



Outcomes of Stent-Assisted Coiling Using the Neuroform Atlas Stent in Unruptured Wide-Necked Intracranial Aneurysms

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Objective : Although stent-assisted coiling (SAC) has been reported to be safe and effective in treating wide-necked aneurysms, the technique has procedure-related complications. Thus, we reported our experiences of SAC using the Neuroform Atlas stent in treating wide-necked aneurysms and evaluated the incidence of and risk factors for procedure-related complications.

Methods : From March 2018 to August 2019, we treated 130 unruptured wide-necked aneurysms in 123 patients with Neuroform Atlas stents. Angiographic results and clinical outcomes were reviewed retrospectively. Clinical and angiographic follow-up were performed in all cases (mean, 12.4 months) after the procedure.

Results : There were eight cases (6.2%) of procedure-related complications (two dissections, five thromboembolisms, and one hemorrhage) and two (1.5%) of delayed complications (one ischemia and one hemorrhage). There was one case (0.8%) of failure of stent deployment and one (0.8%) of suboptimal positioning of the stent. Follow-up angiography showed complete obliteration in 103 (79.2%), residual neck in 16 (12.3%), and residual aneurysm in 11 cases (8.5%). Aneurysm locations in the middle cerebral artery (odds ratio [OR], 2.211; $p=0.046$) and the anterior communicating artery (OR, 2.850; $p=0.039$) were associated with procedure-related complications on univariate analysis. However, no independent risk factor for procedure-related complications was noted in multivariate analysis.

Conclusion : The Neuroform Atlas showed a high rate of technical success. Good clinical and radiographic outcomes in early follow-up suggests that the device is feasible and safe. SAC of aneurysms on the middle cerebral artery or anterior communicating artery may require more attention to prevent possible procedure-related complications.

Key Words : Endovascular procedures · Intracranial aneurysm · Stents.

INTRODUCTION

It is well established that wide-necked intracranial aneurysms are difficult to treat endovascularly due to the risk of coil protrusion in the parent artery and aneurysm recurrence. Stent-assisted coiling (SAC) has been established as one of the

treatment options for these endovascularly challenging aneurysms, thereby improving the results. Intracranial stents allow the reconstruction of the aneurysm neck and help maintain the coil mass within the aneurysm sac. Recently, the Neuroform Atlas stent (Stryker Neurovascular, Kalamazoo, MI, USA), a microcatheter-delivered, self-expanding, mixed open-

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cell/closed-cell stent, has been used widely. With low-profiled, easy handling deliveries, the Neuroform Atlas stent is being widely applied for wide-necked intracranial aneurysms in various ways^{9,12}.

Although SAC using the Neuroform Atlas stent has been reported to be safe and effective in treating wide-necked aneurysms^{1,6,7,13,14}, the technique has procedure-related complications that interventionists need to understand completely. However, none of those studies reported the incidence of and risk factors for procedure-related complications. Thus, this study aimed to report our experience with SAC using the Neuroform Atlas stent in treating unruptured wide-necked aneurysms and to evaluate the incidence of and risk factors for procedure-related complications.

MATERIALS AND METHODS

Patient selection

This retrospective study was approved by Yonsei University Health System, Severance Hospital, Institutional Review Board (4-2020-0573), and the requirement for informed consent was waived. The Neuroform Atlas was approved for use in our country in March 2018. From March 2018 to August 2019, we treated 435 aneurysms (367 unruptured and 68 ruptured) in 381 patients endovascularly. Among 214 aneurysms treated with SAC, 130 unruptured wide-necked aneurysms in 123 patients were treated with Neuroform Atlas stents. Among the 68 ruptured aneurysms cases during the same period, we tried to perform endovascular treatment other than the use of stents considering our results pertaining to SAC for ruptured aneurysms³.

Aneurysm size and morphological characteristics were determined using digital subtraction angiography with 3D rotational imaging. A wide-necked saccular aneurysm was defined as that with a dome-to-neck ratio of <2 or a neck diameter of ≥ 4 mm. Thromboembolic complications were defined as angiographic evidence of thrombosis during or at the end of SAC. Asymptomatic post-operative small diffusion restrictions on diffusion weighted image were not regarded as thromboembolic complications. Hemorrhagic complications were defined as newly developed hemorrhage on computed tomography (CT) or magnetic resonance image within 30 days of the procedure. The incidence of and risk factors for procedure-related complica-

tions were retrospectively evaluated.

