Preliminary experience with self-expanding closed-cell stent placement in small arteries less than 2 mm in diameter for the treatment of intracranial aneurysms

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OBJECT The purpose of this study was to report the authors' preliminary experience using self-expanding closed-cell stents deployed in small arteries (< 2 mm in diameter) to treat intracranial aneurysms.

METHODS A total of 31 patients were studied. All subjects met the following criteria: 1) they received an Enterprise stent for treatment of a wide-necked aneurysm or a dissecting aneurysm or as part of a stent-salvage procedure; and 2) they had an Enterprise stent deployed in a small parent artery (< 2 mm in diameter) that had no atherosclerotic stenosis. Procedure-related complications and follow-up sizes of the parent arteries were evaluated for safety and patency.

RESULTS There were 16 ruptured aneurysms and 15 unruptured aneurysms. Three (9.7%) of the 31 patients experienced procedure-related complications, and they all were asymptomatic. Follow-up angiography was performed in 27 patients (87.1%) (at a mean 15.5 months after surgery). Parent arteries with 2 acute angles (n = 4) were occluded in 3 cases (75.0%), and those with no acute angles (n = 13) or 1 acute angle (n = 6) showed 100% patency on follow-up angiography. There was a significant difference between the follow-up sizes (mean 1.72 ± 0.30 mm) of parent arteries and their sizes (mean 1.59 ± 0.26 mm) before treatment (95% CI -0.254 to -0.009 mm; $p = 0.037$, paired-samples t-test).

CONCLUSIONS In the current series the deployment of self-expanding closed-cell stents in small arteries was safe and resulted in good patency, especially when the stents were deployed in segments of the parent artery with no acute angles or only 1 acute angle.

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KEY WORDS closed-cell stent; Enterprise stent; intracranial aneurysm; self-expanding stent; small parent vessels; vascular disorders

STENT placement has effectively expanded the indications of endovascular treatment (EVT) for intracranial aneurysms. Low-profile endovascular devices enable access to aneurysms farther out in small cerebral arteries measuring < 2 mm in diameter.^{3,10,13} A very recent novel neurovascular self-expanding retrievable closed-cell stent system, the LVIS (Low-Profile Visualized Intraluminal Stent) (MicroVention), can be delivered using the currently lowest-profile microcatheter.¹¹ The LVIS Jr., which has a diameter of 2.5 mm, can be delivered and

deployed in small distal arteries via a 0.017-in microcatheter. Thus, surgeons have recently been using the LVIS Jr. in small cerebral arteries. In the Republic of Korea, the LVIS and LVIS Jr. are not currently available. However, stents are still needed for use in small distal arteries to treat intracranial aneurysms. The self-expanding closed-cell Enterprise stent (Codman Neurovascular), a low-profile endovascular device, is available in our country. It is delivered via a 0.021-in microcatheter and has been proposed for use in wide-necked, intracranial, and saccular

ABBREVIATIONS DSA = digital subtraction angiography; EVT = endovascular treatment; GOS = Glasgow Outcome Scale; LVIS = Low-Profile Visualized Intraluminal Stent.

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aneurysms arising from parent vessels with a diameter of ≥ 2.0 mm and ≤ 4.5 mm that are not amenable to treatment with surgical clipping. Despite these parameters, the Enterprise stent has been widely used in arteries < 2 mm in diameter.^{3,7,10} Thus, the purpose of this study is to report our preliminary experience of using self-expanding closed-cell Enterprise stents deployed in small arteries (< 2 mm) for the treatment of intracranial aneurysms.

