Clinical Study

Acute ischemic dissection of an “S”-shaped carotid artery: The “one-stop” value of using a detachable Solitaire AB stent

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Abstract
This study aimed to evaluate the efficacy and safety of endovascular repair using detachable Solitaire AB stents for acute ischemic dissection of “S”-shaped carotid arteries. From May 2015 to December 2016, a total of 127 patients with acute ischemic stroke (AIS) underwent endovascular treatment in our center. Among them, five AISs were due to acute dissection of an “S”-shaped carotid artery. Coexisting carotid embolism was identified in all five patients, who first underwent successful Solitaire AB stent-based retrieval of the embolism. All patients then underwent Solitaire AB stenting to reopen the occluded carotid arteries, all of which were successfully recanalized. There were no procedure-related complications, except for minor hemorrhage transformation in one patient. The mean NIHSS scores were 12 ± 3.7 and 3.8 ± 3.4 at admission and 90 days after stenting, respectively (P = 0.018). The median modified Rankin Scale score at 90 days was 2.0 ± 1.4. Follow-up computed tomography angiography demonstrated in-stent patency in four of the five patients. Dissection of an “S”-shaped carotid artery infrequently leads to AIS. Such dissected arteries can be safely and reliably repaired by this stenting, ensuring successful reconstruction of the carotid arterial circulation.

1. Introduction
Acute ischemic stroke (AIS) is the most common type of stroke, accounting for approximately 80% of the total number of strokes. It is the third leading cause of death in the United States [1,2]. The high morbidity and mortality and the limited time window require accurate, timely diagnosis and treatment.

Carotid arterial dissection is a less frequent contributor to AIS than cardiogenic thromboembolism. Carotid arterial dissection, however, is increasingly implicated in strokes in young populations [3–5], who seem to have worse clinical prognoses even when thrombolysis is applied [6–8]. The main cause of cerebral infarction is thromboembolism originating from dissection. That is, brain hypoperfusion resulting from acute occlusion of a dissected artery might well lead to a cerebral infarct. The complexity of dissection-related AIS may in part explain some patients being refractory to thrombolytic therapy.

The presence of an acutely obstructed carotid artery due to dissection necessitates timely reconstruction of the carotid blood flow to improve cerebral perfusion. Consequently, stent-based endovascular repair of the dissected artery has been increasingly regarded as a feasible, safe treatment option [6]. However, no consensus has been attained on the choice of stent (i.e., self- or balloon-expandable), which is largely clinically empirical. It is essential, however, that the stent be individually tailored to the lesion’s anatomy [9]. We report our limited experience on the use of stents to treat AIS secondary to carotid arterial dissection with an “S”-shaped carotid artery.

2. Materials and methods
The study protocol was approved by the institutional review board. Informed consent was obtained from all patients or their immediate family members prior to endovascular interventions.

3. Population
From May 2015 to December 2016, a total of 125 patients with AIS underwent endovascular interventions in our center. The patients were aged 31–92 years (mean 69.54 ± 11.73 years), with a significant male predominance (n = 75/125, 60%). All patients experienced acute onset of symptoms lasting no ≥6 h. Among them, five were diagnosed by angiography to have carotid arterial dissection, which was considered the underlying lesion resulting in
acute onset of cerebral ischemia. Demographic data of these patients are shown in Table 1.

4. Clinical evaluation

The National Institutes of Health Stroke Scale (NIHSS) was used at admission to assess the severity of the individual’s neurologic deficit. One patient with an NIHSS score > 25 was considered ineligible for endovascular treatment or intravenous thrombolysis.

