15]. On the other hand, distal migration has been the rule with distal stenting. Closed-cell stents tend to migrate into the larger stented portion if stent placement between parent artery and acute-angled branch is disproportionate [4]. Because only tortuous branch vessels are affected by distal stenting and parent arteries are not bridged, distal migration is not unexpected. Distal stenting also inherently diminishes anchorage, promoting distal migration. In addition, deployed stents are inclined to straighten the arteries involved, inducing arterial remodeling through angle changes. Another concern of distal stenting would be a possibility that proximal flared end of the stent may cause internal injury of the aneurysm (and possibly aneurysm rupture), although there was no such case in our series. It could be possibly avoided by the stent deployment following partial or full insertion of the frame coil. Lastly, although the feasibility of distal stenting is proven, accurate stent placement is mandatory for procedural success.

As a point of emphasis, first-line use of distal stenting for coil embolization of wide-necked aneurysms is not advocated. The efficacy and safety of this approach has yet to be confirmed in a larger patient population. However, we do feel that this technique may have merit in disadvantaged situations where standard options are limited.

Conclusion

The far proximal end of a closed-cell stent confers protection in wide-necked aneurysms that involve origins of acute-angled tortuous branches and may preclude dual Y-shaped stenting in some instances. Delayed stent migration is possible, warranting appropriate follow-up monitoring.

Ethical standards and patient consent We declare that all human and animal studies have been approved by the Institutional Review Board of Seoul National University Hospital and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. We declare that all patients gave informed consent prior to inclusion in this study.

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Conflict of interest We declare that we have no conflict of interest.

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