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CORRESPONDENCE

# New Cerebral Embolic Protection System for Endovascular Revascularization of Stenosis at the Origin of the Right Common Carotid Artery: the Counterflow Technique

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## Introduction

Endovascular therapy for stenosis at the origin of the common carotid artery (CCA) poses a technical challenge [1]. Treatments that have been described for this condition include open retrograde stenting [2–5] and percutaneous antegrade stenting [1, 6–11]. Open retrograde stenting can stabilize the catheter system and facilitate accurate stent placement. Moreover, surgical clamping of the distal CCA can prevent procedure-related cerebral embolism. However, this method is more invasive and complex than the percutaneous approach [12] and carries risks of postoperative cervical hematoma, arterial dissection, infection, and cranial nerve injury [2, 13]. Percutaneous antegrade stenting for such stenosis is technically difficult because the guiding system lacks adequate catheter backup support [1, 14]. To date, methods of cerebral embolic protection have not been well investigated.

To increase backup support and reduce the risk of procedure-related cerebrovascular embolism, we have devised a new cerebral embolic protection system for percutaneous antegrade stenting of stenosis at the right CCA origin, which we have named "the counterflow technique." Herein, we present a case of symptomatic stenosis at the right CCA origin that was successfully treated with percutaneous antegrade stenting using this technique. We also review the relevant literature.

## The Counterflow Technique

The counterflow technique is suitable for use in patients with stenosis at the origin of the right CCA. An 8F balloon guide catheter (0.085″ inner diameter, 90-cm working length; 8F Optimo; Tokai Medical Products, Aichi, Japan) and a 2.6F microballoon catheter (2.6/2.8F [distal/proximal] outer diameter, 0.020″ inner diameter, 150-cm working length; Pinnacle Blue 20; Tokai Medical Products) are used via transfemoral access (TFA) and right transradial access (TRA), respectively.

An 8F sheath is introduced via TFA. The activated clotting time is maintained at >250 s with intravenous heparin. A 5F Simmons catheter is cannulated into the innominate artery through an 8F balloon guide catheter. Under roadmap guidance, the 5F Simmons catheter over a 0.035″ hydrophilic guidewire (150 cm; Radifocus Guidewire M Standard type; Terumo, Tokyo, Japan) is advanced into the distal right subclavian artery, and the guidewire is exchanged for a 0.035″ Amplatz Extra-Stiff guidewire (300 cm; Cook Medical, Bloomington, IN, USA). The 8F balloon guide catheter is engaged into the innominate artery, and the 5F Simmons catheter and Amplatz Extra-Stiff guidewire are removed.

A 3F guiding sheath (5.3F outer diameter, 0.085″ inner diameter, 93-cm working length; 3F Axcelguide; Medikit, Tokyo, Japan) is delivered into the right subclavian artery distal to the origin of the right vertebral artery (VA) via right TRA. A 2.6F microballoon catheter over a 0.014″ microguidewire is navigated into the proximal right VA (Fig. 1a).

Daishiro Abe and Yoshiki Hanaoka contributed equally as first authors to this work.