5. Imaging evaluation

Plain computed tomography (CT) was performed on each of the five patients to rule out contraindications to endovascular treatment or recombinant tissue plasminogen activator (r-tPA)-based intravenous thrombolysis, including cerebral hemorrhage. The CT revealed signs of early infarction in more than one-third of the territory of the middle cerebral artery (MCA). The Alberta Stroke Program Early CT Score [10] was also used to indicate the regions of ischemia. With a range of 1–10, a score of 10 points indicated a normal CT scan, and a score of 0 indicated diffuse ischemia throughout the MCA territory. Patients suspected of having acute large-vessel occlusion then underwent a multi-modal magnetic resonance (MR) examination: three-dimensional time-of-flight MR angiography to confirm large-vessel occlusion; perfusion-weighted imaging to assess ischemic penumbra; and fluid-attenuated inversion recovery to evaluate collateral network conditions.

6. Treatment

Four of the five patients were admitted within 3.5 h after symptom onset and had no contraindications to intravenous (IV) thrombolysis. Hence, they were emergently given r-tPA (0.9 mg/kg IV) for thrombolysis, according to National Institute of Neurological Disorders and Stroke guidelines. During the IV thrombolysis, they were monitored by MR examinations. Clinical status was also reassessed immediately after each MR examination. The results of the MR and clinical assessment indicated large-vessel occlusion. Consequently, they were immediately transferred to the digital subtraction angiography (DSA) room to undergo endovascular treatment. Because the symptom duration had been >4 h in one patient, IV thrombolysis was not applied and the patient was transferred to the DSA room immediately after the MR evaluation confirmed AIS and large-vessel occlusion.

Each of the five patients was safely placed on the DSA table and immobilized by tying wrists and knees to the table with homemade soft belts. They were sedated with dexmedetomidine HCl (0.5 μg/kg IV per hour). The injection rate was mediated based on the patient’s sedation status, heart rate, and respiratory response. The right femoral artery was conventionally used for catheterization access. A 6F sheath (Terumo, Tokyo, Japan) was inserted, through which a 4F pig-tail catheter (Cook, Spencer, IN, USA) was navigated over a 0.035-inch guidewire (Terumo) into the ascending aorta. Aortography was then performed to visualize the aortic arch to confirm the diseased artery that had been previously identified on MRA. Selective catheterization was conducted using a 4F Headway catheter with its tip placed proximal to the diseased artery. Selective angiography was then performed to attain detailed information about the acutely obstructed artery.

Following diagnostic angiography, a 6F guide-catheter (Chap- eron; MicroVention, Columbia, Aliso Viejo, California) was placed in the common carotid artery proximal to the lesion, providing guide sheath support. A micro-catheter (Headway 27; MicroVention) was then navigated over a 0.014-inch micro-guidewire (Traxcess; MicroVention) into the internal carotid artery. Microcatheter/micro-guidewire access was obtained through the dissection flaps with contrast injections confirming true lumen catheterization and opacification of the distal intracranial vasculature. It is relatively common and easy to navigate a micro-guidewire through a dissected occlusion. It should be noted that a micro-guidewire may be in the false lumen when its top gets twisted or entangled. Finally, the micro-catheter was distally placed in the true lumen of the carotid artery, providing a channel for the next stent-based manipulations. For the five patients with thrombosis in the dissected segment of the carotid artery, the clot was removed using a 6 × 30 mm Solitaire AB stent (MicroVention). After successful clot removal, repeat angiography demonstrated dissection-induced occlusion in the C1-C2 segments of the carotid artery. To reopen the occluded dissection, the Solitaire AB stent was inserted via a micro-catheter (Headway 27; MicroVention) that had been previously placed in a normal segment distal to the area of dissection. We then retracted the micro-catheter until the whole stent came into the open field, making sure that the stent had fully covered the dissected segments. Angiography was then repeated via the guide catheter to visualize the patency of the stent and distal circulation. Finally, the stent was detached...

### Table 1

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SPECTS, Alberta Stroke Program Early CT Score; L, left; mRS, modified Rank in Scale; NIHSS, National Institutes of Health Stroke Scale; R, right; TTR, time to recanalization, from symptom onset to recanalization; TTT, time to therapy, from symptom onset to puncture.
electrolytically according to the manufacturer's instructions (Table 2).