Endovascular treatment

The treatment decision was made based on agreement between microvascular neurosurgeons and neuro-interventionists. All SAC procedures were performed under general anesthesia. A 5-Fr to 7-Fr guiding catheter was positioned in the internal carotid artery for anterior circulation aneurysms. A 5-Fr or 6-Fr guiding catheter was positioned in the vertebral artery for posterior circulation aneurysms. Intravenous systemic heparin (50 U/kg) was administered while placing the guiding catheter. An activated clotting time of 2–2.5 times that of baseline was maintained during endovascular treatment. An Excelsior SL-10 (Stryker Neurovascular) was used to deliver the Neuroform Atlas stent. The jailing or semi-jailing techniques were primarily performed, and if these failed, the through the strut (cell-through) technique was implemented.

Patients were administered a daily dose of clopidogrel 75 mg and aspirin 100 mg for more than 7 days before the SAC procedure. For patients with insufficient premedication or when the SAC was planned immediately after the diagnostic digital subtraction angiography, a loading dose of aspirin and clopidogrel of 300 mg each was administered the day before treatment. Platelet function testing was routinely performed for all patients. After the procedure, patients were prescribed 75 mg of clopidogrel daily for 3 months and 100 mg of aspirin daily for at least 12 months. Magnetic resonance imaging was routinely performed within 24 hours after SAC for all patients and included diffusion-weighted imaging, T2-weighted imaging, fluid-attenuated inversion recovery, and gradient echo imaging.

Clinical and radiographic outcomes

Angiographic results and clinical outcomes were reviewed retrospectively. Clinical and angiographic follow-up was performed in all 123 patients with 130 aneurysms between 3 and 20 months (mean, 12.4 months) after the procedure. The angiographic results were evaluated by two independent investigators and 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). Clinical outcomes were assessed using the modified Rankin Scale and evaluated at the time of discharge and out-patient follow-up by an independent investigator who was

not involved in patient care.

Statistical analysis

All statistical analyses were performed after consulting with a biostatistician using R language ver. 3.01 (R Foundation for Statistical Computing, Vienna, Austria). Student's t-tests were used for numeric variables. Chi-square tests were used for nominal variables. Logistic regression analysis was performed to determine the independent risk factors for procedure-related complications. Multiple logistic regression analyses were performed for variables with an unadjusted effect and with a *p* value <0.10 in simple logistic regression analysis. The 95% confidence interval (CI) was calculated for all *p* values, which were considered statistically significant at <0.05.

RESULTS

Baseline demographics and aneurysm characteristics are summarized in Table 1. Of the 123 patients included in this

Table 1. Baseline demographics and aneurysm characteristics

	Value
Patients	123
Age (years)	60.2±10.1
Female	96 (78.0)
Hypertension	63 (51.2)
Diabetes	29 (23.6)
Smoking	19 (15.4)
Dyslipidemia	16 (13.0)
Coronary heart disease	11 (8.9)
Aneurysm	130
Aneurysm size (mm)	5.3±1.7
Neck size (mm)	3.9±0.8
Aneurysm location	
Internal carotid artery	65 (50.0)
Posterior communicating artery	9 (6.9)
Middle cerebral artery	18 (13.8)
Anterior communicating artery	17 (13.1)
Anterior cerebral artery	10 (7.7)
Basilar artery	9 (6.9)
Vertebral artery	2 (1.5)

Values are presented as mean±standard deviation or number (%)

study, there were 96 women, and the median age was 60.2 years (range from 29 to 79). Patient baseline characteristics included hypertension in 63 patients (51.2%), diabetes in 29 (23.6%), smoking history in 19 (15.4%), dyslipidemia in 16 (13.0%), and coronary heart diseases in 11 (8.9%). Aneurysms were located in the internal carotid artery in 65 cases (50.0%), posterior communicating artery in nine (6.9%), middle cerebral artery in 18 (13.8%), anterior communicating artery in 17 (13.1%), anterior cerebral artery in 10 (7.7%), basilar artery in nine (6.9%), and vertebral artery in two (1.5%). The mean aneurysm size was 5.3±1.7 mm, and the mean neck size was 3.9±0.8 mm.