Methods

Patient Selection

This retrospective study was approved by the institutional review board of Yonsei University, and the requirement for informed consent from the patients was waived. Between December 2008 and June 2013, 241 patients underwent EVT in which Enterprise stents were used. Among them, a total of 31 patients (15 men, 16 women; mean age 56.3 ± 10.8 years; range 41–79 years) met the following inclusion criteria: 1) treatment was performed using an Enterprise stent for a wide-necked aneurysm (a wide-necked saccular aneurysm was defined as that with a dome-to-neck ratio of < 2 mm or a neck diameter of ≥ 4 mm) or a dissecting aneurysm or as part of a stent-salvage procedure;³ and 2) the Enterprise stent was deployed in a parent artery that was < 2 mm in diameter and that had no atherosclerotic stenosis. Patients were excluded for the following reasons: 1) the parent artery had atherosclerotic stenosis; 2) an Enterprise stent was used to treat ischemic disease, such as acute ischemic stroke or intracranial stenosis; 3) treatment was a repeat EVT of a previously treated aneurysm using any kind of intracranial stent; 4) multiple overlapping stents were present; or 5) a traumatic pseudoaneurysm was present.

The clinical data of these patients, aneurysm characteristics, indications for stent use, and radiographic images were reviewed. We previously reported data obtained in 9 patients included in the present study in investigations of vertebral artery to posterior inferior cerebellar artery stenting ($n = 3$)⁷ and the stent-salvage procedure ($n = 6$).³ Complications related to the use of Enterprise stents and the sizes of parent arteries at follow-up were evaluated to investigate the safety and patency of the stents.

Endovascular Treatment and Radiographic Outcomes

When stent assistance was required for EVT in patients with ruptured wide-necked aneurysms, surgical clipping was considered the first treatment option. Treatment decisions with respect to patient comorbidities, clinical status, surgical feasibility, and grade of hemorrhage were made by consensus among the neurosurgeons and neurointerventionists. For any patient with an unruptured wide-necked aneurysm, the decision to use an Enterprise stent was based on aneurysm characteristics, such as morphology and the aneurysm–parent vessel relationship. All stenting procedures were performed after induction of general anesthesia. A 6-Fr or 7-Fr guiding catheter was positioned in the internal carotid artery via the common femoral artery for anterior circulation aneurysms or in the vertebral artery for posterior circulation aneurysms. A Prowler Select Plus (Codman

Neurovascular) was used to deliver the Enterprise stent in each case. For emergent procedures involving ruptured aneurysms, heparin was not injected intravenously or subcutaneously but was instead mixed into saline flushes used during the procedure. After femoral puncture, loading doses of 300–600 mg of clopidogrel¹⁴ and 200–400 mg of aspirin were given via nasogastric tube. For elective procedures involving unruptured aneurysms, heparin (50 U/kg) was injected intravenously immediately after femoral puncture. Activated clotting time was maintained at twice that of the baseline throughout the endovascular procedure. Patients were taking a daily dosage of 75-mg clopidogrel and 100-mg aspirin for more than 5 days before the procedure. Regardless of whether their aneurysm was ruptured, all patients were prescribed 75 mg of clopidogrel daily for 3 months and 100 mg of aspirin daily for a minimum of 12 months after the procedure. During the procedure, 1 mg of glycoprotein IIb/IIIa antagonist (tirofiban) was injected intra-arterially when the parent artery was occluded by a thromboembolism.

Digital subtraction angiography (DSA) was performed before the procedure for each patient. The sizes of the parent arteries were evaluated by automated (border-detecting) digital quantitation on postprocessed 2D DSA images, and the sizes were recorded after we rounded up the number of the second digit after the decimal point. The tortuosity of the parent arteries was measured by counting the number of acute angles ($< 90^\circ$) within the segment of each parent artery in which a stent was to be deployed. To measure the angle, we performed 3D rotational angiography in all patients. The angles were measured on selected 3D images and on 2D DSA images that clearly displayed the afferent and efferent segments of the parent arteries. In a selected view of the angiographic image, the first dot was marked on the midpoint of the afferent segment of a parent artery in which a stent would be deployed. The second dot was marked on the midpoint of the efferent segment of the parent artery. The third dot was marked on the midpoint of the angular segment of the parent artery. Then, a line was drawn by connecting the first dot and the third dot, and another line was drawn by connecting the second dot and the third dot. The angle between the 2 lines was then measured. Two independent investigators evaluated the size and angle of each parent artery. We averaged the measured values of the sizes and angles. The angiographic results of aneurysms were categorized as complete occlusion (without a neck remnant), neck remnant ($> 90\%$ occlusion with small neck remnant or dog ear), or partial occlusion (filling of the aneurysm lumen). The clinical outcomes were assessed on the basis of the Glasgow Outcome Scale (GOS) scores.

