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Early Multicenter Experience With the Neuroform Atlas Stent: Feasibility, Safety, and Efficacy

BACKGROUND: The Neuroform Atlas stent™ (by Stryker, Fremont, California) represents the most recent widely available upgrade to intracranial stenting, providing a laser cut open cell stent with a diameter of 3.0 to 4.5 mm that is delivered through an 0.017-inch microcatheter.

OBJECTIVE: To report our initial multicenter experience of the safety, efficacy, and feasibility of the Atlas stent used for treating aneurysms, as well as one case of intracranial stenosis and one carotid artery dissection as well as other pathologies.

METHODS: A retrospective multicenter study of subjects treated with Atlas stent during the period 2018 to 2019.

RESULTS: The total number of patients included in our analysis was 71 patients. The stent was utilized to treat 69 aneurysm cases. Of the aneurysms, 36% presented with acute rupture and 56% of the ruptured aneurysms were high grade. Mean aneurysm dimension was 7 mm with an average neck width of 4.1 mm. Around 30% had received prior treatment. Telescoping or Y-stent was used in 16% of cases. We did not observe any symptomatic major complications in our series. Asymptomatic major complications were seen in 7 patients (10.1%); technical complications occurred in 4.3%. Immediate modified Raymond-Roy-occlusion-outcome class I/II was observed in 87%, and this increased to 97.7% at latest follow-up, which was at 4 mo; 91.8% of patients achieved favorable clinical outcome, and mortality rate was 1.4%.

CONCLUSION: Our series demonstrates the safety, feasibility, and efficacy of the Atlas stent. The low complication rate and the high obliteration rate managing complex aneurysms, even in an acute ruptured setting, are notable.

KEY WORDS: Atlas stent, Embolization, Endovascular treatment, Stent-assisted coiling

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The neurointerventionalists' armamentarium is under constant development and then refinement. Stent-assisted coiling (SAC) has demonstrated improved occlusion rates compared to coiling alone, and flow diversion has increased occlusion rates up to 80% with an acceptable safety profile.[1-3] Nevertheless, complex aneurysms continue to pose a challenge. The Neuroform Atlas stent (Stryker, Fremont, California) received food and drug administration approval in May 2019 for treating aneurysms originating from small parent vessels. The advent of a 0.017-inch "coiling catheter" compatible stent has increased the scope of aneurysms amenable to endovascular treatment by providing safer access to distal circulation and alternative approaches via trans-circulation routes.[1,4,5] We aim to report our initial multicenter experience on the safety, efficacy, and feasibility of the Atlas stent used for SAC for wide-necked aneurysms as well as use in vessel dissection and intracranial stenosis.

ABBREVIATIONS: AComA, anterior communicating artery; **DA,** digital subtraction angiography; **DAPT,** dual antiplatelet therapy; **ICA,** internal carotid artery; **MCA,** middle cerebral artery; **mRS,** modified Rankin scale; **mRRS,** modified Raymond-Roy-occlusion-outcome; **PComA,** posterior communicating artery; **SAC,** stent-assisted coiling; **VPS,** ventriculoperitoneal shunt

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METHODS

Study Cohort

A total of 71 consecutive patients treated with the NeuroForm Atlas stent (Stryker, Fremont, California) at 4 hospitals between February 2018 and March 2019 were included in our study. Each hospital has a different group of neurointerventionalist/neurosurgeons, and open and endovascular options are offered at each facility. The study protocol was reviewed and approved by the Institutional Review Board. Informed consent process was waived due to the retrospective design of this study. The relevant anonymized patient-level data are available on reasonable request from the authors.

Medical charts were reviewed to collect patient characteristics including gender, age, gender, ruptured status, Hunt and Hess scale, smoking, hypertension, cardiovascular disease, length of hospital stay, antiplatelet regimen, and previous treatment.

Aneurysm Characteristics, Modality of Treatment

Aneurysm characteristics were collected for all patients, including dome and neck size, aneurysm shape, and location. The number of stents used, the form of stent placement (eg, Y-stent, telescoping fashion), stent length and width, catheter type and size, as well as coiling technique (eg, jailing technique, where coils are added following stenting, vs coiling followed by stenting), were recorded. Occlusion was determined based on the modified Raymond-Roy-occlusion-outcome (MRRC) on the final control run and on follow-up angiograms. We also determined the access route and whether a trans-circulation approach was used. Trans-circulation is defined as stent placement from the contralateral side (eg, stent placement in the right posterior inferior cerebellar artery from left vertebral artery) or opposite circulation (stent placement in the anterior circulation with access from the posterior circulation or vice versa). Peri-procedural complications were collected. Complications were divided into major complications, symptomatic and asymptomatic, and technical issues.

Procedure Details

Patients undergoing elective treatment of an aneurysm were started on dual antiplatelet therapy (DAPT) with aspirin, 81 mg, and clopidogrel, 75 mg, daily for 10 d before the procedure. Prasugrel or ticagrelor was used when patients were allergic or resistant to clopidogrel. Platelet function was routinely assessed via the P2Y12 assay (VerifyNow®; Accumetrics, San Diego, California) with a platelet inhibition goal of 30% to 90%. The percent inhibition was calculated by having a baseline test before loading the patient with antiplatelet and another test just before the procedure. Patients admitted with subarachnoid hemorrhage (SAH) were loaded with a IIb/IIIa inhibitor IV during the procedure, then loaded after with 650 mg aspirin and 600 mg clopidogrel or 180 mg ticagrelor at the discretion of the treating physician. DAPT was continued for at least 6 mo. Follow-up digital subtraction angiography (DSA) is generally performed at 6 mo. For aneurysms with incomplete occlusion at the first angiographic follow-up, aspirin, 81 mg daily, is continued, the second antiplatelet medication is discontinued, and follow-up imaging versus treatment is performed at the discretion of the neurointerventionalist. Patients with complete aneurysm occlusion at 6 mo are taken off clopidogrel/prasugrel/ticagrelor and maintained on aspirin indefinitely.

Surgical procedures such as ventriculoperitoneal shunt (VPS) and tracheostomy are performed while on DAPT. The shunts are placed using either a soft pass technique where the previous ventriculostomy is exchanged for a ventricular catheter placed without a stylet, or the previous ventriculostomy is cut and connected to the valve.

TABLE 1. Baseline Characteristics

Variables	% (n)
Total number of patients	71
Total number of cases	74
Aneurysms	69
Non-aneurysms	5
Male (M/F)	26.7% (19)/73.2% (52)
Age	61 yr ± 13
	32-87
Hypertension	66.2% (47)
CAD	24% (17)
Smoking	31% (22)

Patient Follow-up

Patients were scheduled for clinical follow-up at an interval of 2 wk, and 6 mo with the neurointerventionalist. At every clinical follow-up, functional outcome was assessed using the modified Rankin scale (mRS); scores ranging from 0 to 2 were regarded as favorable. Follow-up radiological examination at 6 mo was performed primarily with DSA. Aneurysm occlusion was graded using the MRRC. Classes I and II were considered as successful/favorable occlusion outcomes.

End Points

The primary endpoints were a favorable clinical outcome and successful treatment of the pathology at follow-up. The secondary outcomes included complications. Procedural complications were defined as aneurysm rupture, thromboembolic events including in-stent thrombosis and distal emboli, incomplete stent expansion, stent dislodgement, vessel dissection, and inability to deploy the stent.

Statistical Analysis

All statistical analyses were performed using IBM SPSS 24.0 software (IBM). Univariate analysis of discrete data was performed using Chi square or Fisher exact test. *T*-test were conducted to determine differences between parametric dependent variables. For continuous data with deviation from normality, including analysis of scores or ranked data, nonparametric tests were utilized.