Table 2 shows the clinical and radiographic outcomes of the aneurysms. In terms of technical considerations, there was one case (0.8%) of failure of stent deployment and one (0.8%) of suboptimal positioning of the stent. These two events hap-

Table 2. Clinical and radiographic outcomes of the aneurysms

	Value (n=130)
Technical considerations	
Deployment failure	1 (0.8)
Suboptimal positioning	1 (0.8)
Y-stenting	3 (2.3)
Stent salvage	6 (4.6)
Initial angiographic results	
Complete obliteration	61 (46.9)
Residual neck	44 (33.8)
Residual aneurysm	25 (19.2)
Follow-up angiographic results	
Complete obliteration	103 (79.2)
Residual neck	16 (12.3)
Residual aneurysm	11 (8.5)
Procedure-related complications	8 (6.2)
Dissection	2 (1.5)
Thromboembolism	5 (3.8)
Hemorrhage	1 (0.8)
Delayed complications	2 (1.5)
Ischemia	1 (0.8)
Hemorrhage	1 (0.8)
Clinical outcomes	
Morbidity (mRS 1–5)	0 (0.0)
Mortality	0 (0.0)

mRS : modified Rankin Scale

pened because the delivery microcatheters suddenly dropped to the proximal part of very tortuous internal carotid arteries. We performed Y-stenting (Atlas-Atlas; Stryker Neurovascular, Fremont, CA, USA) in three patients (2.3%) and stent salvage in six (4.6%). Immediate postembolization angiographic results showed complete obliteration in 61 aneurysms (46.9%), residual neck in 44 (33.8%), and residual aneurysm in 25 (19.2%). Follow-up angiographic results were obtained in all aneurysms and showed complete obliteration in 103 (79.2%), residual neck in 16 (12.3%), and residual aneurysm in 11 (8.5%). There was no recurrence of the aneurysm during the follow-up period. With respect to clinical outcomes, there were no morbidity or mortality cases even though there were

eight cases (6.2%) of procedure-related complications (two dissections, five thromboembolisms, and one hemorrhage) and two (1.5%) of delayed complications (one ischemia and one hemorrhage). All five patients with thromboembolic complications underwent intra-arterial thrombolysis in which a glycoprotein IIb/IIIa antagonist (tirofiban) was used and showed successful recanalization without any symptoms. Two patients experienced vertebral artery dissection due to guiding catheter placement and were treated conservatively.

Logistic regression analysis was used to determine independent associations of procedure-related complications with other factors. On univariate analysis, aneurysm locations in the middle cerebral artery (odds ratio [OR], 2.211; 95% CI, 1.196–3.993;

Table 3. Potential risk factors for procedure-related complications

Variable	Procedure-related complications		Unadjusted		Adjusted	
	Yes (n=8)	No (n=122)	OR (95% CI)	p-value	OR (95% CI)	p-value
Age (years)	59.0±10.4	60.3±9.9	1.094 (0.944–1.326)	0.823	0.975 (0.962–1.149)	0.652
Sex						
Female (n=102)	6 (75.0)	96 (78.7)	1			
Male (n=28)	2 (25.0)	26 (21.3)	1.085 (0.517–2.023)	0.575	1.029 (0.554–1.898)	0.711
Hypertension, yes	6 (75.0)	62 (50.8)	2.616 (0.828–9.205)	0.138		
Diabetes, yes	2 (25.0)	27 (22.1)	1.312 (0.750–3.206)	0.676		
Smoking, yes	1 (12.5)	18 (14.8)	0.816 (0.471–3.054)	0.765		
Dyslipidemia, yes	0 (0.0)	16 (13.1)	0.625 (0.433–5.224)	0.218		
Coronary heart disease, yes	0 (0.0)	11 (8.5)	0.687 (0.682–3.469)	0.270		
Aneurysm location						
Internal carotid artery (n=65)	1 (12.5)	64 (52.5)	1			
Posterior communicating artery (n=9)	0 (0.0)	9 (7.4)	0.972 (0.300–2.832)	0.442		
Middle cerebral artery (n=18)	3 (37.5)	15 (12.3)	2.211 (1.196–3.993)	0.046	1.525 (0.943–3.021)	0.088
Anterior communicating artery (n=17)	3 (37.5)	14 (11.5)	2.850 (1.298–5.143)	0.039	2.559 (0.954–4.622)	0.067
Anterior cerebral artery (n=10)	0 (0.0)	10 (8.2)	0.575 (0.447–1.866)	0.385		
Basilar artery (n=9)	1 (12.5)	8 (6.6)	0.727 (0.486–1.978)	0.524		
Vertebral artery (n=2)	0 (0.0)	2 (1.6)	0.922 (0.907–1.054)	0.810		
Aneurysm neck						
Relative wide neck (<4 mm, n=76)	6 (75.0)	70 (57.4)	1			
Absolute wide neck (≥4 mm, n=54)	2 (25.0)	52 (42.6)	0.922 (0.668–3.218)	0.186		
Aneurysm size						
Small (<5 mm, n=64)	5 (62.5)	59 (48.4)	1			
Medium (<10 mm, n=59)	3 (37.5)	56 (45.9)	0.750 (0.638–2.169)	0.302		
Large (≥10 mm, n=7)	0 (0.0)	7 (5.7)	0.332 (0.305–1.811)	0.489		

