Endovascular revascularization of symptomatic chronic total occlusions of the internal carotid artery using a proximal balloon protection device

Guojie Zhai1,2†, Zhichao Huang1†, Huaping Du2‡, Yuan Xu2, Guodong Xiao1* and Yongjun Cao1*

1Department of Neurology and Suzhou Clinical Research Center of Neurological Disease, The Second Affiliated Hospital of Soochow University, Suzhou, China
2Department of Neurology, The Affiliated Wujiang Hospital of Nantong University, Suzhou, China

Abstract
To investigate the feasibility, efficacy, and safety of endovascular recanalization for symptomatic chronic internal carotid artery occlusions (ICAO). Thirty patients with symptomatic chronic ICAO were treated using the endovascular recanalization method. Proximal balloon protection devices were used to prevent embolic migration by completely blocking the blood flow. The morphology of the internal carotid artery (ICA) at the occluded segment based on catheter angiography was analyzed. Recanalization of symptomatic chronic internal carotid artery occlusion (CICAO) was successful in 20 of the 30 patients (66.7%). The time required for successful revascularization ranged from 120 to 180 min (mean, 150 min). Of the 20 successful patients, 14 were at the cervical ICAs, and six were at the intracranial ICAs. No permanent complications occurred.

†These authors contributed equally to this work.
*These authors contributed equally as the corresponding author.

Corresponding authors:
Yongjun Cao, Department of Neurology and Suzhou Clinical Research Center of Neurological Disease, The Second Affiliated Hospital of Soochow University, Suzhou, Jiangsu 215004, China.
Email: yongjuncao@126.com

Guo-dong Xiao, Department of Neurology and Suzhou Clinical Research Center of Neurological Disease, The Second Affiliated Hospital of Soochow University, Suzhou, Jiangsu 215004, China.
Email: yarrowshaw@sina.com
in our study. Ischemic symptoms related to chronic ICAO did not occur during the 18.3 month follow-up period (range, 12–24 months) in the 20 successful patients. Endovascular revascularization can improve hemodynamic compromise. The treated sites of all 20 successfully recanalized patients were patent on computed tomographic angiography or carotid duplex sonography, and no case with >50% restenosis was observed during the follow-up period. Three patients with failed recanalization had a stroke during the follow-up period. Endovascular revascularization of symptomatic CICAO using a proximal balloon protection device is technically feasible in selected patients, and the outcomes are favorable for patients who benefit from revascularization.

**Keywords**
Chronic internal carotid artery occlusion, endovascular revascularization, a proximal balloon protection device, stroke, morphology

**Introduction**

The clinical outcomes of symptomatic chronic total occlusion of the ICA with hemodynamic impairment are unfavorable. Ipsilateral ischemic stroke was found to be significantly associated with total occlusion of the ICA. Symptomatic CICAO with hemodynamic impairment has a higher risk of recurrent cerebral infarction despite intensive medical therapies. Successful recanalization can not only prevent stroke but also improve cerebral perfusion as well as global cognitive function. Carotid endarterectomy (CEA) for CICAO is safe, but the rate of recanalization is low (about 34%). Beneficial results of extracranial-intracranial (EC-IC) bypass surgery for ICAO were not observed in the Carotid Occlusion Surgery Study (COSS) trial. Endovascular therapy is technically challenging and may have serious complications. However, it is relatively safe, feasible, and increases the rate of recanalization to about 60%. There are several technical challenges in this procedure, such as preventing embolization, choosing proper CICAO patients, and passing guidewires across long occlusive lesions. Preventing embolization is particularly important in this procedure. The proximal balloon protection devices can protect from an ischemic stroke, while distal filter protection devices are difficult to use in patients with total occlusions. Here, we investigate the feasibility, efficacy, and safety of endovascular recanalization for CICAO by analyzing 30 cases of symptomatic CICAO treated between 2011 and 2018 at our institution.

**Methods**

**Study population**

This retrospective study includes 30 patients with symptomatic CICAO that were treated with endovascular recanalization at our institution between March 2011 and August 2018. The recruitment of patients for research and clinical observation in this study is regulated by the Patients and Medical Volunteers Welfare Act 2001 of the People’s Republic of China. All procedures were performed on the patients included in this study after approval was granted by the Hospital Ethics
Committee of the Second Affiliated Hospital of Soochow University (APPROVAL NUMBER: JD-LX-2018-022), licensed under the Act 2001. Our study was complied with the tenets of the Declaration of Helsinki. Written informed consent was obtained from all subjects or their legally authorized representatives before the study.

The inclusion criteria were as follows: (1) patients aged ≥ 18 years; (2) symptomatic CICAO with hemodynamic impairment; (3) tapered stump, no stump or blunt stump; (4) duration from last neurologic event was ≥ 14 days; and (5) National Institutes of Health Scale score was ≤ 10. ICAO was detected by Doppler ultrasound, computed tomography (CT), magnetic resonance imaging (MRI), or conventional angiography. All cases were confirmed by conventional angiography to rule out pseudo-occlusion. The exclusion criteria were as follows: (1) infarct size ≥ one-third of the territory of the ipsilateral middle cerebral artery (MCA); (2) intracranial aneurysm, arteriovenous malformation, or any bleeding disorder; (3) contraindications to heparin, aspirin, or clopidogrel; and (4) concomitant end-stage disease with a predicted survival of ≤ 1 year. Neurologic events were defined as an ipsilateral transient ischemic attack (TIA) or cerebral infarction.

All of the assessments and procedures listed above were carried out by neurologists and interventionists of our institution, including the collection of the clinical data, evaluation of neurological function, assessment of the angiography findings, and appraisal of the interventional results.