Statistical Analysis

Statistical analysis was performed using SPSS 18.0 (SPSS, Inc.). A paired-sample t-test was performed to compare the sizes of the parent arteries before and after treatment. Mann-Whitney U-tests were used for numeric variables. Chi-square or Fisher exact tests were used for nominal variables. Univariate analysis was performed to determine the association of the size increments of parent arteries on follow-up angiography with other factors.

Binary logistic regression analysis was then performed on variables with an unadjusted effect and a *p* value of < 0.10 on univariate analysis to determine independent associations of the size increments of parent arteries with other factors. *p* < 0.05 was considered statistically significant.

Results

Table 1 shows clinical data of all the patients. Of 31 patients, an Enterprise stent was deployed in the anterior cerebral artery in 11 (35.5%), the middle cerebral artery in 4 (12.9%), the posterior cerebral artery in 7 (22.6%), and the posterior inferior cerebellar artery in 9 (29.0%). There were 16 ruptured and 15 unruptured aneurysms. Enterprise stents were used in 16 patients with wide-necked aneurysms, 4 patients with dissecting aneurysms, and 11 patients who required the stent-salvage procedure. Three (9.7%) of the 31 patients experienced procedure-related complications (in-stent thrombosis) that were resolved completely by intraarterial injection of a glycoprotein IIb/IIIa antagonist. All 3 of these patients were asymptomatic. The technical success rate of stenting was 100%, and there was no failure to navigate or deploy any stent.

Follow-up angiography was performed in 27 patients (87.1%) between 6 and 24 months (mean 15.5 months) after the procedure. Among them, 24 patients (88.9%) exhibited good parent artery patency on follow-up angiography. Parent artery occlusion was found in 3 patients (11.1%). In terms of the numbers of acute angles in the parent arteries, 17 patients (63.0%) had none, 6 (22.2%) had 1 acute angle, and 4 (14.8%) had 2 acute angles (Table 2). Parent arteries with 2 acute angles (*n* = 4) were occluded in 3 cases (Fig. 1), and 1 exhibited a reduction on follow-up (Fig. 2). Patients with no acute angle or 1 acute angle showed 100% patency of the parent artery, but 1 patient with 1 acute angle had a size decrement on follow-up. Among the 24 patients with good parent artery patency, the average size of the parent arteries was 1.59 ± 0.26 mm (median 1.60 mm, IQR 1.38–1.81 mm) before the procedure and 1.72 ± 0.30 mm (median 1.75 mm, IQR 1.61–1.92 mm) on follow-up angiography. There was a significant difference between the sizes of the parent arteries at follow-up and their sizes before the procedure (95% CI –0.254 to –0.009 mm; *p* = 0.037, paired-samples *t*-test) (Fig. 3).

Ruptured aneurysms and tortuosity of the parent arteries (the number of acute angles), with *p* < 0.10 on univariate analysis (*p* = 0.051 and 0.022, respectively), were included in the multivariate logistic regression analysis to determine predisposing factors for the size increments of parent arteries after stenting on follow-up angiography. Tortuosity of the parent arteries (OR 1.936, 95% CI 0.842–3.226; *p* = 0.041) remained the only independent predisposing factor for the size increments of parent arteries after stenting on follow-up angiography (Table 3).