Values are presented as mean±standard deviation or number (%) unless otherwise indicated. OR : odds ratio, CI : confidence interval

$p=0.046$) and the anterior communicating artery (OR, 2.850; 95% CI, 1.298–5.143; $p=0.039$) was associated with procedure-related complications (Table 3). However, no independent risk factor for procedure-related complications was noted in the multivariate logistic regression analysis adjusted for age and sex.

DISCUSSION

In the present study, the procedure-related complication rate was 6.2% among 123 patients with 130 unruptured wide-necked aneurysms. Further, no case of morbidity/mortality was noted with SAC for unruptured wide-necked intracranial aneurysms with the Neuroform Atlas. Thromboembolic complications were the most common at 3.8% followed by dissection (1.5%) and hemorrhage (0.8%). The technical success rate of delivering and deploying the stent was 98.5% among the 130 cases. Delayed ischemia due to transient ischemic attack and a small amount of delayed hemorrhage in the left frontal lobe occurred in one case each during the follow-up period, with both patients being asymptomatic. We found that stent deployment in the middle cerebral artery and anterior communicating artery was associated with procedure-related complications in the univariate analysis.

An expected benefit of the Neuroform Atlas stent is its increased navigability, which allows easy delivery¹². The Neuroform Atlas stent is the latest version of the Neuroform series with reinforced navigability within a smaller microcatheter that confers stability to the vessel wall (high radial force), enables accurate placement (ease of use with very low foreshortening), and allows wall apposition, conformability, and coil protection. It can be delivered via a 0.0165-inch microcatheter, the smallest profile, allowing neurointerventionists to perform SAC without difficulty. The cell size of the Neuroform Atlas stent is smaller compared to that of its predecessor, the Neuroform stent. This enables better coil protection in aneurysms and allows the use of smaller coils. Additionally, the width of the struts has been reduced to improve flexibility and conformability of the stent. Furthermore, the segmental opening of the struts allows stable positioning and direct vessel wall apposition by anchoring the stent after the first rows of the struts exit the microcatheter. These characteristics of the Neuroform Atlas make SAC safer and more effective.

There have been a few reports on SAC with Neuroform At-

las stents, of which most have reported that SAC using Neuroform Atlas stents is safe and effective in treating wide-necked aneurysms^{1,6,7,13,14}. From their experience with 27 consecutive patients, the authors of one study concluded that Neuroform Atlas SAC is feasible for treating ruptured and unruptured wide-necked aneurysms that are not amenable to conventional coiling or clipping¹³. The aneurysm occlusion and favorable clinical outcomes were consistent with those previously reported for SAC of wide-neck aneurysms using other devices¹³. These previous authors reported favorable and complete occlusion rates of 69.2% and 53.8% at 6 months, respectively. Another report concluded that deployment of the Neuroform Atlas stent was a safe and effective method for the treatment of wide-necked aneurysms from their experiences with 37 aneurysms in 36 patients¹⁴. They reported satisfactory immediate angiographic outcomes: complete aneurysm obliteration was observed in 84% cases, while neck remnants were observed in the remaining 16%. Furthermore, high-resolution time-of-flight magnetic resonance angiography revealed an occlusion rate of 100% at the 5-month follow-up. Additionally, other reports showed a complete occlusion rate of 86.7% with the Neuroform Atlas system⁶. The complete occlusion rate of 79.2% in the present study is in accordance with the results published previously, highlighting the efficacy of the Neuroform Atlas.