**Data availability** Data and materials are available from the corresponding author on reasonable request.

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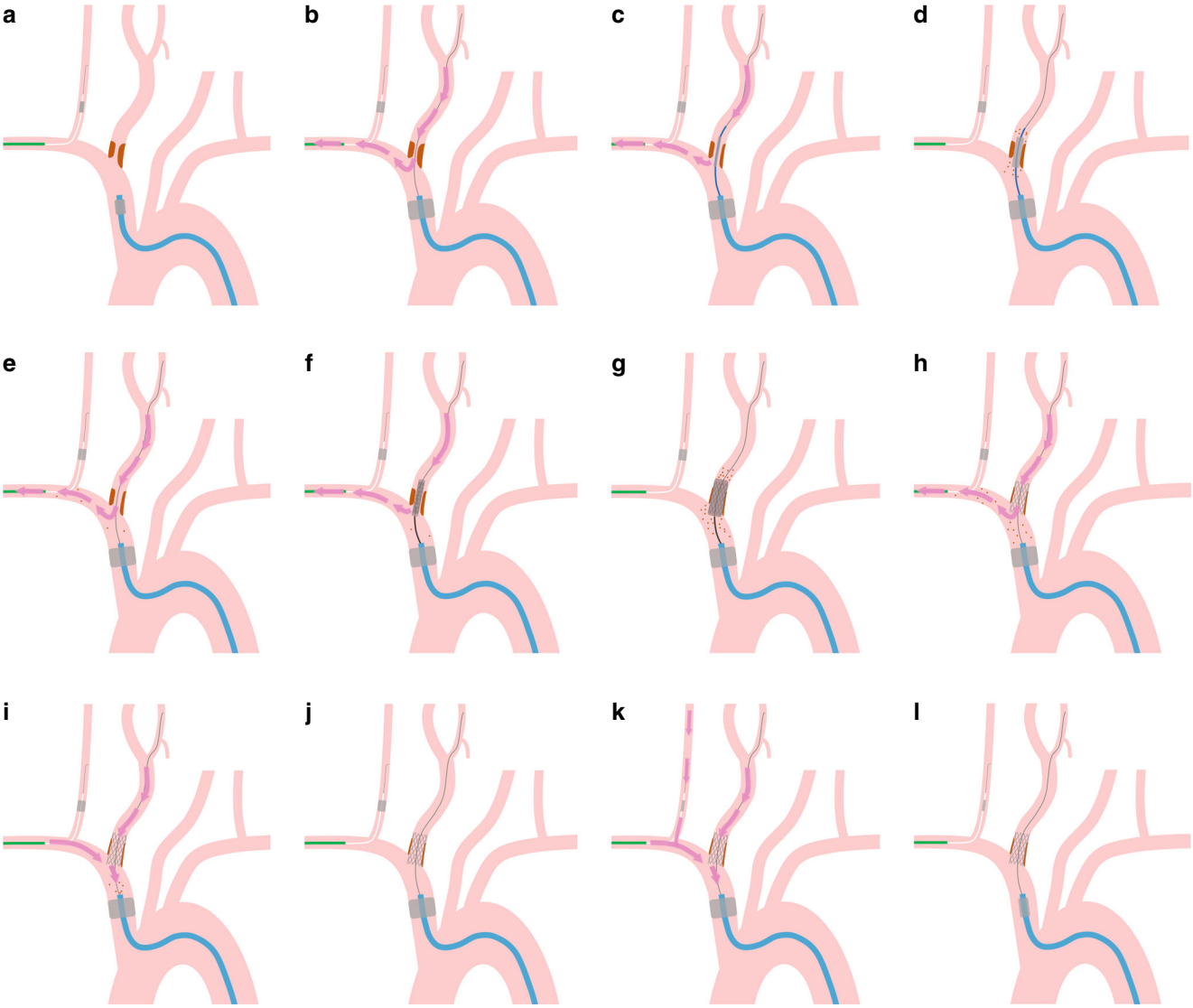


**Fig. 1** Schematic diagrams showing common carotid artery (CCA) stenting using the counterflow technique for stenosis at the origin of the right CCA. **a** An 8F balloon guide catheter is inserted into the innominate artery via transfemoral access. A 3F guiding sheath is introduced into the right subclavian artery distal to the origin of the right vertebral artery (VA) via right transradial access. A 2.6F microballoon catheter over a 0.014″ microguidewire is navigated into the proximal right VA; **b** A 0.035″ guidewire is delivered into the right external carotid artery through the 8F balloon guide catheter. The 8F balloon guide catheter and 2.6F microballoon catheter are inflated. The 8F balloon guide catheter is anchored to the innominate artery. The dual balloon inflation induces counterflow in the right CCA; **c** A percutaneous transluminal angioplasty balloon catheter is delivered into the lesion; **d** Pre-dilation is performed. Procedure-related debris occurs; **e** Procedure-related debris is flushed away toward the distal right subclavian artery; **f** A 0.035″ compatible balloon-expandable stent is placed in the lesion. Under roadmap guidance, the proximal end of the balloon-expandable stent is strictly placed to correspond with the CCA orifice; **g** The balloon-expandable stent is deployed. Procedure-related debris occurs; **a** Procedure-related debris is flushed away toward the distal right subclavian artery; i, j Manual aspiration is performed through the 8F balloon guide catheter until there is no visible debris; **k** After deflation of the 2.6F microballoon catheter, manual aspiration is performed through the 8F balloon guide catheter to remove stagnant blood in the right VA; **l** The 8F balloon guide catheter is deflated

