Coil Embolization for Cerebral Aneurysms Using a Semi-Jailing Technique and Open-Cell Stent

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■ BACKGROUND: **Numerous reports have described the semi-jailing technique (SJT) using a closed-cell stent for stent-assisted coil embolization, revealing issues including poor expansion and thrombotic complications in curved vessels. This paper reports preliminary experience with SJT using an open-cell stent, a novel type of stent allowing stent placement from a microcatheter.**

■ METHODS: **First, this research investigated differences between open- and closed-cell types in SJT using silicone vessel models. Next, 43 patients who underwent SJT for the internal carotid artery were divided into 2 groups to investigate treatment outcomes: 24 patients with placement of an open-cell stent (open-cell group) and 19 patients with closed-cell stents (closed-cell group).**

■ RESULTS: **In the silicone vessel model, coils could be placed with the open-cell stent deployed with a shorter length than the closed-cell stent. No significant differences were found between groups in terms of maximum diameter of the aneurysm or dome-neck ratio. The open-cell group showed a trend toward higher complete embolization immediately after surgery (54.2% vs. 26.3%, $P = 0.06$), with few cases of stent malapposition (0% vs. 31.6%, $P < 0.01$). However, 1 case of ischemic complication in the closed-cell group and 1 case of hemorrhagic complication in open-cell group occurred. All cases of modified Rankin Scale scores at discharge were 0–1.**

■ CONCLUSIONS: **Although the open-cell stent carries the disadvantage of an unresheathable design, coil placement with a shorter stent deployment length may be advantageous during SJT for internal carotid artery aneurysm embolization with favorable consequences for excellent vessel wall apposition.**

INTRODUCTION

A number of studies have demonstrated the effectiveness of stent-assisted coil embolization for wide-necked cerebral aneurysms.[1-4] Intraaneurysmal microcatheter insertion is typically performed using either the transcell or jailing techniques.[5-7] The transcell technique performs coil insertion beyond the stent strut following stent placement, while the jailing technique places the intraaneurysmal coil before stent placement. The jailing technique has been frequently employed in Japan in an effort to avoid potential damage to the aneurysm during the insertion procedure.[6] However, this technique carries some procedural issues including possible prolapse of the microcatheter from the targeted aneurysm and immobilization of the microcatheter by the stent.

Some articles have reported a semi-jailing technique (SJT) that addresses these issues.[8-11] The typical SJT employs a resheathable closed-cell stent but may encounter issues with tortuous blood vessels including stent migration and poor wall apposition.[9,12,13] Ko et al[10,11] reported on a SJT with an open-cell stent employing the over-the-wire type Neuroform 3 in 70 patients. Immediately after surgery, 70% of the patients achieved complete embolization, but the incidence of perioperative complication was considerably high (8.8%).

The Neuroform Atlas stent (Stryker, Freemont, San Francisco, California, USA) is a new type of commercially available, open-cell stent that can be placed by a catheter with an internal diameter of 0.0165 inches. This stent has cells of smaller size than all currently existing open-cell types, which may help prevent coil prolapse.

Key words
- Coil embolization
- Open-cell stent
- Semijailing technique

Abbreviations and Acronyms
CT: Computed topography
D/N ratio: Dome/neck ratio
ICA: Internal carotid artery
SJT: Semi-jailing technique

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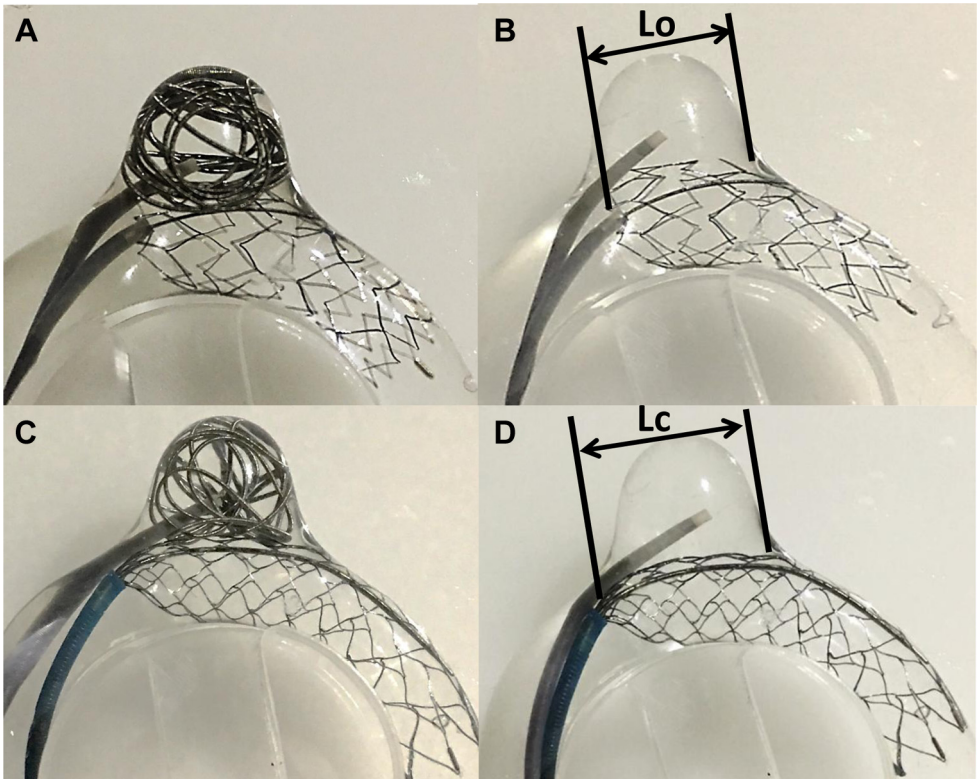