RESULTS

Baseline Characteristics

The total number of patients included in our analysis was 71 patients (73.2% females, average age 61). Baseline characteristics are shown in Tables 1 and 2, Figure 1A and 1B. In total, 82 Neuroform Atlas stents (Stryker) were used to treat 74 lesions. The stent was utilized to treat 69 aneurysms, 1 case of carotid dissection, 1 case of intracranial stenosis, 1 case for an incompletely opened, previously deployed flow diverter (the distal end of the Surpass device [Stryker] was tacked open by deploying an Atlas stent from the M1 into the internal carotid artery [ICA]),

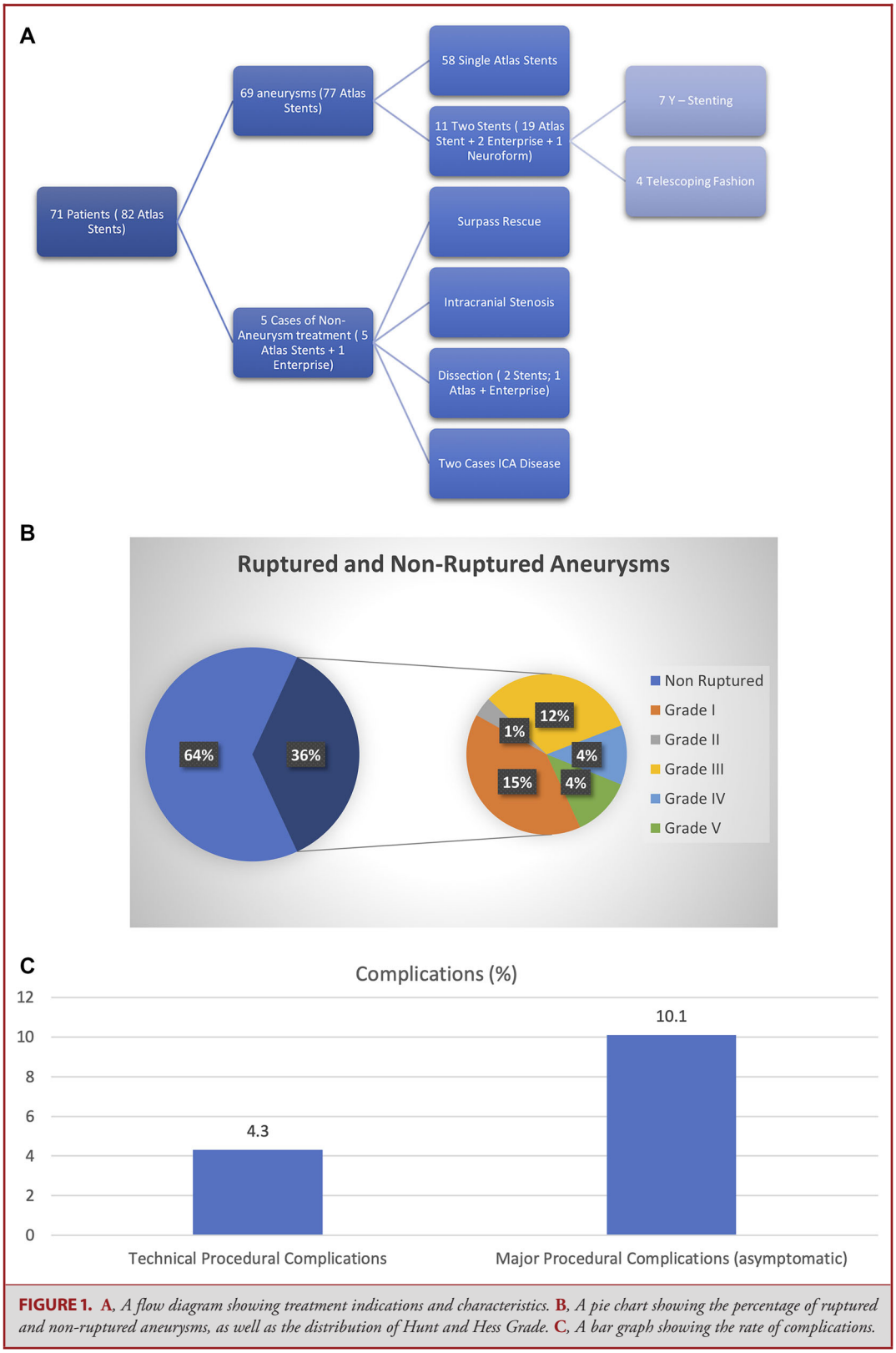

FIGURE 1. **A**, *A flow diagram showing treatment indications and characteristics.* **B**, *A pie chart showing the percentage of ruptured and non-ruptured aneurysms, as well as the distribution of Hunt and Hess Grade.* **C**, *A bar graph showing the rate of complications.*

TABLE 2. Percentage of Ruptured Aneurysms and Their Breakdown According to Hunt and Hess Scale

Variables	% (n)
Total number of ruptured aneurysms	36.2% (25)
Grade	
I	40% (10)
II	4% (1)
III	32% (8)
IV	12% (3)
V	12% (3)

and 1 case of bilateral cavernous ICA stent. The patient was referred by the otolaryngologist requesting ICA stenting for a sinonasal mass encompassing the cavernous carotids to maintain the structural integrity of the carotid artery, and aid in visualization during tumor resection.[6-9]

A total of 47 (66.2%) had hypertension, 24% (17) had coronary artery disease, and 31% (22) were smokers. Of the aneurysms, 36.2% (25) presented with acute rupture treated using 27 stents, and 56% (14) of the ruptured aneurysms were high grade.

Aneurysm Characteristics

Aneurysm characteristics are shown in Table 3. The mean largest aneurysm dimension was 7 mm, ranging between 2 and 18 mm, with an average dome of 5.7 mm and an average neck of 4.1 mm. Most aneurysms (97.2%, 67) were saccular, 1 was fusiform, and 1 was a dissecting aneurysm. Of the aneurysms, 74% (52) were located in the anterior circulation and 28% (20) received previous treatment.

Treatment Details

Treatment details are shown in Table 4. A single stent was utilized in 84% (58), while Y-stenting or telescoping stent deployment was utilized in 16% (10.1% and 5.8%, respectively)—in 4 cases, a stent other than Atlas was used. The smallest stent caliber (3 mm) was used in 71% (49) and was deployed mainly using an SL-10® catheter (Stryker Neurovascular, Fremont, California) (76.8%, 53). Other catheters used were Headway® Duo (MicroVention, Aliso Viejo, California) and Excelsior® XT Microcatheters (Stryker Neurovascular). SAC was performed in 94.2% (65) primarily using a jailing technique in 79.7% (55) of cases. A trans-circulation route was used in 18% (13). Balloon angioplasty was performed in 3 cases (4.4%).

Obliteration Rates, Complications, and Functional Status

Obliteration rates, complications, and functional status are shown in Table 5, Figure 1C, and Figure 2. Initial angiographic results were classified according to the MRRC and were as follows: grade I 52% (36), grade II 35% (24), grade IIIa 10% (7), and grade IIIb 3% (2). Complete or near complete occlusion increased from 87% to 97.7% at an average of 5.6 mo. The MRRC at latest follow-up was according to the following: grade I 63% (31), grade II 34.7% (17), grade IIIa 2.0% (1), and none as grade IIIb. Three patients (4.3%) required retreatment due to recanalization. Aneurysm form and location were not significantly associated with obliteration (*P* value of .728 and .267, respectively).

TABLE 3. Aneurysm Characteristics

Variables	% (n)
Aneurysm size	7 ± 3.5
	2-18 mm
Dome size	5.7 ± 3.4
	1.80-19 mm
Neck size	4.1 ± 2.2
	1.40-13.30 mm
Aneurysms forms	
Saccular	97.2% (67)
Fusiform	1.4% (1)
Dissecting	1.4% (1)
Location	
ICA terminus	2.9% (2)
Ophthalmic	4.3% (3)
SHA	1.4% (1)
Anterior choroidal	1.4% (1)
MCA	16% (11)
Pericallosal	8.7% (6)
AComA	30.4% (21)
PComA	10.4% (7)
Vertebral	1.4% (1)
PICA	4.3% (3)
Basilar	17.4% (12)
SCA	1.4% (1)
Anterior/posterior	74% (51)/26% (18)
Previous treatment	28% (20)
Coiling	80% (16)
Clipping	5% (1)
Coiling + stent	15% (3)

We did not observe any symptomatic major complications in our series. Asymptomatic major complications were seen in seven patients (10.1%), a case of contrast extravasation, four cases of peri-procedural in-stent clot formation that were treated using intra-arterial thrombolytics, and 2 cases of vessel thrombosis at follow-up. In the case of contrast extravasation, this followed uneventful Y-stenting and resulted from placement of the first coil in the aneurysm. This was controlled immediately following deployment of the second coil. This was controlled immediately following deployment of the second coil.