Under roadmap guidance, a 4F catheter over the 0.035″ hydrophilic guidewire is carefully advanced into the right external carotid artery through the 8F balloon guide catheter. The guidewire is exchanged for the 0.035″ Amplatz Extra-Stiff guidewire, and the 4F catheter is removed. To occlude the antegrade flow of the innominate artery and the right VA, the 8F balloon guide catheter and 2.6F microballoon catheter are inflated (Fig. 1b). The 8F balloon guide catheter is then anchored to the innominate artery. This dual balloon inflation induces retrograde flow (i.e., counterflow) in the right CCA (Fig. 1b). Pre-dilation is performed under counterflow protection (Fig. 1c–e). A 0.035″ compatible balloon-expandable stent is advanced into the right CCA origin stenosis over the Amplatz Extra-Stiff guidewire (Fig. 1f). Under roadmap guidance, the proximal end of the balloon-expandable stent is strictly placed to

correspond with the CCA orifice (Fig. 1f), and the balloon-expandable stent is deployed (Fig. 1g, h). Manual aspiration is conducted through the 8F balloon guide catheter until there is no visible debris (Fig. 1i, j). Following deflation of the 2.6F microballoon catheter, manual aspiration is performed in the same fashion to remove stagnant blood in the right VA (Fig. 1k). Finally, the 8F balloon guide catheter is deflated (Fig. 1l).

## Case Presentation

A patient in his 70s was admitted to hospital with mild left hemiparesis. The patient had a history of hypertension and diabetes mellitus but no history of smoking, drinking alcohol, coronary artery disease, or arteriosclerosis obliterans. His hypertension and diabetes mellitus were well controlled with oral medications. The patient showed no neurological deficits. Magnetic resonance angiography (MRA) identified stenosis at the origin of the right CCA (Fig. 2a). Diffusion-weighted imaging (DWI) demonstrated acute cerebral infarction in the territory of the right internal carotid artery (Fig. 2b). Computed tomography angiography (CTA) detected severe stenosis at the origin of the right CCA which was identified as the cause of the stroke events (Fig. 2c). The patient had a type III aortic arch ([15]; Fig. 2c). Dual antiplatelet therapy (aspirin 100 mg/day and cilostazol 200 mg/day) and high-dose statin therapy were initiated.

Five years later, the patient developed right amaurosis fugax. MRA revealed loss of signal intensity at the origin of the right CCA (Fig. 2d). Magnetic resonance plaque imaging detected stenosis at the origin of the right CCA with a large lipid-rich plaque (Fig. 2e). To prevent future ischemic cerebrovascular events, endovascular revascularization was performed for the medically refractory symptomatic stenosis at the origin of the right CCA using the counterflow technique.

### Endovascular Procedure

Under general anesthesia, an 8F balloon guide catheter was introduced into the innominate artery via TFA (Fig. 3a). A 2.6F microballoon catheter was delivered into the proximal right VA through a 3F guiding sheath via right TRA (Fig. 3b). Under the dual balloon inflation (Fig. 3c), pre-dilation was performed with a 4.0 × 20 mm Mustang balloon (Boston Scientific, Marlborough, MA, USA) (Fig. 3d). An 8.0 × 17 mm balloon-expandable stent (Express Vascular LD stent; Boston Scientific) was deployed at 8 atm (Fig. 3e–g). Following manual aspiration through the 8F balloon guide catheter, the 2.6F microballoon catheter