Among the 27 patients with follow-up angiography, the initial radiographic results revealed 19 cases of complete occlusion, 7 cases of neck remnants, and 1 case of incomplete occlusion. There were 21 cases of complete occlusion and 6 cases of neck remnant on follow-up angiography (Table 1). The 27 patients with follow-up angiography showed good clinical outcomes with a GOS score of 4 or

5 between 12 and 30 months posttreatment (mean 18.5 months).

Discussion

Results of this study indicate that 88.9% of parent arteries were patent on follow-up angiography (mean 15.5 months). Although 3 (75%) of 4 patients with a parent artery that had 2 acute angles showed parent artery occlusion, 100% patency was demonstrated on follow-up angiography in parent arteries that had no acute angle or 1 acute angle. The average size of the parent arteries increased on follow-up angiography compared with that before the procedure (Fig. 3). On multivariate logistic regression analysis, the tortuosity (the number of acute angles) of parent arteries was determined to be only a predisposing factor for the size increments of parent arteries on follow-up angiography. Furthermore, 100% successful navigation and deployment of stents was achieved without symptomatic procedure-related complications. These results suggest that the angiographic vascular configuration and traveling course of the parent arteries might be important factors for maintaining the patency of parent arteries. Stent deployment in small parent arteries seems to be safe from a technical viewpoint.

The new self-expanding, retrievable, closed-cell stent, the LVIS, has a low-profile delivery system. The LVIS Jr. has a diameter of 2.5 mm and the lowest profile of any other current delivery system (a microcatheter with an inner diameter of 0.017 inch), enabling it to be delivered by the Scepter C balloon (MicroVention) system for the “balloon-then-stent” (“monoaccess”) method.¹¹ However, the safety and long-term patency of the LVIS Jr. in distal small arteries have yet to be reported. In addition, the LVIS and LVIS Jr. are currently not available in the Republic of Korea.

The Enterprise stent also has a low-profile delivery system (a microcatheter with an inner diameter of 0.021 in and an outer diameter of 2.3 Fr), and its navigability is better than that of the previously developed intracranial stents, such as the Neuroform.^{9,10} These stents can be easily delivered to small distal arteries, resulting in 100% successful navigation and stent deployment in this study. Mocco et al.⁹ reported the superior navigability of Enterprise stents. They successfully navigated and deployed stents in 97% of 142 aneurysms with 143 attempted stent deployments. Siddiqui et al.¹⁰ performed 8 horizontal stent-assisted coil embolizations with the Enterprise stent in vessels with a mean diameter of 1.58 mm. They followed up with all patients with DSA for 3–12 months after treatment. They concluded that the stents were deployed successfully and accurately in vessels < 2 mm in diameter, and there were no cases of stent occlusion. In our study, we have shown that 88.9% of parent arteries were patent on follow-up angiography (mean 15.5 months). However, 3 (11.1%) patients showed occlusion of the parent artery. When the patients were grouped according to number of acute angles, 100% patency was demonstrated in parent arteries with no acute angles or 1 acute angle on follow-up angiography. Conversely, among the 4 patients with 2 acute angles in their parent arteries, 3 (75%) patients showed parent artery occlusion (Table 2). In addition, 2 patients (Case 27 had 2