Figure 1. Differences between open- and closed-cell stents for tortuous blood vessels using the semi-jailing technique. (**A**) Semi-jailing technique using open-cell stent (during coil insertion). The stent adhesion is satisfactory even in the curved blood vessel. The wider working space for the microcatheter to insert coils is provided. During the coil embolization, the microcatheter for the coil insertion is not fixed by the open-cell stent. Therefore it is easier to maneuver the microcatheter for coil deployment. (**B**) Semi-jailing technique using open-cell stent (without coil insertion). After the coil is withdrawn, the length between distal end of aneurysmal neck and the tip of microcatheter for stent (Lo) is measured. (**C**) Semi-jailing technique using closed-cell stent (during coil insertion). The deployment of the stent over long distance is necessary for stent apposition with the curved blood vessel. In the procedure, the closed-cell stent deployment was gradual and was stopped at the point where the coil could not prolapse from the aneurysm. (**D**) Semi-jailing technique using closed-cell stent (without coil insertion). After the coil is withdrawn, the length between distal end of the aneurysmal neck and the tip of microcatheter for stent (Lc) is measured.

Moreover, the stent is deployed from the tip of the microcatheter in a segmental fashion to prevent stent migration and to offer improved apposition to the curved vessel wall.

This article reports on our preliminary experience with cerebral aneurysm coiling using the SJT with Neuroform Atlas stents.

MATERIAL AND METHODS

In Vitro Study

This study investigates differences between open- and closed-cell stent placements and coil embolization of wide-necked aneurysms using the SJT in a 4-mm silicone vascular model. A microcatheter (Excelsior SL-10 preshape 45; Stryker, Freemont, San Francisco, California, USA) was placed in the wide-necked aneurysm (neck, 6 mm; maximum diameter, 6 mm). Coils (Target 360 soft 6 mm × 20 mm; Stryker, Freemont) were inserted using the SJT with an open-cell stent (Neuroform Atlas 4 mm × 21 mm) and a closed-cell stent (Enterprise 2 VRD, 4 mm × 39 mm; CERENOVUS, Irvine, California, USA).

Stents were deployed gradually and stopped at the earliest position where the coil would not prolapse (Figure 1A and C). At this point, length was measured from the distal end of the neck of the aneurysm to the tip of the catheter to evaluate the working space of the microcatheter for coiling (Figure 1B and D). The mean value of the length was calculated from a total of 5 measurements for each stent.

Clinical Study

From August 2015 to March 2018, a total of 152 patients underwent stent-assisted coil embolization in our hospital. Among them, 43 patients underwent stent-assisted coil embolization using the SJT for unruptured internal carotid artery (ICA) aneurysms. Twenty-four of these patients were treated with an open-cell stent, and 19 were treated with a closed-cell stent (Enterprise 2 VRD or LVIS;