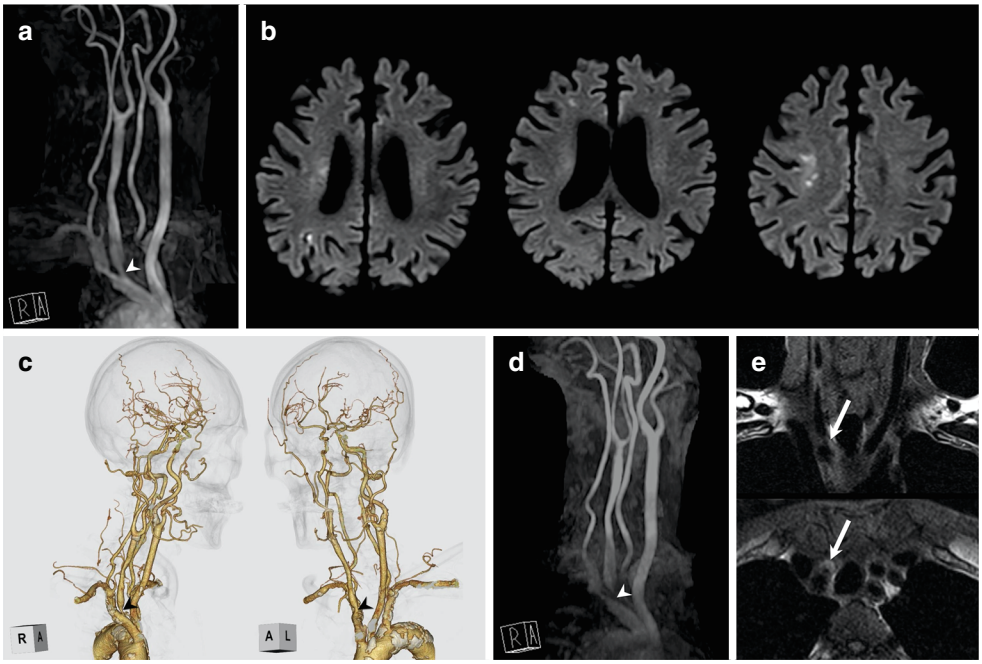


**Fig. 2** Imaging at the first onset (**a**–**c**) and at the second onset of symptoms (5 years after the first onset) (**d** and **e**) in our patient. **a** Preprocedural magnetic resonance angiography (MRA) showing stenosis at the origin of the right CCA (*white arrowhead*); **b** Diffusion-weighted imaging (DWI) showing acute ischemic stroke in the territory of the right internal carotid artery; **c** Computed tomography angiography showing severe stenosis at the origin of the right CCA (*black arrowheads*). The patient has a type III aortic arch; **d** MRA showing loss of signal intensity at the right CCA (*white arrowhead*); **e** Coronal (*upper*) and axial (*lower*) black-blood T1-weighted imaging of the right CCA origin stenosis showing a T1 high-intensity plaque (*white arrows*)