TABLE 1. Clinical data of all the patients

Case No.	Age (yrs), Sex	Initial HHG	An Location	Parent Vessel	An Type	Reason for Stenting	Cx Related to Stent Usage	Parent Vessel Tortuosity (no. of acute angles)	An Size (mm)			Initial Vessel Size (mm)	FU Vessel Size (mm)	FU Time (mos)	Stent Size (mm)	Initial Radio-graphic Result	FU Radio-graphic Result	FU GOS Score (mos)
									L	W	D	Neck						
1	43, M	3	ACoA	ACA	Saccular	Stent salvage	None	0	8.9	5.1	5.4	4.1	1.4	1.6	12	4.5 × 22	CO	No FU 4 (12)
2	64, M	0	BA bif	PCA	Saccular	Wide-necked An	None	0	6.3	9.5	6.9	8.3	1.8	1.8	12	4.5 × 22	CO	No FU 5 (12)
3	66, M	5	ACoA	ACA	Saccular	Stent salvage	In-stent thrombosis	0	7.2	4.3	7.6	4.1	1.4	No FU	No FU	4.5 × 22	NR	No FU 2 (2)
4	46, F	2	PCA (P ₁₋₂)	PCA	Saccular	Stent salvage	None	0	7.5	8.7	6.8	2.5	1.2	No FU	No FU	4.5 × 37	IC	No FU 5 (12)
5	50, F	4	PCA (P ₂₋₃)	PCA	Saccular	Stent salvage	None	0	4.1	3.3	4.8	4.9	1.7	No FU	No FU	4.5 × 28	CO	No FU 2 (6)
6	74, F	4	PICA	PICA	Saccular	Wide-necked An	None	1	8.8	6.9	5.7	4.5	1.4	No FU	No FU	4.5 × 22	CO	No FU 4 (12)
7	49, M	4	VA	PICA	Dissecting	Dissecting	None	0	13.2	5.4	—	—	1.7	1.8	12	4.5 × 37	CO	No FU 5 (12)
8	69, F	0	SCA	PCA	Saccular	Wide-necked An	None	0	6.4	6.5	5.1	6.2	1.9	1.9	12	4.5 × 28	CO	No FU 5 (12)
9	58, M	0	DACA	ACA	Saccular	Stent salvage	None	0	3.1	2.1	2.4	1.6	1.8	2.0	12	4.5 × 22	NR	5 (24)
10	41, F	0	PICA	PICA	Saccular	Wide-necked An	None	1	6.3	3.1	3.0	3.1	1.5	1.7	18	4.5 × 22	CO	5 (18)
11	48, M	3	ACA (A ₁)	ACA	Saccular	Wide-necked An	None	0	4.5	3.4	3.5	3.1	1.9	2.1	12	4.5 × 22	CO	5 (18)
12	41, F	4	VA	PICA	Dissecting	Dissecting An	None	1	10.1	3.8	—	—	1.4	1.8	12	4.5 × 28	CO	5 (30)
13	54, M	0	ACoA	ACA	Saccular	Wide-necked An	None	0	2.9	3.1	5.3	4.9	1.9	2.3	24	4.5 × 22	CO	5 (24)
14	79, F	0	SCA	PCA	Saccular	Wide-necked An	None	0	5.5	4	6.7	3.8	1.8	1.8	24	4.5 × 28	IC	5 (24)
15	47, F	2	ACoA	ACA	Saccular	Stent salvage	In-stent thrombosis	0	4.1	4.1	3.6	2.8	1.8	2.0	24	4.5 × 22	CO	5 (24)
16	68, F	0	ACoA	ACA	Saccular	Wide-necked An	None	0	6.0	6.0	6.0	5.0	1.9	1.9	12	4.5 × 22	CO	5 (20)
17	65, F	0	SCA	PCA	Saccular	Wide-necked An	None	0	21.0	9.7	8.9	8.8	1.3	1.5	18	4.5 × 37	NR	5 (18)
18	47, M	2	VA	PICA	Dissecting	Dissecting An	None	1	8.4	4.6	—	—	1.2	1.7	24	4.5 × 37	CO	5 (24)
19	56, M	2	ACoA	ACA	Saccular	Stent salvage	None	0	6.5	5.9	7.8	5.9	1.4	1.7	18	4.5 × 22	CO	5 (30)
20	49, F	2	DACA	ACA	Saccular	Stent salvage	None	0	10.1	7.8	8.0	4.3	1.1	1.2	22	4.5 × 22	NR	5 (24)
21	48, F	2	MCA bif	MCA	Saccular	Stent salvage	None	1	6.6	3.6	4.9	3.2	1.9	2.0	18	4.5 × 22	NR	5 (24)
22	60, M	3	ACoA	ACA	Saccular	Stent salvage	None	0	4.6	3.7	3.7	3.4	1.4	1.8	18	4.5 × 22	NR	5 (24)
23	44, F	2	DACA	ACA	Saccular	Stent salvage	None	0	3.7	4.8	2.9	2.9	1.6	1.6	12	4.5 × 22	CO	5 (15)
24	50, M	0	VA	PICA	Dissecting	Dissecting An	None	0	4.5	5.6	—	—	1.2	1.6	20	4.5 × 22	CO	5 (24)
25	58, F	0	PICA	PICA	Saccular	Wide-necked An	None	0	3.1	2.8	6.4	3.2	1.6	1.7	11	4.5 × 22	NR	5 (20)
26	52, M	0	PICA	PICA	Saccular	Wide-necked An	None	1	6.7	3.3	3.6	3.1	1.5	1.5	12	4.5 × 22	NR	5 (18)
27	66, M	0	MCA bif	MCA	Saccular	Wide-necked An	None	2	5.6	4.3	6.6	4.3	1.4	0.9	12	4.5 × 22	CO	5 (20)
28	68, M	0	PICA	PICA	Saccular	Wide-necked An	None	1	3.2	3.3	3.2	2.9	1.8	1.5	11	4.5 × 22	CO	5 (18)
29	48, M	2	PCA (P ₂₋₃)	PCA	Fusiform	Wide-necked An	None	2	15.9	13.0	13.3	—	1.7	Occluded	6	4.5 × 22	CO	4 (15)