7. Management after endovascular treatment

Plain CT scanning was performed immediately and 24 h after endovascular treatment to determine if cerebral hemorrhage had occurred. Each of the five patients was then transferred to the neurologic intensive care unit where he or she was closely monitored for vital signs and neurologic deficits, blood pressure, and the need for anti-platelet therapy.

To prevent acute in-stent thrombosis, tirofiban was administered at an initial dose of 0.4 mg IV over 30 min and then continued at a rate of 0.1 mg/kg IV per hour. If the post-procedural CT demonstrated no cerebral hemorrhage, tirofiban administration was started before stent placement and continued for 24 h. Dual anti-platelet therapy (acetylsalicylic acid 100 mg plus clopidogrel 75 mg per day) was administered orally once a day for at least 3 months, with the acetylsalicylic acid (100 mg/day) continued for life.

NIHSS assessment was repeated 24 h after the procedure. Clinical outcomes were assessed at discharge and at 90 days postoperatively with the modified Rankin Scale and the NIHSS. Imaging-based evaluation using CT angiography was performed at 90 days after the procedure to evaluate the in-stent patency and distal circulation.

8. Results

The demographic information and clinical presentations prior to and after endovascular treatment are shown in Table 1. The mean NIHSS score was 12.0 ± 3.7 at admission. The mean time to therapy was 3.0 ± 1.05 h (range 1.6–4.4 h). The door-to-needle time for these patients was 32.7 ± 15.2 min (range 17–46 min).

The lesion characteristics are shown in Table 2. Three patients presented with focal carotid dissection, and two patients presented with long-segmental dissection involving the proximal cervical-to-horizontal petrous segments. All patients showed progression to an acute occlusion, typically appearing as a flame-like sign on angiography (Fig. 1).

After clot retrieval, the contour of the internal carotid artery (ICA) was clearly revealed. All patients had increased tortuosity of the ICA, similar to an S-shaped curve, above the dissection. Additionally, one patient had contralateral ICA tortuosity and non-occluded dissection (Fig. 1). Such morphologic changes in the ICA could indicate fibromuscular dysplasia. Case 5 had acutely occlusive dissection of the left ICA and chronic long-segmental occlusion of the right ICA. Case 2 also had chronic occlusion on the left vertebral artery unrelated to the onset of AIS.

The technical success was 100% in terms of recanalization of the area of the carotid dissection and stent-based clot retrieval. After successful thrombectomy, we repeated the digital subtraction angiography at 15-min intervals to confirm whether the patency of the dissected carotid arteries had been maintained, which it had re-occluded in all five patients in the study. Five Solitaire AB stents had thus been successfully placed to cover the dissected carotid artery, thereby restoring blood flow and improving distal perfusion. All patients achieved mTICI grade 3 blood reperfusion in the MCA territory.

Endovascular treatments were relatively safe, with procedure-related complications occurring in only one patient (case 5), who, at discharge, was found to have developed parenchymal hemorrhage in the left frontal lobe without neurologic deficits. There was no procedural mortality at discharge or at the 90-day follow-up. Postprocedural clinical improvement was observed from a mean NIHSS score of 12.0 ± 3.7 on admission to 3.8 ± 3.4 at discharge (P = 0.018). Moreover, a median modified Rankin scale score of 2.0 ± 1.4 was achieved at the 90-day follow-up. No recurrent ischemic events, including transient ischemic attacks and strokes, were reported during the clinical follow-up.

Follow-up CT studies at 90 days. which were available for four patients, showed in-stent patency and no evidence of in-stent thrombosis or significant stenosis. Two patients who had had long-segmental dissection showed an irregular contour of the stented artery. One patient (case 5) refused to undergo CT examination, but clinical assessment and carotid Doppler ultrasonography indicated favorable outcomes.