Technical complications were observed in three patients (4.3%). We noted one case of stent dislodgement into the aneurysm sac, 1 case of coil herniation through the stent necessitating the deployment of a telescoping Enterprise stent (Codman, Raynham, Massachusetts), and 1 case of failed catheterization of the target vessel leading to termination of the case.

In-stent stenosis was observed in 2.9% (2) at 6 mo; 1 case was mild and managed medically and the second case was 100% occlusion, but was asymptomatic.

TABLE 4. Treatment Details of Aneurysms

Number of stents	% (n)
One stent	84% (58)
Two stents	16% (11)
Form of stent placement	
Telescoping	5.8% (4)
Y-stenting	10.1% (7)
Stent width	
3.0 mm	71% (49)
4.0 mm	24.6% (17)
4.5 mm	16% (11)
Stent length	
15 mm	17.4% (12)
21 mm	63.8% (44)
24 mm	21.7% (15)
30 mm	8.7% (6)
Catheter used	
SL - 10	76.8% (53)
Duo	5.8% (4)
XT	17.3% (12)
Trans-circulation	18.8% (13)
Access	
Femoral	85% (59)
Radial	13% (9)
Combined	1.4% (1)
Stent + coils	94.2% (65)
Technique used	
Jailing	79.7% (55)
Stent then coil/crossing	17.3% (12)
Postcoiling	2.9% (2)
Balloon angioplasty	4.4% (3)

TABLE 5. Obliteration Rates, Complications, and Functional Status

Variables	% (n)
Initial angiographic result	
Complete occlusion	52% (36)
Residual neck	35% (24)
Residual neck + coil contrast	10% (7)
Residual neck + wall contrast	3% (2)
LOS	7 d ± 8.5
	1-32
Technical procedural complications	4.3% (3)
Symptomatic major procedural complications	0% (0)
Asymptomatic major procedural complications	10.1% (7)
In-stent stenosis	2.9% (2)
Retreatment	4.3% (3)
Duration of retreatment	5 mo ± 3
	2-8
Latest occlusion	71% (49)
Complete occlusion	63% (31)
Residual neck	34.7% (17)
Residual neck + coil contrast	2.0% (1)
Residual neck + wall contrast	0%
Duration for latest occlusion	5.6 mo ± 1.6
	1-9
Latest follow-up	4 mo ± 2.7
	1-10
mRS	89.9% (62)
0-1	87% (54)
2	4.8% (3)
3-4	6.5% (4)
6	1.4% (1)

Good functional outcome was observed in 91.8% (mRS 0-1 = 87%, mRS 2 = 4.8%) at an average follow-up duration of 4 mo. SAH was significantly associated with unfavorable outcome, mRS 3 to 6, 19%, 4 vs 2.4%, 1; $P = .04$. Mortality was observed in 1.4% (1) in a case of grade 5 SAH presentation.

Outcomes were compared between aneurysms originating from small vessels (SCA, PICA, Pericallosal, and anterior choroidal artery) to aneurysms originating from large vessels. There was no significant difference in asymptomatic major complications, favorable occlusion, and favorable functional outcome at 3 mo (Table 6). Also, comparison was performed between non-ruptured and ruptured aneurysms, revealing higher asymptomatic major complications in the non-ruptured group (6 vs 1; $P = .4$), and no technical complications encountered in the ruptured group.

DISCUSSION

SAC is a well-established treatment option for treating wide-necked aneurysms and has increased the scope of aneurysms amenable to endovascular treatment. SAC has introduced a useful adjunct to prevent coil protrusion into the parent vessel and increase occlusion rates, especially in wide-necked aneurysms.[10-15] Several types of stents have been introduced such as open cell stents, closed cell stents, braided stents, flow diverting stents; each have different technical features.[16-19] Initially, the Neuroform Atlas stent (Stryker, Fremont, California) was introduced as an intracranial stent for the treatment of wide-necked aneurysms. Because of the open cell design, these stents were not re-constrainable once deployment was initiated.[20] These were followed by second-generation stents that had a closed cell structure, such as Enterprise (Codman, Raynham, Massachusetts) and Solitaire (Medtronic, Dublin, Ireland) stents, allowing retrieval and repositioning after partial deployment. However, inherent to a closed cell design, the stent is more prone to ovalization, especially at vessel curves, which may result in poor wall apposition.[21-23] The modifications introduced to the third-generation devices such as LVIS, LVIS Jr (MicroVention), Leo, and Leo Baby (BALT Extrusion) were braided individual nitinol strands allowing delivery through a smaller microcatheter and the ability to reposition after partial deployment.[20]

The Neuroform Atlas stent is a new generation stent designed to have better scaffolding due to the higher number of connectors and alternating cell numbers, enhanced conformability to the vessel wall due to its open cell design, easier deliverability, and improved deployment accuracy. In our experience, the Atlas stent has nearly completely supplanted other intracranial stents for SAC procedures. We find the delivery to be reliable, accurate,

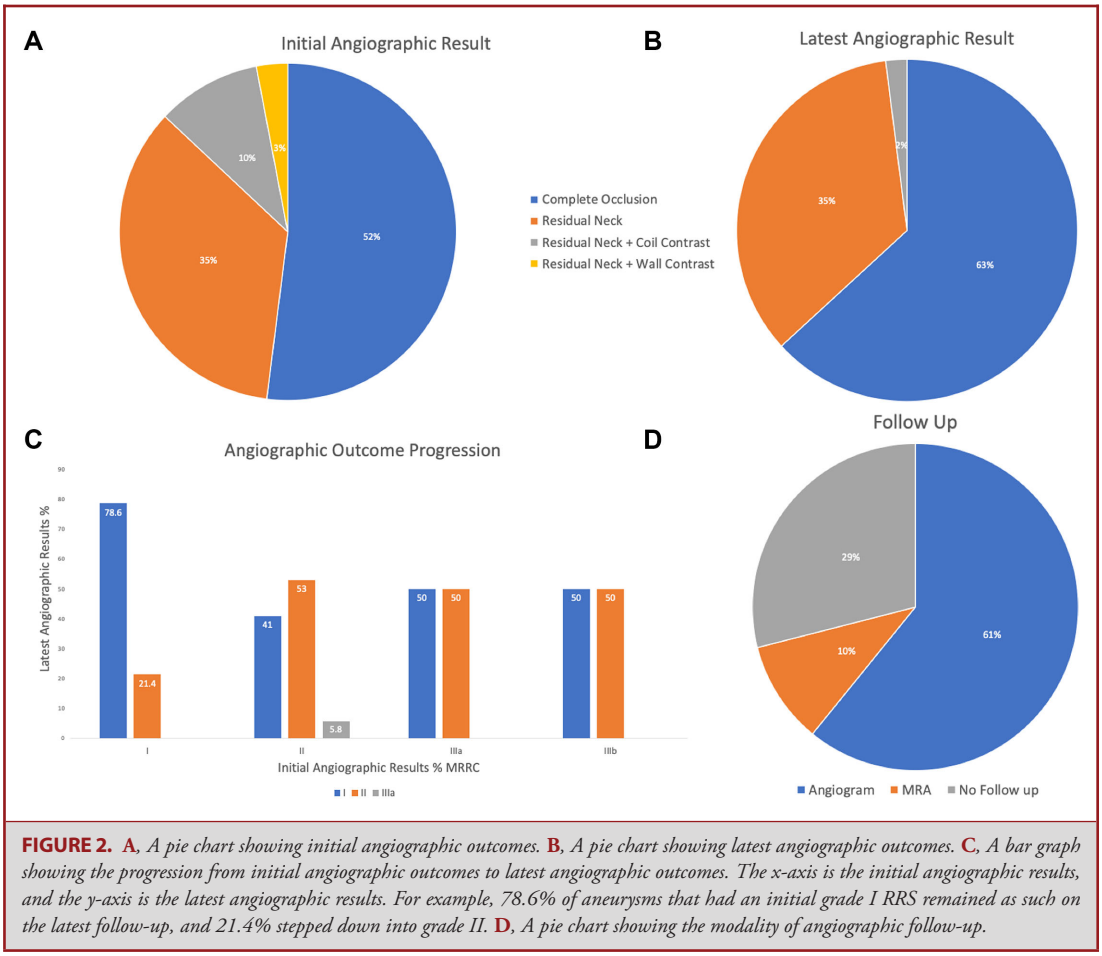

FIGURE 2. **A**, *A pie chart showing initial angiographic outcomes.* **B**, *A pie chart showing latest angiographic outcomes.* **C**, *A bar graph showing the progression from initial angiographic outcomes to latest angiographic outcomes. The x-axis is the initial angiographic results, and the y-axis is the latest angiographic results. For example, 78.6% of aneurysms that had an initial grade I RRS remained as such on the latest follow-up, and 21.4% stepped down into grade II.* **D**, *A pie chart showing the modality of angiographic follow-up.*