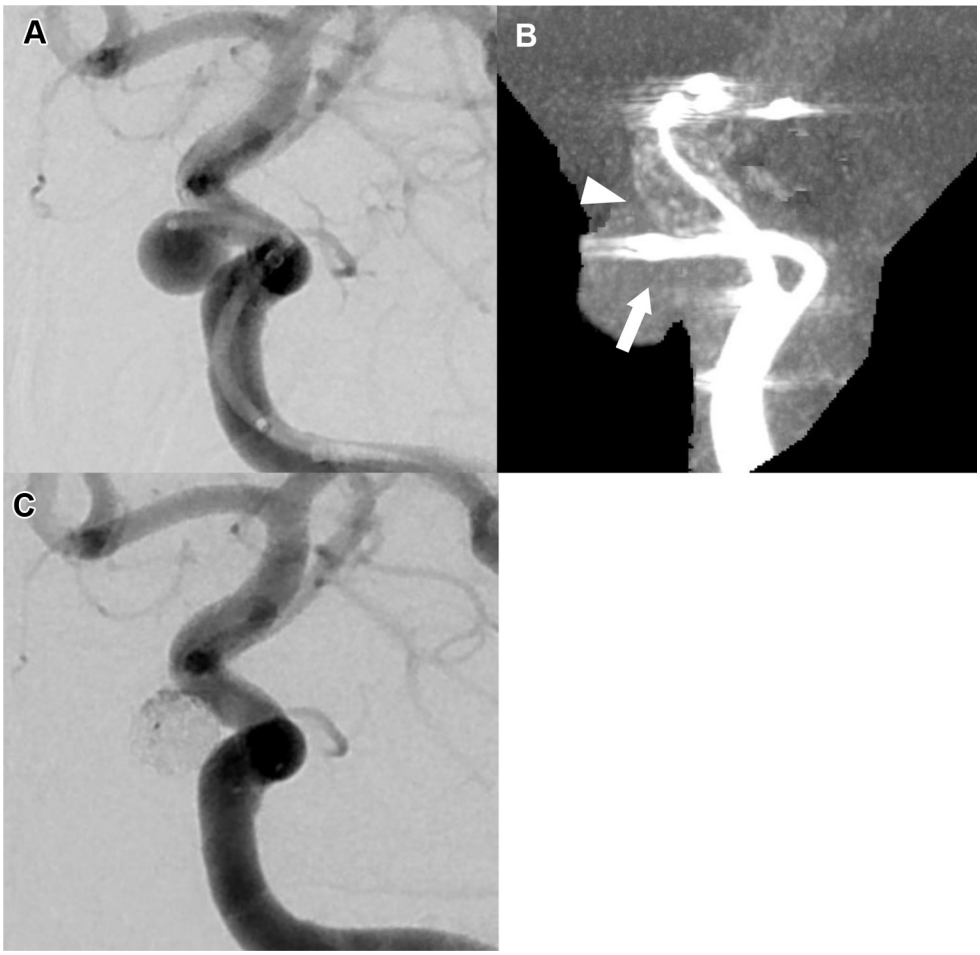

Figure 2. Complete coil embolization of a paraclinoid aneurysm at the left internal carotid artery using the semi-jailing technique with an open-cell stent. (**A**) Preoperative angiography. It shows a paraclinoid aneurysm with a maximum neck diameter of 6.3 mm and a D/N ratio of 1.41. (**B**) Perioperative computed tomography–like image (maximum intensity projection image of 3-dimensional angiography) demonstrates sufficient working space for the coil embolization by the microcatheter (*arrow*), even though the neck is partially covered by the open-cell stent (*arrowhead*). (**C**) Postoperative angiography. Complete coil embolization is achieved using the semi-jailing technique and open-cell stent.

MicroVention Inc., Aliso Viejo, California, USA). Patient demographics were recorded for age, sex, site, size, neck diameter, and dome/neck ratio (D/N ratio) of the aneurysms, as well as degree of curvature of the placed stents. Treatment results were evaluated by the rate of embolization immediately after the procedure, as well as technical and clinical complications. The degree of curvature of the placed stents was measured postoperatively, defined as the angle between both ends of the stents on a maximum intensity projection image of a computed tomography (CT)-like image.[12] Stent malapposition was also evaluated on maximum intensity projection images.[12] Cerebral angiographic evaluation for coil embolization was performed using the Raymond classification by 2 radiologists blinded to surgery information.[14]

The study protocol was approved by the Institutional Review Board of Hyogo College of Medicine (identification 2835), and all subjects gave informed consent before enrollment.

Statistical analysis was performed using the Student's *t*-test for age, chi-squared test for technical complications, Fisher test for sex and radiologic results, and Wilcoxson test for maximum diameter of the aneurysm, D/N ratio, and degree of curvature of the deployed stents (SAS, Jump version 12 software, Cary, North Carolina, USA). Values of $P < 0.05$ were considered significant.