9. Discussion

This study retrospectively evaluated the efficacy and safety of endovascular repair and/or stent-based retrieval for five patients with AIS caused by acutely occlusive carotid dissection and thrombosis. Carotid dissections in all patients were repaired with detachable Solitaire AB stents. At the short-term follow-up, each was found to have achieved favorable in-stent patency and clinical outcome. Although the sample was small, this limited experience suggested that endovascular treatment is technically safe and clinically efficacious for patients with occlusive carotid dissection and thrombosis.

Five randomized trials (MR CLEAN, ESCAPE, REVASCAT, SWIFT PRIME, and EXTEND IA) [11–15], all published in 2015, showed the greater efficacy of endovascular thrombectomy than provided by standard medical care in patients with AIS caused by occlusion of arteries of the proximal anterior circulation, irrespective of
Based on the evidence from these trials, the American Heart Association/American Stroke Association updated the 2013 guidelines for early management of patients with AIS, concluding that certain endovascular procedures can clinically benefit selected patients with AIS [17].

The importance of angioplasty and stenting to reopen the proximal arterial occlusion at the time of thrombectomy, however, had not been well established [9,17]. In today’s practice, the use of stenting is largely empiric. Compared with other etiologies of ischemic stroke, occlusive internal carotid artery dissection responds poorly to intravenous thrombolysis, as proved in our study. Stent-based retrieval of the embolism alone does not achieve TICI grade 2b/3 reperfusion of the affected brain territory because of the complete occlusion attained by the dissected lesion. Hence, we believed it vital to open the occluded dissection as soon as possible (i.e., within 6 h of stroke onset) to attain TICI grade 2b/3 reperfusion. We therefore used angioplasty and stenting to open the occluded segment at the time of thrombectomy in the setting of acute carotid artery dissection. Our results suggest that it is a valid approach, although future randomized studies are needed for verification.

For this endeavor, we used a Solitaire AB stent to open the occluded lesion in patients with dissection involving the proximal segment of the ICA for the following reasons: (1) Although other available carotid stents were superior to Solitaire AB in terms of radial force, opacity, and the area covered by the stent, a Solitaire stent seems to have better flexibility and affinity for the arterial wall—features especially important when the lesion involves an “S”-shaped carotid artery. (2) The carotid dissections in our patients were not due to arteriosclerosis, and there were no calcified plaques. Hence, the Solitaire AB stent might have enough supportive strength to open this type of dissected occlusion. (3) The navigation and deployment of this Solitaire device are via a micro-catheter, which is previously placed above the occlusion. Using a micro-catheter to pass the occluded dissection is technologically safe, allowing us to inject contrast medium to confirm its position in the actually dissected lumen (not in a false channel) thereby avoiding potential complications, such as vascular perforation or an enlarged dissection [18]. (4) The Solitaire AB has the additional advantage of being able to remove the embolus if it is located above the dissected segments. The Solitaire AB stent is detachable and so can be detached to allow repair of the dissected area if required. Thus, the merits of the Solitaire AB make the operation convenient and time-saving.

Mourand et al. [19] reported two cases with acute occlusive carotid dissection treated with intracranial stents—one with an Enterprise stent and the other with a Wingspan stent. Based on the 1-year follow-up, the two patients had good neurological outcomes.
Similarly, we suggest that such intracranial stents can be used for strictly selected patients who are believed to have nonatherosclerotic, relatively focal, occlusive carotid dissection.

We used the Solitaire AB stent for particular reasons. (1) The Solitaire AB stent can be used for both thrombectomy and recanalization, an advantage especially valuable for Chinese patients because it is economically beneficial (with its two uses) when considering medical insurance policies. The need to use additional stents could increase the economic burden. (2) Follow-up imaging demonstrated the patency of the stented carotid artery and good repair of the dissection, although these limited findings suggest the need for further studies.