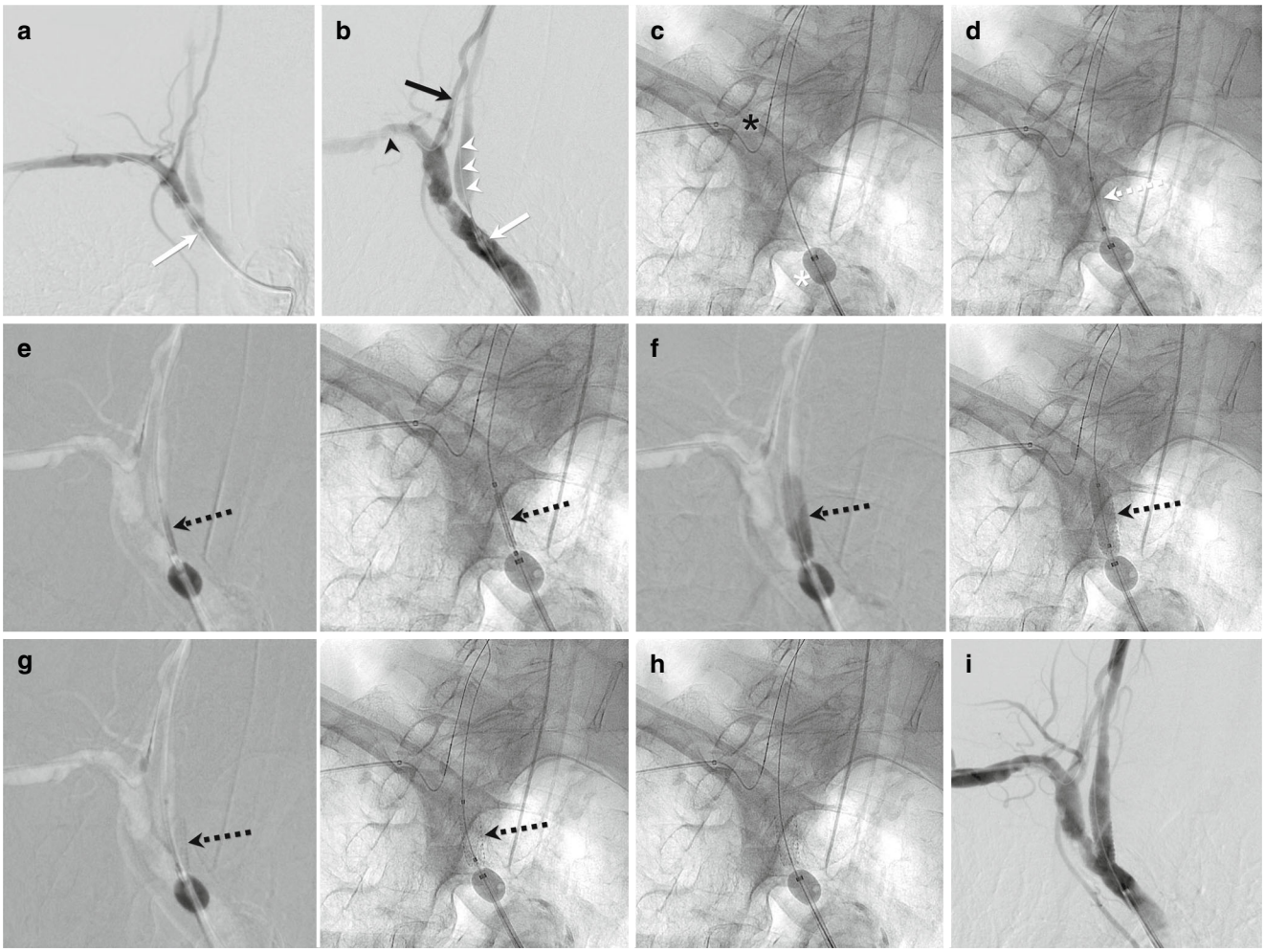


**Fig. 3** Intraprocedural angiography, fluoroscopic imaging, and roadmap imaging during CCA stenting using the counterflow technique for stenosis at the origin of the right CCA. **a** Right oblique view (working projection) obtained using angiography showing an 8F balloon guide catheter (*white arrow*) placed in the innominate artery via transfemoral access; **b** A 2.6F microballoon catheter (*black arrow*) is placed in the proximal right VA through a 3F guiding sheath (*black arrowhead*) via right transradial access. A 0.035″ guidewire (*white arrowheads*) is delivered into the right external carotid artery through the 8F balloon guide catheter (*white arrow*); **c** Right oblique view obtained using fluoroscopic imaging showing dual balloon inflation: the balloon of the 8F balloon guide catheter (*white asterisk*) and the balloon of the 2.6F microballoon catheter (*black asterisk)*; **d** Pre-dilation is performed with a 4.0 × 20 mm Mustang balloon (Boston Scientific, Marlborough, MA, USA) (*white dotted arrow*); **e–g** Right oblique views obtained using roadmap imaging (*left*) and fluoroscopic imaging (*right*) showing stenting for stenosis at the origin of the right CCA. Under roadmap guidance, the proximal end of an 8.0 × 17 mm balloon-expandable stent (Express Vascular LD stent; Boston Scientific) (*black dotted arrows*) is accurately placed to correspond with the orifice of the CCA (**e**). The balloon-expandable stent (*black dotted arrows*) is deployed at 8 atm **f**, **g** Manual aspiration is performed through the 8F balloon guide catheter until there is no visible debris; **h** The 2.6F microballoon catheter is deflated. Manual aspiration is performed through the 8F balloon guide catheter to remove stagnant blood in the right VA; **i** Innominate artery angiography shows successful revascularization

was deflated (occlusion time = 10 min) (Fig. 3h). After further manual aspiration through the 8F balloon guide catheter, the 8F balloon guide catheter was deflated (occlusion time = 1 min). Angiography of the innominate artery showed successful revascularization without vessel injury (Fig. 3i).