Surgical Procedures

Patients began an antiplatelet regimen of aspirin at 100 mg/day and clopidogrel at 75 mg/day 14 days before surgery. Platelet aggregation was measured on day 10 after regimen initiation, with platelet aggregation determined by light transmission aggregometry using a Hematracer M system (MC Medical, Tokyo, Japan). The evaluation used collagen for the effectiveness of aspirin and adenosine diphosphate for the effectiveness of clopidogrel. On the

Table 1. Patient Demographics and Aneurysm Characteristics

	Open-Cell Group ($n = 24$)	Closed-Cell Group ($n = 19$)	*P* Value
Mean age, years (SD)	58 (3)	60 (3)	0.62
Females, n (%)	21 (87.5)	16 (84.2)	0.77
Median maximum diameter of aneurysm, mm [IQR]	5.1 [4.6—6]	4.5 [3.9—5.9]	0.19
Median maximum diameter of aneurysmal neck, mm [IQR]	3.5 [3—4.1]	3.1 [2.7—3.9]	0.22
Median dome-neck ratio, [IQR]	1.1 [1—1.3]	1.2 [1—1.4]	0.47
Median angle of parent artery, degree [IQR]	124.5 [105.3—135.8]	105 [79—120]	0.06

SD, standard deviation; IQR, interquartile range.

basis of the evaluation, adjustments to the regime were made to achieve a therapeutic antiplatelet effect before the procedure.

All selected patients underwent femoral artery puncture via which a 7-French Superlong sheath (Shuttle Guiding Sheath; Cook, Bloomington, Indiana, USA) was guided to the ICA. An intravenous bolus of 5000 units of heparin was injected following the insertion of the sheath. A microcatheter for stenting was then guided to the middle cerebral artery, and a microcatheter for coil embolization was placed within the aneurysm. The stent was then partially deployed to cover half to three-quarters of the aneurysm neck, and coil insertion was initiated. During embolization, if the coil prolapsed into the parent vessel, the stent was deployed further to a point where embolization could be achieved without prolapse to the parent vessel. The stent was fully deployed when sufficient coil embolization was achieved. The procedure was completed by further coil insertion and ejection of the microcatheter from the aneurysm. During the procedure, heparin was infused to target activated clotting time above 200 seconds. Postoperatively, treatment with double antiplatelet medications was continued for 3 months, followed by a single antiplatelet therapy from the third month until complete withdrawal after 1 year from the antiplatelet regimen.

Table 2. Comparison of Radiologic and Technical Results and Clinical Complications in Coil Embolization of Cerebral Aneurysms Between Open-Cell and Closed-Cell Stents Using Semijailing Technique

	Open-Cell Group (n = 24)	Closed-Cell Group (n = 19)	*P* Value
Radiologic results			
Complete occlusion, number (%)	13 (54.2)	5 (26.3)	0.06
Neck remnant, number (%)	5 (20.8)	9 (47.3)	0.06
Body filling, number (%)	6 (25)	5 (26.3)	0.59
Technical results			
Coil protrusion, number (%)	6 (25)	1 (5.3)	0.09
Stent malapposition, number (%)	0 (0)	6 (31.6)	<0.01
Clinical results			
Ischemic, number (%)	0 (0)	1 (5.2)	0.44
Hemorrhagic, number (%)	1 (4.2)	(0)	0.55
Modified Rankin Scale score 0—1 at discharge, number (%)	24 (100)	19 (100)	—

Representative Patient

A 58-year-old woman was diagnosed from magnetic resonance imaging with a paraclinoid aneurysm at the left ICA, with a maximum diameter of 6.3 mm and a D/N ratio of 1.41 (Figure 2A). A SJT employing an open-cell stent was selected for the intervention due to predicted relative difficulty of inserting a catheter into the tortuous ICA proximal to the neck of the aneurysm. A combination of aspirin (100 mg/day) and clopidogrel (75 mg/day) was prescribed for 14 days before the surgery. The platelet aggregometry before surgery demonstrated a therapeutic antiplatelet effect. Femoral artery puncture was performed to insert a 7-French Superlong sheath, which was guided to the left ICA. An intravenous bolus of 5000 units of heparin was injected after insertion of the sheath. After a manually shaped microcatheter (SL-10) was placed intraaneurysmally, a Neuroform Atlas stent was partially deployed and CT-like images were captured. The images demonstrated that the deployed stent segment provided sufficient coverage over half of the aneurysm neck (Figure 2B). With control of the microcatheter, 11 coils were inserted to completely embolize the aneurysm. The stent was then fully deployed to complete the procedure. No perioperative complications were encountered (Figure 2C).

RESULTS

In Vitro Study

The SJT was viable in all procedures. Compared with the closed-cell stent, the open-cell stent was deployed at significantly shorter lengths while still able to prevent coil protrusion (Neuroform Atlas, 4 ± 0.3 mm vs. Enterprise 2, 8 ± 0.5 mm: $P < 0.01$).