Minor hemorrhage transformation occurred in one patient (case 5). The patient was initially treated with IV thrombolysis followed by endovascular repair with stenting. Therefore, it is difficult to attribute the hemorrhage transformation to thrombolysis or reperfusion damage. Probably, a relatively low Alberta Stroke Program Early CT Score played a role. Another factor was the use of tirofiban, a glycoprotein IIb/IIIa inhibitor, which was used to prevent acute in-stent thrombosis but which also increased the risk of cerebral bleeding. Zhu et al. [20] reported that minor hemorrhage occurred in 6 of 26 patients (23.1%) following the use of tirofiban plus other thrombolytic therapy but none in patients following tirofiban alone. As reported by Li et al. [21], 3 of 41 patients (7.3%) experienced hemorrhage transformation after receiving the combined use of alteplase and tirofiban. At present, however, it is difficult to suggest an optimal protocol for using r-tPA, tirofiban, and/or stent placement.

This knowledge requires large randomized controlled trials to determine the best combination of the aforementioned therapies to minimize the risks but maximize the benefits [17].

The carotid artery dissections in our patients were nonatherosclerotic in nature. The etiologies of carotid artery dissection vary, among them iatrogenic damage [22], fibromuscular dysplasia [23,24], and minor or major trauma [25,26]. Kim et al. [26] reported an association between cervical artery dissection and tortuous cervical arteries. In agreement with their views, all patients in the present study had increased tortuosity of the ICA, appearing as an S-shaped vessel above the dissection, indicative of fibromuscular dysplasia. Thus, the association between fibromuscular dysplasia and carotid artery dissection requires further study.

Compared with carotid occlusion caused by atherosclerosis, there is some evidence that can be used to support a diagnosis of dissected occlusion. (1) Age predilection: Carotid dissection occurs more commonly in younger populations. The patients with carotid dissection in the present study all lacked the risk factors for atherosclerosis (i.e., smoking, hyperglycemia, hyperlipidemia) but had the risk factors for dissection (i.e., tortuous carotid contour, history of neck massage). Two patients had transient neck pain prior to symptom onset. (2) Location predilection: Carotid atherosclerotic plaques commonly involve the carotid bifurcation, including the orifice of the external and internal carotid arteries and the terminus of the common carotid artery, whereas carotid dissection commonly involves the segment of the ICA superior to the area of the atherosclerosis. (3) A “flame-like sign” and “double-lumen sign” on intra-arterial angiography might indicate a dissected occlusion. (4) A dissected occlusion can be reopened using a fully released Solitaire AB stent with no signs of thrombosis in situ or atherosclerotic stenosis.

To exclude the possibility of iatrogenic dissection caused by embolectomy, the following evidence may be helpful. Our neurointerventional team is highly experienced. Thus, navigation of the micro-guidewire and micro-catheter was performed skillfully, so their passage did not encounter any difficulties. Finally, we used angiography via the micro-catheter to show that the tip of catheter was in the lumen of the carotid artery.

The limitations of the study should be noted. First, the sample is small. Only five patients with acute carotid artery dissection were included in this retrospective study. Moreover, one of the five patients had minor hemorrhage transformation. Thus, the complication rate was not low (20%). We must therefore evaluate the real complication rate only after increasing the sample size. Any conclusions drawn from the study might be limited if expanded to other clinical practices. Second, the follow-up period was relatively short, so the long-term performance of these intracranial stents in dissected arteries has not been demonstrated. Third, due to a lack of guidelines on the use of stents for carotid artery dissection, we opted to study the Solitaire AB simply because it has dual roles: clot retrieval and stenting. A new stent should be specifically designed in the future that appropriately adheres to the morphology of dissections with tortuous contours. Finally, staged stent implantation can be considered if the dissection does not affect blood flow.

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Conflict of interest

We declare no conflict of interests.

Ethical approval

The study protocol was approved by the institutional review board.

Informed consent

Informed consent was obtained from all patients or their immediate family members prior to endovascular interventions.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jocn.2018.04.075.

References