TABLE 6. Outcome Comparison Between Aneurysms Originative From Large and Small Vessels

	Large Vessel % (58)	Small Vessel % (11)*	*P* value
Asymptomatic major complications	8.6% (5)	18.2% (2)	.30
Favorable occlusion (MRRC 1 and 2)**	97.4% (38)	100.0% (11)	1.00
Favorable outcome (mRS 0-2)**	92.2% (47)	90.9% (10)	1.00

*Small vessels included: SCA, PICA, pericallosal, and anterior choroidal artery.
**Of patients with follow-up.

safe, and technically straightforward. The ability to place a 3 to 4.5-mm diameter stent using an 0.017-inch catheter presents obvious advantages and has allowed us to push the limits of distal and cross-circulation approaches (Figures 3-7). Interestingly, nontraditional stenting cases have revealed somewhat surprising outcomes with regards to flow remodeling (Figure 8). Here, we intend to present a multicenter real-life experience on the use of the Atlas stent for various indications. Our rates of successful deployment, aneurysm obliteration, and functional outcomes speak to the safety and efficacy of the Atlas stent.

Aneurysm Obliteration

The initial favorable and complete obliteration rate were 87% and 52%, respectively, and increased at last follow-up to 97.7% and 62%, respectively. Retreatment rate was 4.3%. Immediate occlusion rates of intracranial wide-necked aneurysms treated with SAC reported by three meta-analyses ranged between 53.2% and 57.7%.[10,11,24] Studies focusing on SAC in the acute setting reported similar rates of immediate complete occlusion (45.5%) increasing to 75.7% at follow-up.[25] As for complete occlusion rates reported with the use of the mini-stents, LEO Baby and LVIS

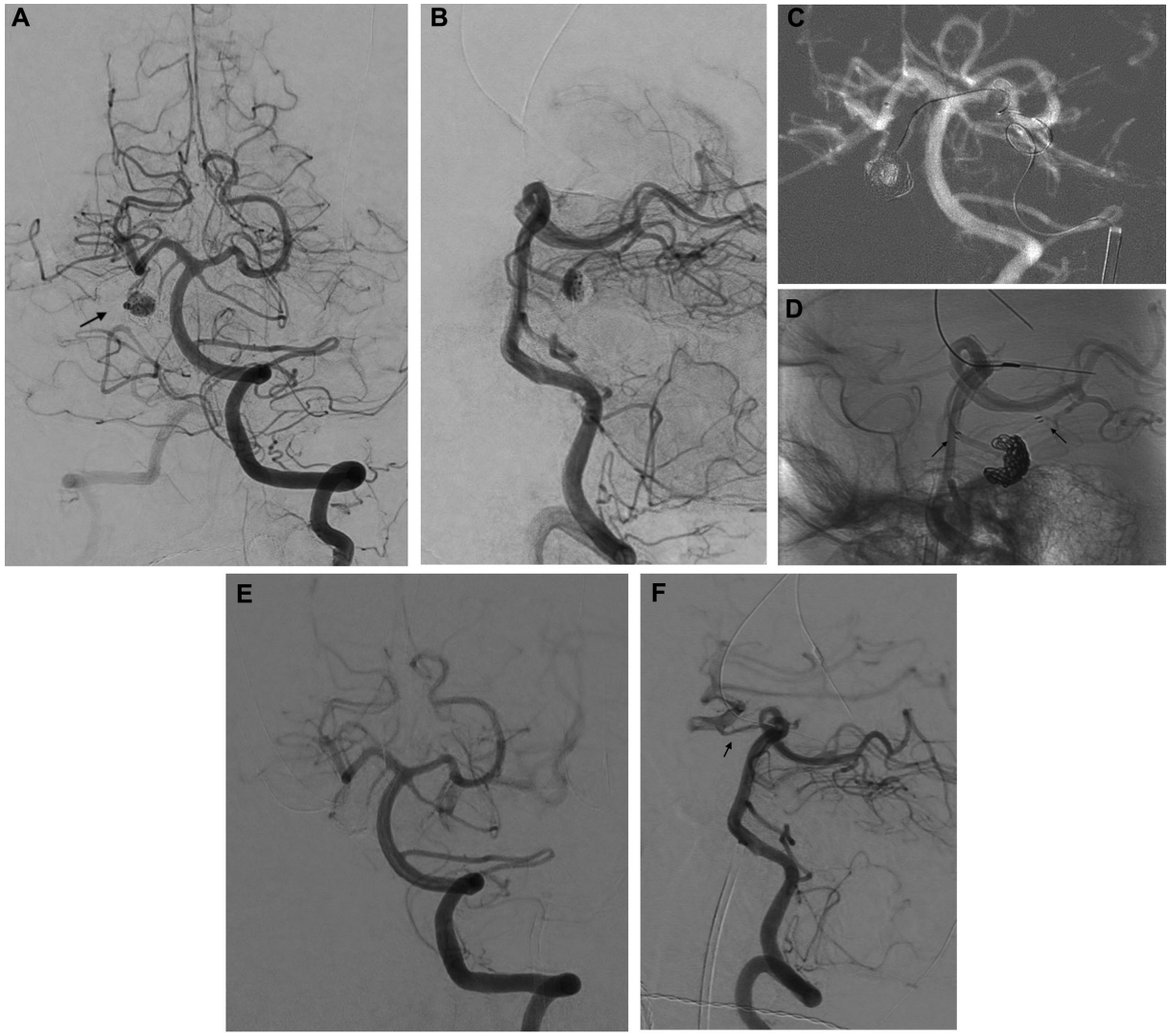

FIGURE 3. **A**-**F**, *Previously coiled right superior cerebellar artery aneurysm treated with Neuroform Atlas stent (Stryker) using a trans-circulation approach from the anterior circulation through the PComA.* **A**, *Anteroposterior (AP);* **B**, *lateral pre-op DSA of the right SCA aneurysm;* **C**, *an anterior-posterior view of a roadmap view showing the trans-circulation navigation through the left PComA;* **D**, *A lateral DSA post-SAC of the SCA aneurysm (arrow);* **E**, *AP and* **F**, *lateral follow-up DSA showing complete aneurysm occlusion. Note the size of the PComA (arrow).*

Jr, immediate was 75% and 85% and at follow-up, 85.7% and 82%, respectively.[26,27] As for recanalization rates, 3 meta-analyses reported 12.7%, 13.3%, and 16.2%.[10,11,28] Caragliano et al[16] reported 100% technical success with accurate stent deployment in a large multicenter series of 113 wide-necked aneurysms treated with Atlas stent. An immediate complete obliteration was observed in 88% of patients and 82% at 12 mo follow-up (Table 7).[1,29-31]

Complications and Functional Outcome

No major complications related to the stent were observed in our series, with a single mortality (1.4%) of a patient grade 5 SAH. Asymptomatic major complications occurred at a rate of 10.1%; 4 patients developed intraprocedural stent thrombus formation managed with thrombolytics, 1 patient developed contrast extravasation while deploying the coils following uneventful Y-stenting that was immediately controlled with further coiling, and there were 2 cases of delayed asymptomatic vessel thrombosis. The 4 cases of periprocedural thrombus formation were 2 cases of anterior communicating artery (AComA) and 2 cases of M2 bifurcating aneurysms, and only one of the cases was a ruptured aneurysm. In three of the four cases, two stents were deployed, and the deployed stent width was 3 mm. Most importantly, the P2Y12 value was not available for the 4 cases. Based on that more than