## Postprocedural Course

The postprocedural course was uneventful. DWI showed no evidence of ischemic stroke (Fig. 4a). The patient was discharged without neurological deficits. CTA at a 6-month follow-up showed no in-stent restenosis (Fig. 4b).

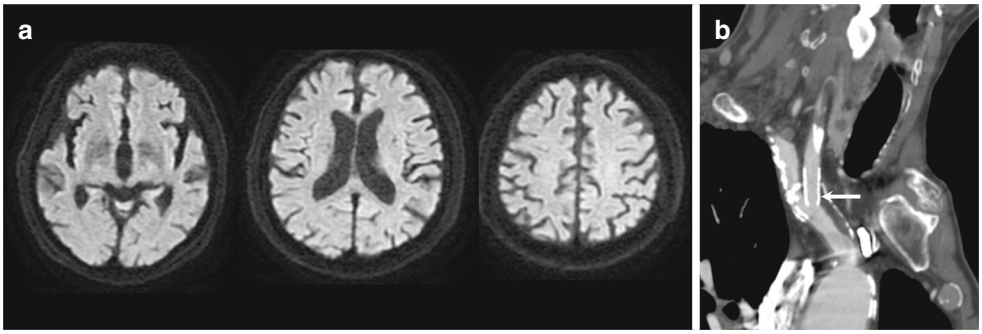


**Fig. 4** Postprocedural DWI and computed tomography angiography at 6-month follow-up in a patient treated for stenosis at the origin of the right CCA with endovascular revascularization using the counterflow technique. **a** Postprocedural DWI showing no evidence of ischemic stroke; **b** Computed tomography angiography 6 months after the endovascular stenting shows no in-stent restenosis (*white arrow*)

## Discussion

Percutaneous antegrade stenting for stenosis at the origin of the right CCA is technically challenging due to the difficulty of stable catheter support and the risk of procedure-related cerebrovascular embolism [1, 5, 8, 14]. To date, only four cases have been described in the literature (Table 1; [1, 6–8]). Paukovits et al. [6] and Kadkhodayan et al. [7] reported transfemoral percutaneous antegrade stenting using a non-balloon guide catheter. However, depending on the aortic arch anatomy, their system may provide insufficient guide catheter support for antegrade stenting. Moreover, their method lacks intraoperative cerebral embolic protection. Cam et al. [8] documented transfemoral percutaneous antegrade stenting under distal filter protection with a 0.014″ buddy wire. This system also provides poor support, especially in patients with type III aortic arches. It also carries a risk of procedure-related cerebrovascular embolism due to the passage of small particles through the filter protection [16]. Tsuji et al. [1] have reported transfemoral percutaneous antegrade stenting under a distal double-balloon protection system using two Percusurge GuardWires (Medtronic, Minneapolis, MN, USA). One of these is placed at the external carotid artery origin, while the other is positioned in the petrous internal carotid artery. The double-balloon inflation anchors the system. Under the distal double-balloon protection, a 0.035″ compatible balloon-expandable stent is introduced over the two GuardWires, and the stent is then deployed. This system allows for total cerebral embolic protection with stable guide support. However, the GuardWire was discontinued in April 2021 [17].

Our system provides both stable guide support and embolic protection during antegrade stenting for stenosis at the origin of the right CCA. Inflation of the 8F balloon guide catheter placed in the innominate artery anchors the system, which increases system stability during antegrade stenting. Indeed, in the current case (type III aortic arch), the procedure was successfully achieved without system instability. When the 8F balloon guide catheter is inflated in the innominate artery (causing occlusion of the innominate artery), the direction of blood flow in the right CCA and VA may be, theoretically, as follows, based on their hemodynamic relationship: 1) antegrade flow in the CCA and retrograde flow in the VA (Fig. 5a); 2) retrograde flow in the CCA and antegrade flow in the VA (Fig. 5b); or 3) retrograde flow in both the CCA and VA (Fig. 5c). The direction