Clinical Study

There were no significant differences in age or sex between the open-cell group and the closed-cell group. There were no significant differences in the maximum aneurysm diameter (open-cell group, 5.1 mm vs. closed-cell group, 4.5 mm; $P = 0.19$) or D/N ratio (open-cell group, 1.1 vs. closed-cell group, 1.2; $P = 0.47$). The

open-cell group tended to present with more steeply curved blood vessels than did the closed-cell group (124.5°vs. 105°; $P = 0.06$) (Table 1). There were no statistically significant intergroup differences in the coil embolization rate immediately after surgery, although complete embolization tended to be more achievable in the open-cell than closed-cell group (54.2% vs. 26.3%; $P = 0.06$). Stent malapposition was not found in any of the patients in the open-cell group (0%) but was present in 3 patients in the closed-cell group (31.6%, $P < 0.01$). Coil protrusion occurred more frequently in the open-cell group (25% vs. 5.3%, $P = 0.09$). Ischemic complication occurred in 1 patient in the closed-cell group (5.2%), and hemorrhagic complication occurred in only 1 patient in the open-cell group (4.2%). All patients had a 0–1 score from the modified Rankin scale at discharge (Table 2).

DISCUSSION

This study represents the first report of a microcatheter-guided open-cell stent (Neuroform Atlas) for intracranial aneurysm coiling using a SJT. Compared with the closed-cell stent, the open-cell stent provided a wider working space for coil insertion and thus improved coil embolization. This stent was more applicable in the steeply curved blood vessels. Stent malapposition was not found in patients with the open-cell stent but was present in 31.6% of patients with the closed-cell stent. Although coil protrusion seemed to be more prevalent in the patients with the open-cell stent, only 1 patient (4.2%) presented with hemorrhagic complication. Moreover, there were no thrombotic complications, and only 1 patient with the closed-cell stent developed ischemic complication (5.2%). Therefore our results in this preliminary study suggest that the SJT using a microcatheter-guided open-cell stent is effective and safe for wide-necked aneurysm coiling in steeply curved blood vessels.

In patients with steeply curved blood vessels, a closed-cell stent may fail to remain in close contact with the vessel wall (stent malapposition). In such cases, coil prolapse may result due to insufficient neck coverage of the stent, thus potentially increasing the perioperative risk for thrombotic complications.[12] To avoid this, a closed-cell stent requires a longer length of stent deployment in patients with steeply curved vessels. In contrast, open-cell stents are designed to deploy in a segmental fashion, thus allowing for better stent apposition to the vessel wall and subsequently reduced risk of thrombotic complications.

In addition to the stent malapposition, partial deployment of either an open-cell or a closed-cell stent in the SJT may also increase the likelihood of thrombotic complications. However, there were no thrombotic complications in our patients with open-cell stents. One patient (5.2%) developed ischemic complications in the closed-cell stents. In contrast, previous reports have described ischemic complications at a rate of 5.9%–9.0% despite administration of 2 antiplatelet medications 3 days before the surgery.[4-6] Other studies have reported that up to 28.6% of patients were nonresponders to clopidogrel, with a significantly higher incidence of ischemic complications in patients without additional antiplatelets,[15,16] indicating the possibility of insufficient preoperative platelet aggregation. Therefore we attribute successful coil embolization of intracranial aneurysms without thrombotic complications to our effective therapeutic antiplatelet regimen.

Although coil protrusion was more prevalent in our open-cell group, hemorrhagic complication was only observed in 1 patient. It occurred after full deployment of the stent and final coil insertion for embolization. This is the stage in which the SJT has evolved over the jail technique. In this stage, the microcatheter was fixed by the stent and the coil was deployed with slightly excessive force that led to hemorrhage. Therefore we consider hemorrhage a complication of the coiling, rather than the SJT itself.

Stent-assisted coil embolization for treating wide-neck cerebral aneurysm has the disadvantage of not allowing periprocedural microcatheter repositioning during embolization. This problem can be addressed by the SJT. Still, some patients with a steep curve in the effected vessel pose extreme challenges to stent guidance and placement. These patients can benefit from the SJT using a microcatheter-guided open-cell stent, and this embolization approach can serve an effective technique for treating wide-necked cerebral aneurysms.

The key limitations of this research include the single-center, retrospective study design and an insufficient number of patients enrolled to provide strong statistical power. Further research is warranted to clarify the safety and efficacy of the SJT in a larger number of patients and evaluate the long-term clinical results. In addition, some bias in the stent selection may have occurred among the different backgrounds of the patients.

CONCLUSION

An SJT employing the Neuroform Atlas offers a more effective and safer approach to the wide-necked cerebral aneurysm coiling in the curved blood vessels than currently existing approaches.

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