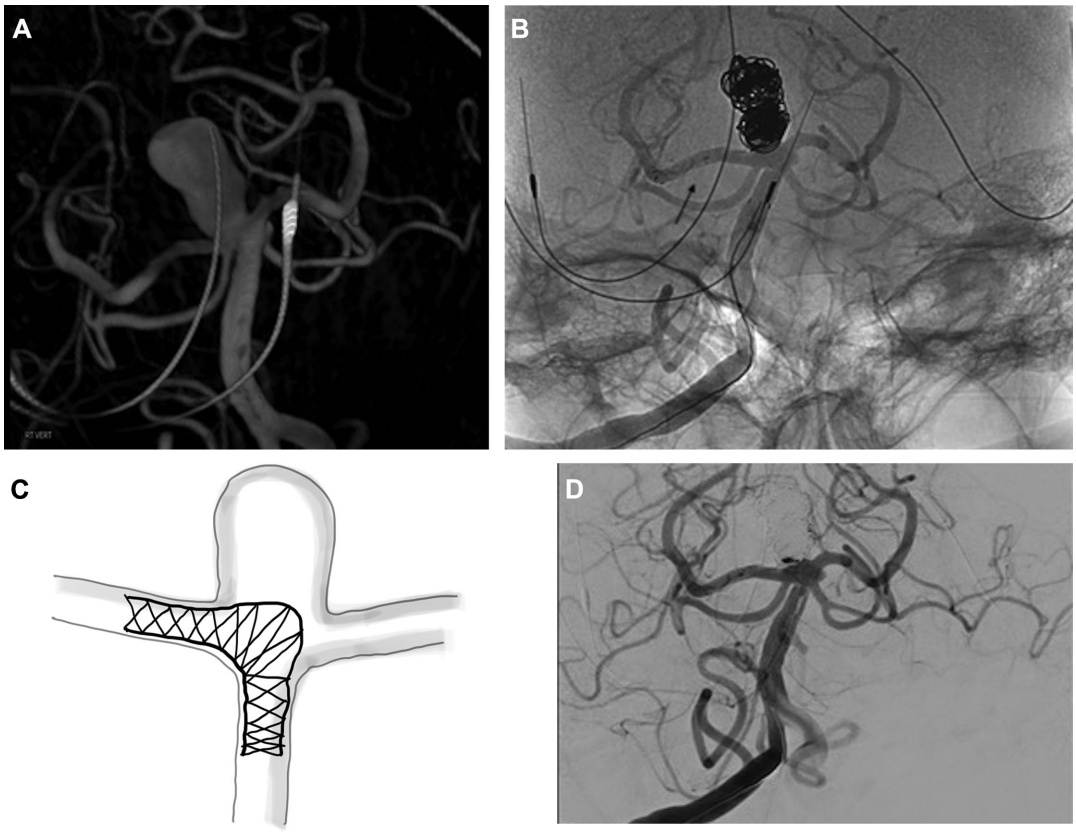

FIGURE 4. **A-D**, *Large wide-necked aneurysm treated with a stent-assisted coiling using a single Neuroform Atlas stent (Stryker) deployed from the right PCA into the basilar artery.* **A**, *AP 3D reconstruction image showing a large basilar tip aneurysm.* **B**, *AP DSA image showing SAC using a single Atlas stent (arrow).* **C**, *Sketch diagram showing how the open cell design allows the Atlas stent to bulge out and cover the aneurysm neck, avoiding the need for Y-stenting.* **D**, *AP DSA follow-up showing complete aneurysm obliteration at 6 mo.*

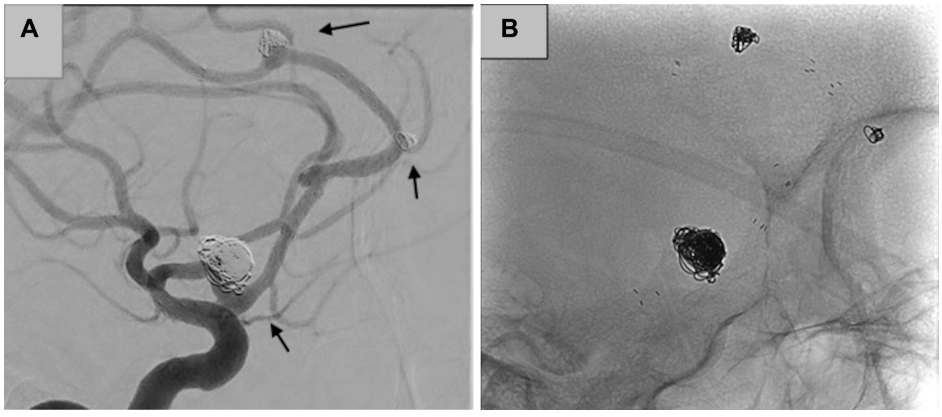

FIGURE 5. **A-B**, *Treatment of ruptured AComA, and 2 distal ACA aneurysms. Lateral DSA* **A** *and non-subtracted lateral view* **B** *showing SAC of AComA aneurysm, callosomarginal aneurysm, and distal ACA aneurysm.*