(continued)

TABLE 1. Clinical data of all the patients (continued)

Case No.	Age (yrs), Sex	Initial HHG	An Location	Parent Vessel	An Type	Reason for Stenting	Cx Related to Stent Usage	Parent Vessel Tortuosity (no. of acute angles)	An Size (mm)			Initial Vessel Size (mm)	FU Vessel Size (mm)	FU Time (mos)	Stent Size (mm)	Initial Radio-graphic Result	FU Radio-graphic Result	FU GOS Score (mos)
									L	W	D	Neck						
30	64, F	0	MCA bif	MCA	Saccular	Wide-necked An	None	2	5.1	7.7	5.2	7.7	1.4	12	4.5 × 22	CO	CO	5 (12)
31	75, F	0	MCA bif	MCA	Saccular	Wide-necked An	In-stent thrombosis	2	10.1	6.4	10.7	5.7	1.6	18	4.5 × 22	CO	CO	5 (24)

ACA = anterior cerebral artery; ACoA = anterior communicating artery; An = aneurysm; BA = basilar artery; bif = bifurcation; CO = complete occlusion; Cx = complication; D = depth; DACA = distal anterior cerebral artery; FU = follow-up; HHG = Hunt and Hess Grade; IC = incomplete occlusion; L = length; MCA = middle cerebral artery; NR = neck remnant; PCA = posterior cerebral artery; PICA = posterior inferior cerebellar artery; SCA = superior cerebellar artery; VA = vertebral artery; W = width.

TABLE 2. Parent artery tortuosity (according to the number of acute angles)*

Patency of Parent Artery	No Acute Angles (n = 17)	1 Acute Angle (n = 6)	2 Acute Angles (n = 4)
Patent	17 (100)	5 (83.3)	0 (0)
Patent but decreased in size	0 (0)	1 (16.7)	1 (25.0)
Occluded	0 (0)	0 (0)	3 (75.0)

* Value are presented as the number (%) of patients.

acute angles, and Case 28 had 1 acute angle) showed size decreases in their parent artery on follow-up angiography. These arteries might occlude in the future.