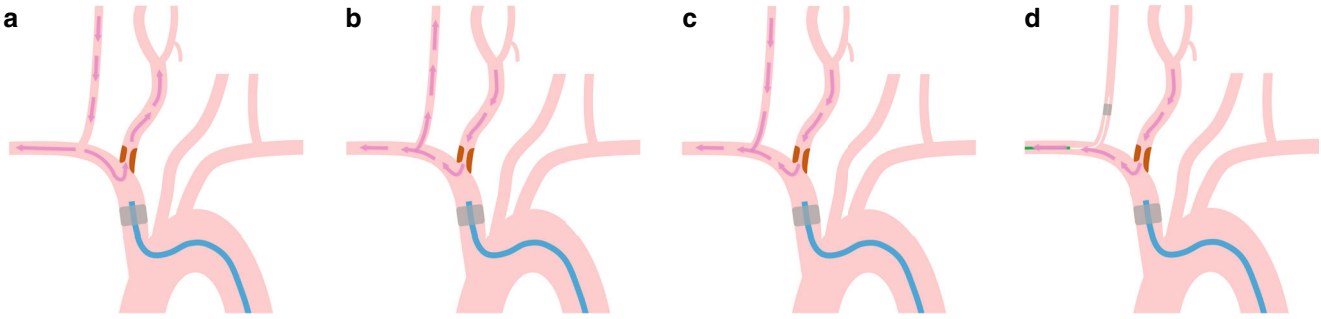


**Fig. 5** Schematic diagrams showing blood flow in the right CCA and VA when the innominate artery is occluded in patients with stenosis at the origin of the right CCA. **a** Antegrade flow in the CCA and retrograde flow in the VA; **b** Retrograde flow in the CCA and antegrade flow in the VA; **c** Retrograde flow in both the CCA and VA; **d** Occlusion of both the innominate artery and the right VA causes constant counterflow in the right CCA

**Table 1** Summary of reported cases of stenosis at the origin of the right CCA treated with antegrade percutaneous transluminal angioplasty and/or stenting

| | Paukovits et al. (2008) [6] | Kadkhodayan et al. (2009) [7] | Cam et al. (2012) [8] | Tsuji et al. (2016) [1] | Current case | |
|---|---|---|---|---|---|---|
| *Patient age (years)* | 51 | 44 | 77 | 71 | 75 | |
| *Sex* | Female | Male | Female | Male | Male | |
| *Lesion* | | | | | | |
| Type | Asymptomatic | Asymptomatic | NA | Symptomatic | Symptomatic | |
| Etiology | Atherosclerosis | Dissection[a] | Atherosclerosis | Atherosclerosis | Atherosclerosis | |
| *Aortic arch* | NA | NA | NA | NA | Type III | |
| Plaque nature | NA | NA | NA | NA | Vulnerable | |
| *Endovascular procedure* | | | | | | |
| Access | TFA | TFA | TFA | TFA | TFA | Right TRA |
| System | 7F sheath/7F guide catheter/0.035″ guidewire | NA | Guide catheter[b]/0.014″ guidewire[c] and 0.014″ Accunet[d] | 9F sheath/9F guide catheter/two 0.014″ GuardWires[e] | 8F sheath/8F balloon guide catheter[f]/0.035″ guidewire | 3F guiding sheath[g]/2.6F microballoon catheter[h] |
| Protection | None | None | Distal filter protection | Distal double-balloon protection by temporary occlusion of the right ICA and ECA | Dual-balloon protection by temporary occlusion of the innominate artery and right VA | |
| Treatment | PTA/stenting | Stenting | PTA/stenting | PTA/stenting | PTA/stenting | |
| PTA balloon | 0.035″ compatible PTA balloon[i] | NA | NA | 0.035″ compatible PTA balloon [j] | 0.035″ compatible PTA balloon[k] | |
| Stent | NA | SMART stent[l] | Palmaz Genesis[m] | Express Vascular LD stent[n] | Express Vascular LD stent | |
| Complications | NA | None | None | None | None | |
| *Restenosis* | None at 17-month follow-up | None at 18.5-month follow-up | NA | None at 11-month follow-up | None at 3-month follow-up | |