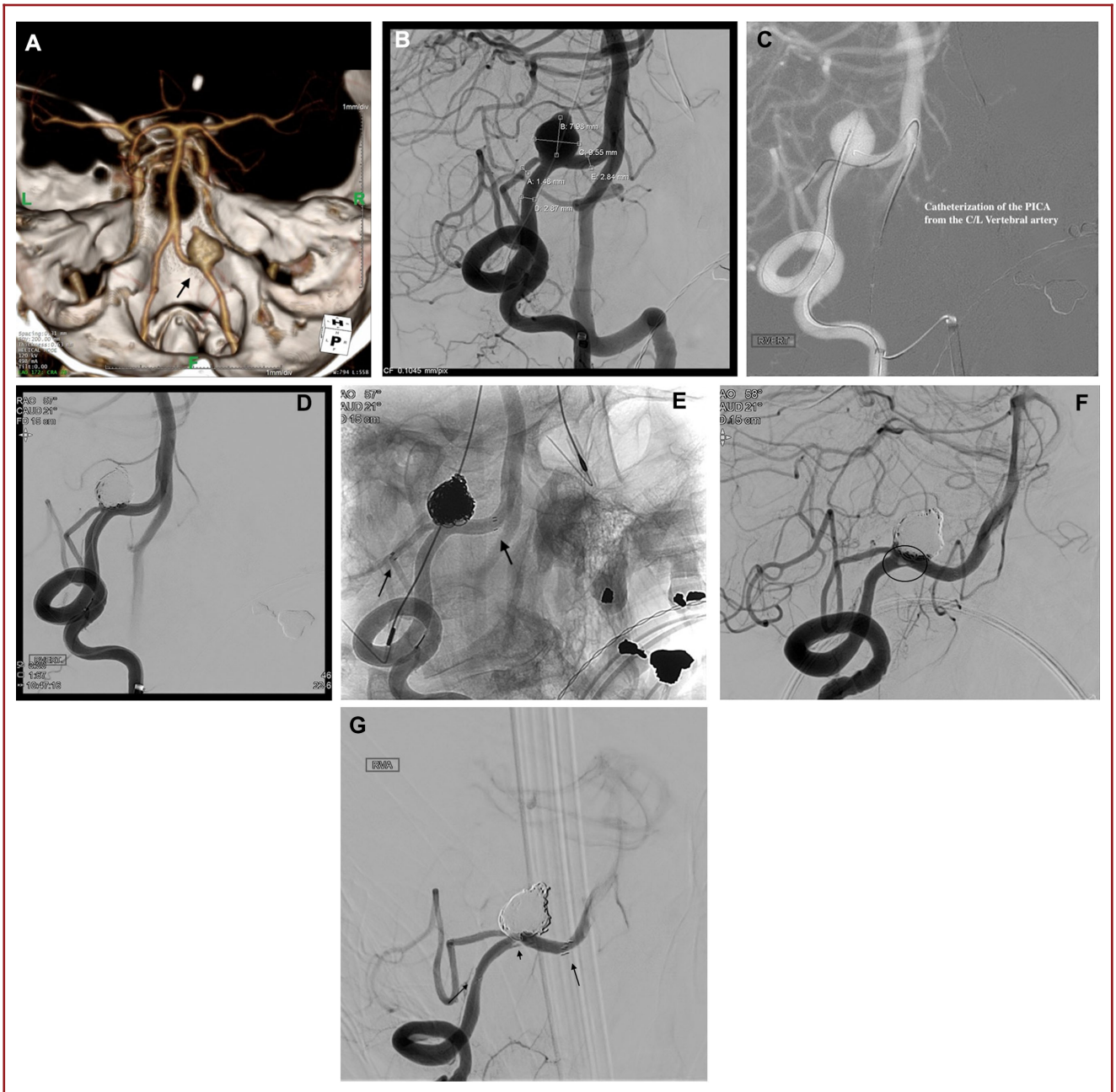

FIGURE 6. **A**-**G**, *PICA aneurysm treated through C/L vertebral artery approach using SAC; the Neuroform Atlas stent (Stryker) was deployed from the PICA into the distal vertebral artery. Close follow-up showed a flow defect at the PICA-vertebral artery junction, so a rescue stent was deployed in the vertebral artery traversing the previous Atlas stent.* **A**, *Three-dimensional reconstruction;* **B**, *AP DSA image showing the right PICA aneurysm.* **C**, *Roadmap view showing C/L approach to catheterize the right PICA, and a microcatheter jailed in the aneurysm.* **D**-**E**, *AP view showing complete occlusion of the PICA aneurysm (arrow).* **F**, *One-week follow-up angiogram showed thrombus formation at the base of the stent (black circle).* **G**, *Six-month follow-up angiogram showing complete aneurysm occlusion, and a persistent non-limiting flow defect. Arrow pointing to the proximal and distal ends of the vertebral stent.*

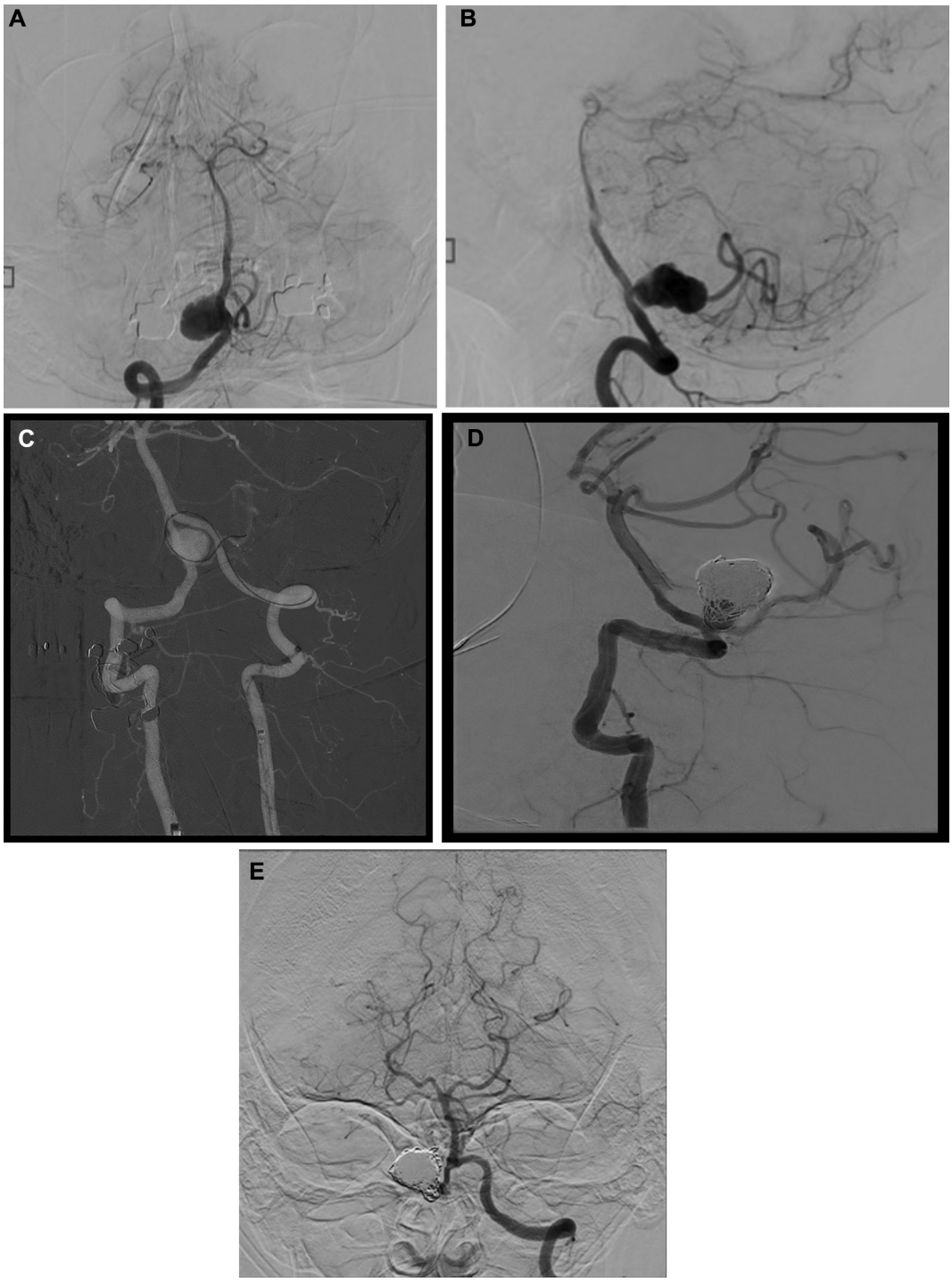

FIGURE 7. **A**-**E**, *PICA aneurysm treated through C/L vertebral artery approach using SAC; the Neuroform Atlas stent (Stryker) was deployed from the PICA into the vertebral artery. Six-month follow-up showed asymptomatic complete obliteration of the aneurysm and occlusion of the right vertebral artery.* **A**, *AP and* **B**, *lateral DSA view showing large dissecting PICA aneurysm.* **C**, *Roadmap view showing C/L approach for catheterizing the right PICA.* **D**, *Lateral DSA view showing SAC of the PICA aneurysm.* **E**, *Six-months follow-up angiogram showing complete obliteration of the aneurysm and occlusion of the right vertebral artery.*

TABLE 7. Review of Atlas Series Reported in the Literature

	Number of Patients	Obliteration rate		Complication rate	Technical success	Recanalization rate	mRS (0-1)	Morbidity	Mortality
		Immediate	Follow-up						
Cay et al[1]	55	–	94.1%*	1.8%	100%	5.8%	–	0%	0%
Caragliano et al[16]	113	88%	82%	6.2%	100%	–	96.5%	0.85%	2.65%
Jankowitz et al[29]	30	60%	92.6%	3.3%	100%	–	100%	0%	0%
Ulfert et al[30]	36	84%	93%	2.7%	100%	0%		0%	0%
Tsai et al[31]	58	79.7%	–	8.6%	100%	–	100%	0%	0%
Brinck et al[35]	27	63%	53.8%	30.7%	88.9%	15.4%	84.6%**	0%	3%
Quintana et al[36]	30	90%	>90%	3.3%	96.6%	6.6%	–	–	0%
Gross et al[37]	37	57%	81%	3%	97%	0%	–	3%	0%
Our Series	71	52%	63%	10.1%***	95.7%	4.3%	87%	0%	1.4%

*Favorable, **mRS 0-2, ***asymptomatic major complications.