Incomplete stent apposition is more likely to be found in arteries with tortuous anatomy.⁵ Stents with a closed-cell design show poor wall apposition in tortuous vessels compared with open-cell stents. The low radial force of stents could be one cause of poor wall apposition. Although poor wall apposition may improve by deploying closed-cell stents very slowly,⁸ this technique might not work in a small-sized tortuous parent artery. The stent might not fully deploy in the segment between the 2 acute angles because of kinking or ovalization at the angles. This is especially concerning in arteries with a small diameter. In addition, increased metal surface coverage might increase the risk of thromboembolism when stents are deployed in small arteries. For the treatment of intracranial aneurysms, however, most stents are deployed in healthier segments of parent arteries without atherosclerosis stenosis. For this reason, self-expanding stents destroy smaller amounts of endothelium than intracranial atherosclerotic lesions. Previous reports suggested that Enterprise stents might be better suited for use in small vessels, because

FIG. 1. A 48-year-old man (initial Hunt and Hess Grade II) with a ruptured right posterior cerebral artery aneurysm was treated by stent-assisted coil embolization. Shown are pretreatment 3D (A) and 2D (B) angiographic images in anteroposterior (left) and lateral (right) views. The posterior cerebral artery was 1.7 mm in diameter and tortuous with 2 acute angles. Immediate posttreatment angiograms (C) showed a patent posterior cerebral artery and complete aneurysm obliteration. Arrows indicate the proximal and distal stent markers. The right posterior cerebral artery distal to the aneurysm was occluded on 6-month follow-up angiography (D). Figure is available in color online only.

FIG. 2. A 66-year-old man with an unruptured left middle cerebral artery aneurysm was treated by stent-assisted coil embolization. **A:** The pretreatment working angle of the 3D reconstructive image shows a segment of the left middle cerebral artery with 2 acute angles (*lines*). **B:** The superior division of the middle cerebral artery was 1.4 mm on the pretreatment anteroposterior view of a 2D image. **C:** Immediate posttreatment angiogram showing patent superior division (*arrowhead*) of the left middle cerebral artery with complete aneurysm obliteration. *Arrows* indicate proximal and distal stent markers. **D:** The superior division (*arrowhead*) of the left middle cerebral artery decreased to 0.9 mm on 1-year follow-up angiography. *Arrows* indicate proximal and distal stent markers.

they show poor wall apposition in larger-diameter vessels.^{5,8} The use of an Enterprise stent in a small parent artery without tortuosity might be tolerable for acute thromboembolic occlusion or in-stent restenosis. In this study, the average size of the parent arteries (1.72 ± 0.30 mm) was found to increase on follow-up angiography compared with that before the procedure (1.59 ± 0.26 mm, $p = 0.037$; Fig. 3). The deployment of stents also changed the angiographic configuration and traveling course of the parent arteries in all 27 patients who had follow-up angiography (results not shown). Stent placement indirectly affected hemodynamics by changing parent vascular configuration and the angles between efferent and afferent segments of parent vessels,⁶ which might explain not only the size increase of parent arteries but also why there was no recurrence of aneurysms on follow-up angiography in this study (Table 1).

Dual antiplatelet coverage is the most important consideration for these patients. The decision to use a stent in a small parent artery is affected by the risk of potential thromboembolic complications resulting from foreign-body placement and also by hemorrhagic complications resulting from antiplatelet therapy. In this study, no bleeding complications were experienced. The rate of hemorrhagic complications resulting from antiplatelet therapy in stent-assisted coil embolization is approximately 7%–8%.^{1,2,12} Among 72 patients with ruptured wide-necked aneurysms treated using stents, 6.9% experienced hemorrhagic complications. Among 459 patients with unruptured

FIG. 3. Box-and-whisker plots showing the average sizes of the parent vessels at pretreatment and follow-up angiography. There was a significant difference between the follow-up sizes of the parent vessels and their sizes before the procedure (95% CI -0.254 to -0.009 ; $p = 0.037$, paired-samples t-test). *Horizontal lines* in the boxes indicate the medians. *Error bars* represent ranges, and *boxes* represent the lower quartile (25%) and upper quartile (75%) values.