Compared to the Low-profile Visualized Intraluminal Support Junior device (LVIS Jr; MicroVention, Tustin, CA, USA), the Neuroform Atlas is less visible because only the stent markers at each end of the stent are radiopaque, although the struts themselves are invisible. Nevertheless, the visibility of the Neuroform Atlas was sufficient to allow accurate placement and deployment of the device in the present study. Additionally, the high outward radial force of the Neuroform Atlas ensures opening and wall apposition of the stent. If the complete opening of the stent is doubtful, the struts can be visualized by unenhanced flat-panel detector CT¹³. This approach can be employed to overcome the disadvantage of the open-cell design of the Neuroform Atlas stent, which causes resheathing after its deployment difficult. However, neurointerventionists should be aware of the possibility of delivery microcatheters unexpectedly falling down in tortuous parent arteries for the optimal deployment of the stent. According to the thromboembolic complications, it seems that there is no difference in the rate of thromboembolic complications be-

tween Neuroform Atlas and LVIS stents. We reported 6.5% of thromboembolic complications using Neuroform Atlas stents, whereas LVIS family (LVIS and LVIS Jr) had 3.6–5.8%^{2,5,15}. However, intra-procedural thromboembolic complications occurred in 8% among 25 patients in SAC of anterior communicating artery aneurysms using the LVIS Jr stent¹⁰, supporting our result of possible higher rate of procedure-related complications in the parent arteries with small diameter, such as middle cerebral artery or anterior communicating artery. Another report showed that a series of 100 patients treated with the LVIS Jr stent with thromboembolic complications occurring in 14% of the cases and concluded that the potentially inadequate antiplatelet response and use of the stent itself are possible reasons for thromboembolic phenomena in patients with acutely ruptured aneurysms¹¹.

With increasing clinical experience and development of new devices, SAC of aneurysms with a small parent artery has been known to be feasible in selected cases and show good long-term patency rates of parent arteries^{4,8,16,17}. Regardless of the stent type (open-cell or closed-cell), the deployment of stents in small arteries, such as anterior cerebral arteries, middle cerebral arteries, posterior cerebral arteries, or posterior inferior cerebellar arteries, was safe and resulted in good patency. Nevertheless, the possibility of thromboembolic complications and parent artery occlusion should not be neglected when performing SAC of aneurysms with a small parent artery. In the present study, no independent risk factors for procedure-related complications could be determined through a multivariate logistic regression analysis adjusted for age and sex. However, SAC of aneurysms located in the middle cerebral artery or anterior communicating artery showed an association with procedure-related complications in univariate analysis. Thus, using the Neuroform Atlas in distal small parent arteries might be feasible, although its possible procedure-related complications should be considered.

Stents with an open-cell design show better wall apposition in tortuous vessels compared with closed-cell stents. However, incomplete stent apposition is more likely to be found in small arteries with tortuous anatomy. In addition, the low radial force of stents could be one cause of poor wall apposition. Although poor wall apposition may improve by open-cell stents, it might not work properly in a small-sized tortuous parent artery. The stent might not fully deploy in small arteries with acute angles because of kinking, twisting, or ovalization at the

angles. This is especially concerning in arteries with a small diameter. Furthermore, increased metal surface coverage might increase the risk of thromboembolism when stents are deployed in small arteries. Thus, it can't be too careful of performing SAC in the parent artery with small diameter, such as anterior cerebral artery or middle cerebral artery.

The present study had several limitations including the retrospective data collection and the small number of patients with an unruptured aneurysm enrolled, and thus, the effects of possible selection bias cannot be excluded. Moreover, as the follow-up period was short (less than 2 years), longer follow-up is needed to assess the stability of adequate obliteration. Furthermore, there was no true control group for the evaluation of the efficacy and safety of the device. Thus, comparisons with different devices and laboratory experiments to improve the technical defects of the Neuroform Atlas should be performed in additional clinical trials.

CONCLUSION

The Neuroform Atlas stent showed a high rate of technical success with good navigability. Good clinical and radiographic outcomes in early follow-up suggest that the device is safe and reliable with minimal risks for SAC of unruptured intracranial aneurysms in both anterior and posterior circulation. In cases of SAC of unruptured intracranial aneurysms in the middle cerebral artery or anterior communicating artery, more careful use of the Neuroform Atlas may be required to prevent possible procedure-related complications. Large cohort studies with a longer follow-up are necessary to determine the long-term durability and safety of the device as well as the risk factors for procedure-related complications.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

INFORMED CONSENT

This type of study does not require informed consent.

AUTHOR CONTRIBUTIONS

Conceptualization : JC

Data curation : OK, JC

Formal analysis : OK

Methodology : OK, JC

Writing - original draft : OK

Writing - review & editing : JC

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