1 variable may play a role in the clot formation (1) mainly and most importantly the sub-therapeutic P2Y12 value, (2) multiple foreign materials, (3) and in 1 particular case, traumatic damage of the stent. In the latter case, Y-stenting for an AComA, crossing the 2 walls of the deployed stent for coiling a small neck residue was challenging, and after multiple attempts, a clot started to form, limiting distal flow through the ACA. This was managed immediately with IA tPA and left no neurological deficit. Brinck et al reported 2 Y-stenting cases where thrombus formed at the stent crossing,[35] and Gross et al described a case of clot formation following multiple failed attempts to cross the stent.[37]

In our 2 cases of crossing the vertebral-basilar junction to place a stent from the PICA to distal vertebral artery for a ruptured PICA aneurysm, this seemed to affect flow in such a way that the vertebral artery ipsilateral to the aneurysm began to shut down due to clot formation outside the stent, specifically at the junction of the stent and the vertebral artery (Figure 6 and 7). Clot formation may be due to turbulent blood flow caused by the stent traversing the vertebral artery, and the low blood demand due to compensation by the contralateral vertebral artery. In one instance, we happened to "catch" this while performing an angiogram to treat symptomatic vasospasm in a different distribution, and a second stent was placed along the ipsilateral vertebral artery, seemingly preventing the vessel from shutting down. On follow-up imaging, the vessel remained patent but with a filling defect. The other case resulted in asymptomatic vertebral artery occlusion right at the point where the stent traversed the vessel, noted incidentally at the 6-mo angiogram. Interestingly, the same technique was used in the anterior circulation, where a stent was placed from the middle cerebral artery (MCA) to the posterior communicating artery (PComA) traversing the ICA; however, the patient did not develop any vessel thrombosis on follow-up magnetic resonance angiography and has remained clinically normal. The difference in physiological blood demand between the anterior circulation and the posterior circulation, where the contralateral vertebral artery may compensate for flow, may explain why no vessel thrombosis was observed in the anterior circulation.

Technical complications occurred in three cases (4.3%). Failure to catheterize the P1 segment in one case resulted in termination of procedure. In another case, the proximal stent was inadvertently pushed forward into the aneurysm by the microcatheter, while attempting subsequently to access the aneurysm for coiling. This was managed by jailing the microcatheter in the aneurysm and then telescoping a second stent within the first, landing the proximal end appropriately. The patient has done well through 4 mo of clinical follow-up, although the malpositioned stent prevented complete aneurysm coiling and will require close follow-up. We now prefer to jail a microcatheter when possible, as the stent can definitely be pushed inadvertently during maneuvers to access the aneurysm subsequent to stenting. Finally, coil herniation through the stent was encountered during coiling a bilobed 6-mm basilar tip aneurysm. In this case, a 4 × 24 mm Atlas stent was deployed from the right posterior cerebral artery into the basilar artery. Multiple attempts were made to position the first coil, and while we never witnessed clot formation in the vessel lumen, the coils appeared to herniate through the stent. Therefore, an Enterprise stent (4 × 23 mm) was placed in a telescoping fashion and coiling was performed uneventfully. The aneurysm was completely treated and remained obliterated on 6-mo angiographic follow-up (Figure 9). Tsai et al reported a similar technical complication. In their case, a 3 × 15 mm Atlas stent was deployed across the neck of an A1-A2 junction aneurysm. During deployment of the last coil, several loops of a previously detached coil herniated. Thrombus formed on the herniated coil, resulting in flow interruption in the right A2. A 3 × 24 mm Atlas stent was then deployed distal to the initial stent in a telescoped fashion, jailing the herniated coil loops.[32]

In-stent stenosis was observed in two patients (3%). The first patient developed "traditional" in-stent stenosis where the A1 portion of a stent placed from the left MCA to the left A1 from a right sided approach developed mild stenosis that was noted

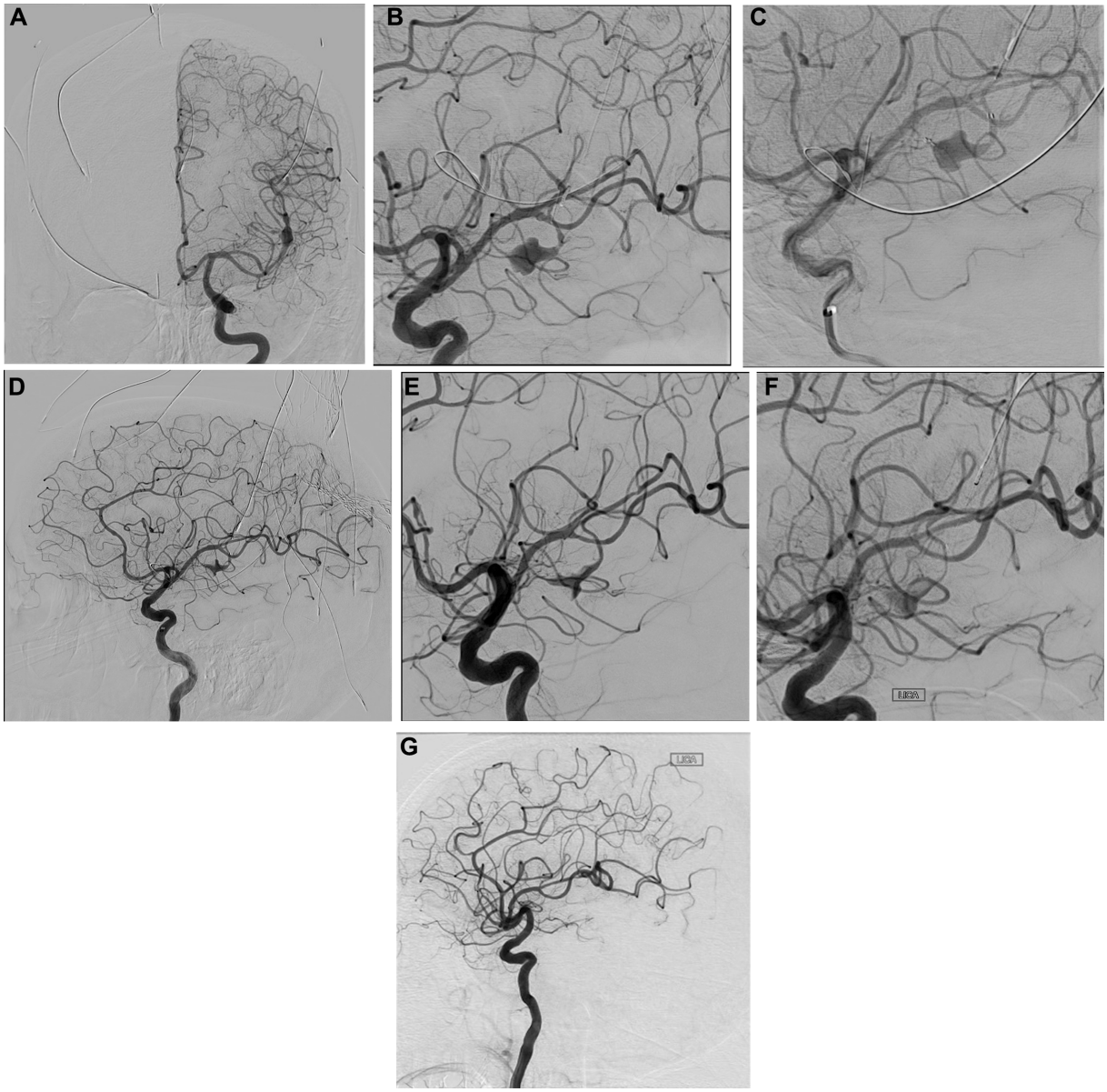

FIGURE 8. **A**-**G**, *A ruptured mycotic fusiform M3 aneurysm treated using Neuroform Atlas stent (Stryker). Follow-up angiogram showed asymptomatic complete occlusion of the artery.* **A**, *AP and* **B**, *lateral DSA view showing a ruptured fusiform M3 aneurysm.* **C**, *Deployment of a 3 × 21 mm Atlas stent.* **D**, *Final control run showed contrast stasis in the aneurysm.* **E**, *A total of 15-d and* **F**, *25-d follow-up angiograms showed aneurysm remodeling.* **G**, *Four-month follow-up angiogram showed complete aneurysm obliteration, as well as asymptomatic complete artery occlusion.*

6 mo after stent-assisted coiling treatment of an ICA terminus aneurysm. This was managed medically with antiplatelet therapy (aspirin after 6 mo), and the patient remains asymptomatic at 1 yr. In the second case, the patient developed asymptomatic 100% stent occlusion documented on follow-up angiogram. Here, the patient presented with a ruptured fusiform mycotic M3 aneurysm, failed an awake test occlusion (receptive aphasia), and so we attempted stent coiling. The afferent vessel was too small to allow a jailing catheter, and after placing the stent, we were unable to access the aneurysm without moving the proximal tines. We stopped, with the intention of possibly returning to coil once the stent had healed into place, yet final angiographic runs demonstrated slow filling of the aneurysm with increased contrast stasis within the diseased segment immediately. Follow-up angiogram 1 wk later showed improved vessel remodeling. Three-month control angiogram revealed that the stent and aneurysm had