aneurysms treated using stents, 8 (1.7%) had hemorrhagic complications, including 2 (0.4%) with fatal hemorrhages.⁴

There are several limitations to this study. First, this was a retrospective study without randomization, and there was no true control group for evaluating the safety and patency of the stents. Second, a small number of patients were recruited, so it was difficult to evaluate risk factors for stent-related complications or predisposing factors. A study with a larger number of patients might yield different results. Third, a longer follow-up period is needed to evaluate the patency of parent arteries. Finally, it was challenging to describe the geometry and tortuosity of cerebral arteries in 3D space, because determining uniform measurement standards was difficult. In this study, vessel tortuosity was considered to apply to parent arteries with 2 or more acute angles in the segment where a stent would

TABLE 3. Predisposing factors for the size increments of parent arteries after stenting on follow-up angiography

Variable	Size Increase of Parent Arteries		p Value	
	Yes (n = 16)	No (n = 11)	Univariate*	Regression† (OR [95% CI])
Age (mean ± SD) (yrs)	50.9 ± 7.0	63.4 ± 11.0	0.083‡	
Sex (no. [%])			0.325	
Male (n = 14)	9 (64.3)	5 (35.7)		
Female (n = 13)	7 (53.8)	6 (46.2)		
Ruptured (no. [%])			0.051	0.084 (1.328 [0.461–3.664])
Yes (n = 12)	10 (83.3)	2 (16.7)		
No (n = 15)	6 (40.0)	9 (60.0)		
Aneurysm size (mean ± SD) (mm)	7.87 ± 4.40	7.67 ± 3.39	0.524‡	
Aneurysm type (no. [%])			0.317	
Saccular (n = 22)	12 (54.5)	10 (45.6)		
Nonsaccular (n = 5)	4 (80.0)	1 (20.0)		
Aneurysm location (no. [%])			0.325	
Anterior circulation (n = 14)	9 (64.3)	5 (35.7)		
Posterior circulation (n = 13)	7 (53.8)	6 (46.2)		
Neck size (mean ± SD) (mm)	3.03 ± 2.41	4.53 ± 2.39	0.116‡	
Parent artery (no. [%])			0.194	
ACA (n = 10)	8 (80.0)	2 (20.0)		
MCA (n = 4)	1 (25.0)	3 (75.0)		
PCA (n = 5)	1 (20.0)	4 (80.0)		
PICA (n = 8)	6 (75.0)	2 (25.0)		
Tortuosity (no. [%])			0.022	0.041 (1.936 [0.842–3.226])
0 or 1 acute angle (n = 23)	16 (69.6)	7 (30.4)		
2 acute angles (n = 4)	0 (0.0)	4 (100.0)		
Procedure-related complications (no. [%])			0.628	
Yes (n = 2)	1 (50.0)	1 (50.0)		
No (n = 25)	15 (60.0)	10 (40.0)		

* Determined using univariate analysis.

† Determined using logistic regression analysis.

‡ Mann-Whitney U-test.

be deployed. There might also be other 3D anatomical factors that affect the patency of parent arteries.

Conclusions

Our technical success rate of stenting was 100%, and there were no morbidities related to stent usage. The majority of parent arteries increased in diameter and showed good patency (88.9%) on follow-up angiography rather than decreasing in size as a result of in-stent stenosis. The deployment of self-expanding closed-cell stents in small (< 2-mm) arteries was safe and resulted in good patency, especially when the stents were deployed in a segment of the parent artery with no acute angle or 1 acute angle.

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Conception and design: Kim, Chung, Shin. Acquisition of data: Chung, Suh, Lim, Shin. Analysis and interpretation of data: Chung, Suh, Lim. Drafting the article: Chung. Critically revising the article: Kim, Hong, Joo, Shin. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Kim. Statistical analysis: Chung, Hong. Administrative/technical/material support: Suh. Study supervision: Kim.

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