*CCA* common carotid artery, *ECA* external carotid artery, *ICA* internal carotid artery, *NA* not available or not applicable, *PTA* percutaneous transluminal angioplasty, *TFA* transfemoral access, *TRA* transradial access, *VA* vertebral artery

[a] The patient developed iatrogenic carotid artery dissection due to the placement of the right internal jugular dialysis catheter

[b] Amplatzer left 1 guide catheter with a distal tip straightened using boiling water. This was used to allow access to the carotid artery without engaging the lesion

[c] A 0.014″ guidewire was used as a buddy wire

[d] Accunet (Abbott Vascular, Santa Clara, CA, USA) was placed along with the 0.014″ buddy wire as distal filter protection

[e] PercuSurge GuardWire (Medtronic, Minneapolis, MN, USA)

[f] 8F Optimo (Tokai Medical Products, Aichi, Japan)

[g] 3F Axcelguide (Medikit, Tokyo, Japan)

[h] Pinnacle Blue 20 (Tokai Medical Products)

[i] Wanda balloon catheter (Boston Scientific, Marlborough, MA, USA)

[j] After a 0.035″ compatible PTA balloon catheter was introduced into the stenotic lesion over the two GuardWires, pre-dilation was performed under distal double-balloon protection

[k] Mustang balloon dilatation catheter (Boston Scientific)

[l] SMART stent (Cordis, Miami, FL, USA)

[m] Palmaz Genesis (Cordis)

[n] After an Express Vascular LD stent (Boston Scientific) was introduced into the stenotic lesion over the two GuardWires, the stent was carefully positioned and deployed

of blood flow in the right CCA and VA can change intraoperatively because the hemodynamic relationship between the two changes after revascularization of the stenosis (e.g., patients with retrograde flow in both the CCA and VA may develop retrograde flow in the CCA and antegrade flow in the VA after revascularization of the stenosis). In the counterflow technique, the right VA is occluded using the 2.6F microballoon catheter, which induces ongoing counterflow in the right CCA throughout the procedure (Fig. 5d). Thus, procedure-related debris is flushed away toward the distal right subclavian artery—providing a cerebral embolic protection system. After stent deployment, procedure-related debris in the proximal right VA and subclavian artery is removed using manual aspiration through the 8F balloon guide catheter (Fig. 1f). The microballoon is then deflated, and manual aspiration is again performed through the 8F balloon guide catheter to remove any stagnant blood in the right VA, which could otherwise cause thrombus formation (Fig. 1g). The 2.6F microballoon catheter is delivered into the right VA through a low-profile 3F guiding sheath via right TRA. In our case, no access-related complications were observed. TRA has clear advantages over TFA, including a reduction in access-related complications and patient preference [18–26]. Furthermore, the low-profile system can contribute to favorable outcomes [27]. To precisely control stent deployment, we used a balloon-expandable stent under roadmap guidance for CCA stenting [28]. In the current case, the proximal end of the Express Vascular LD stent was accurately deployed in the CCA orifice. Therefore, our technique is a useful treatment option for stenosis at the origin of the right CCA.

This method cannot be applied to patients with stenosis at the origin of the left CCA and those with an innominate artery whose vessel diameter is larger than the maximum balloon diameter of the 8F balloon guide catheter. Neurointerventionalists should be aware of the potential risk of vessel injury during microballoon catheter inflation in the right VA. Further research is required to clarify the utility, potential risks, and limitations of the counterflow technique.

## Declarations

**Conflict of interest** D. Abe, Y. Hanaoka, J.-i. Koyama, T. Nakamura, S. Kitamura, T. Ogiwara and T. Horiuchi declare that they have no competing interests.

**Ethical standards** All procedures performed in studies involving human participants or on human tissue were in accordance with the ethical standards of the institutional and/or national research committee and with the 1975 Helsinki declaration and its later amendments or comparable ethical standards. This study was approved by the ethics committee and was performed in accordance with the ethical standards of the 1964 Declaration of Helsinki and its later amendments. Informed consent was obtained from all individual participants included in the study.

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