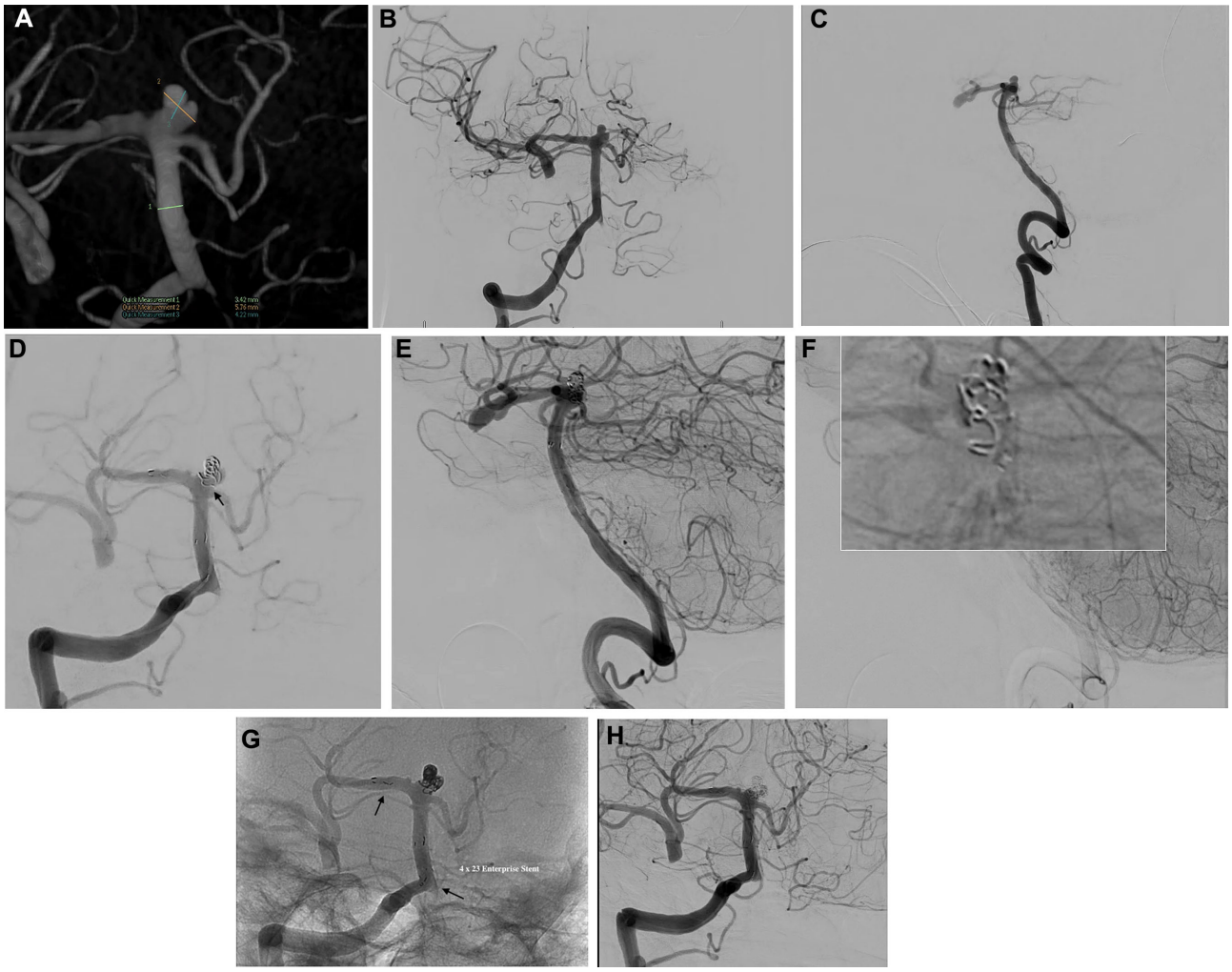

FIGURE 9. **A**-**H**, *A bilobed 6-mm basilar tip aneurysm initial treatment plan was to deploy a 4 × 24 mm Neuroform Atlas stent (Stryker) from the right PCA into the basilar artery. The first coil appeared to herniate through the stent. Therefore, an Enterprise stent (Codman) (4 × 23 mm) was placed in a telescoping fashion and coiling was performed uneventfully.* **A**, *A 3D reconstruction;* **B**, *AP; and* **C**, *lateral DSA image showing a bilobed basilar tip aneurysm.* **D**, *AP DSA showing the tines of the deployed Atlas stent and the coil that appears to herniate through the stent (black arrow).* **E**, *Lateral and* **F**, *magnified lateral DSA showing the herniated coil.* **G**, *An Enterprise stent (4 × 23 mm) was placed in a telescoping fashion and* **H**, *coiling was performed uneventfully.*

completely occluded without any symptoms and no capillary defect. The asymptomatic progressive vessel occlusion following flow diversion for complex MCA aneurysm has been described in the literature.[33]

Good functional outcome in our series at an average of a 4-mo follow-up was achieved by 91.8% with a significantly higher proportion in non-ruptured aneurysms, no morbidity, and a mortality rate at 1.4%. A meta-analysis involving 2698 mixed open and closed cell type SAC reported a similar mortality rate at 1.4%.[34] Comparing the Atlas stent to other micro-stents shows comparable outcomes. A multicenter retrospective study using the braided LVIS Jr micro-stent reported 3.3% morbidity rate with no mortality.[35] Outcomes compared to earlier Atlas series show a similar safety profile.[36] Quintana et al[37] reported a series composed of 30 non-ruptured aneurysms treated with Atlas stent. They reported one case of hemorrhage (3%) without leaving any neurological deficit and no incidents of acute or late stent thrombosis.

Limitations

Limitations of this study include its retrospective design, as well as the small sample size, which limits the power of the drawn conclusions. Furthermore, the short follow-up period may not accurately reflect obliteration rates. A longer follow-up duration

is required for more robust conclusions. Also, this is a multicenter study, and although standardized measurement scales have been used, there may be an interobserver variation and reporting bias. Future studies of larger sample sizes are needed to assess better the efficacy and safety of the Atlas stent in a wide range of indications.

CONCLUSION

This series demonstrates the safety, feasibility, and efficacy of the Neuroform Atlas stent (Stryker, Fremont, California) and, as mentioned previously, this is now our "go-to" stent for SAC procedures. We have found that jailing the microcatheter when possible is advantageous. Also, we have identified instances of asymptomatic vessel remodeling after treatment, which is not entirely predictable and may be related to the stent and/or the small and diseased lumen where the stent can be placed. In conclusion, our increasing confidence in and comfort with the device has enabled us to expand yet again what is possible to safely treat from an endovascular approach. The Atlas stent is clearly a valuable contribution to the neurosurgical endovascular armamentarium.

Disclosures

Dr Jabbour is a consultant for Medtronic and MicroVention. Dr Tjoumakaris and Dr Gooch are consultants for Stryker. The other authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

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COMMENT

The authors provide a series of 71 patients in which 82 total Atlas stents (Stryker) were used to treat 74 lesions. They demonstrate the versatility of the device by including 69 aneurysms arising from various parent arteries in both the anterior and posterior circulation, single stent technique as well as Y-stenting and telescoping, and non-aneurysmal lesions such as carotid dissection, intracranial stenosis, and rescue of a previously incompletely opened flow diverter. Complete or near-complete occlusion was found in 87% of treated aneurysms immediately, and 97.7% at follow-up. Their results in addition to the literature review that they provide nicely demonstrate the safety and efficacy of the Atlas stent.

The example cases that the authors provided help illustrate several of the advantages of the Atlas stent that we have observed in our own practice. Compared to braided stents and earlier generations, the Atlas stent deploys exactly where the user intends it to without foreshortening or kinking even within small arteries and tight bends, with minimal deformation of the parent vessel, as seen in Figures 3, 6, and 7. The fact that there were no cases of the stent failing to deploy or shift during deployment should ease the hesitation that many interventionalists feel over the fact that the stent is not re-sheathable. The publication of series such as these are thus useful to help guide the practice of interventionalists worldwide, despite limitations such as lack of long-term follow-up.

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