**Preprocedural management and follow-up method**

Neurological status was evaluated, and all cases’ clinical data were acquired by the neurologists at our institution. All patients showed recurrent ischemic symptoms despite intensive medical therapies. All patients received aspirin 100 mg (aspirin enteric-coated tablets, Bayer Healthcare Company Beijing Ltd), and clopidogrel 75 mg (clopidogrel hydrogen sulfate tablets, Sanofi (Hangzhou) Pharmaceutical Co., Ltd) or cilostazol 200 mg (Zhejiang Otsuka Pharmaceutical Co., Ltd, Shanghai, China) daily for at least 7 days before the procedure. Platelet reactivity was evaluated using thromboelastography. If the adenosine diphosphate inhibition ratio was < 50%, which reveals a relative resistance to aspirin or clopidogrel, the patients were immediately administered cilostazol 100 mg twice a day.

The exact time of internal carotid artery (ICA) occlusion is unclear. Therefore, in this study, the date of CICAO was that when ICAO was confirmed. The distance between the proximal stump and the distal site of the reconstituted ICA was recognized as the length of the occlusion. The distal site of the reconstituted ICA was determined using digital subtraction angiography. The occlusion length of the cutoff was 50 mm. If the distal site of the occluded ICA was not visible on conventional angiography, the occlusion length was recognized as > 50 mm. We used the Hasan et al.\textsuperscript{14} classification in stratifying the occlusion. The mean duration of the occlusion was 2.3 months and ranged from 2 weeks to 9 months.
Brain computed tomographic perfusion (CTP) was performed to evaluate hypoperfusion. Cerebral blood flow (CBF) of the ipsilateral hemisphere with less than 80% of the normal value was recognized as hypoperfusion (Table 1). Brain CTP was performed before the procedure in all patients who satisfied the criteria given above. Complete neurological status was evaluated, and brain CT was performed within 24 h after the procedure. All patients were followed up 1, 6, and 12 months after the procedure. A thrombolysis in cerebral infarction grade of three on catheter angiography at the end of the procedure was defined as the technical success of endovascular recanalization. Clinical events, including stroke or death, were recorded on the follow-up chart. Whole-brain MR images with an echo-planar diffusion-weighted imaging (DWI) sequence were performed 7 days after the procedures to detect ischemic lesions related to the procedure. Computed tomographic angiography (CTA) or carotid duplex sonography was used to confirm 1 year patency of the recanalized ICA. Brain CTP was performed again to evaluate cerebral hemodynamics 6 months after the revascularization.

**Table 1.** The results of the relative CBF, CBV, MTT, and TTP of the ipsilateral hemisphere compared to the healthy hemisphere.

|                      | The ipsilateral hemisphere | The healthy hemisphere | T     | P       |
|----------------------|---------------------------|------------------------|-------|---------|
| CBF (mL·100 g⁻¹ min⁻¹) | 25.33 ± 4.87              | 30.72 ± 5.25           | 4.123 | 0.000   |
| CBV (mL/100 g)       | 3.17 ± 0.62               | 3.35 ± 0.58            | 1.161 | 0.250   |
| MTT (s)              | 6.27 ± 0.83               | 5.73 ± 0.79            | 2.581 | 0.012   |
| TTP (s)              | 17.82 ± 4.16              | 14.17 ± 3.88           | 3.514 | 0.001   |

CBF: cerebral bloodflow; CBV: cerebral bloodvolume; MTT: mean transit time; TTP: time to the peak.

Brain computed tomographic perfusion (CTP) was performed to evaluate hypoperfusion. Cerebral blood flow (CBF) of the ipsilateral hemisphere with less than 80% of the normal value was recognized as hypoperfusion (Table 1). Brain CTP was performed before the procedure in all patients who satisfied the criteria given above. Complete neurological status was evaluated, and brain CT was performed within 24 h after the procedure. All patients were followed up 1, 6, and 12 months after the procedure. A thrombolysis in cerebral infarction grade of three on catheter angiography at the end of the procedure was defined as the technical success of endovascular recanalization. Clinical events, including stroke or death, were recorded on the follow-up chart. Whole-brain MR images with an echo-planar diffusion-weighted imaging (DWI) sequence were performed 7 days after the procedures to detect ischemic lesions related to the procedure. Computed tomographic angiography (CTA) or carotid duplex sonography was used to confirm 1 year patency of the recanalized ICA. Brain CTP was performed again to evaluate cerebral hemodynamics 6 months after the revascularization.

**Revascularization method**

The procedure was performed under local anesthesia. All intervention cases were achieved via an 8F or 9F femoral sheath. Proximal balloon protection devices were used to prevent distal embolism in all cases. The principle of a proximal balloon protection device (Mo.Ma, Invatec, S.p.A. Italy) is to fill the occluded balloons located at the origin of the external carotid artery (ECA) and common carotid artery (CCA), thus causing blood reflux in the ICA or completely block blood flow. These systems utilize Willis ring vascular anastomosis. After occlusion of the CCA and the ECA, the ipsilateral flow to the Willis ring produces the so-called “reverse pressure,” which prevents the forward flow to the ICA.15,16 The proximal balloon protection device was placed in the CCA and ECA using an exchange technique. The balloons in the CCA and ECA were filled. A 204 cm micro-guidewire (0.014 in Transend EX, Boston Scientific) and a microcatheter (rebar 18 or 27, Micro Therapeutics Inc. DBA eV3 Neurovascular) were used to cross the occluded segment in some cases. However, a 0.035 in or 0.018 guidewire had to be used to
penetrate the occluded segment in the remaining cases. If a microcatheter entered the distal lumen, contrast agent was gently injected to confirm that the microcatheter was located inside the distal true lumen. After confirmation, the 204 cm microguidewire was withdrawn. A 300 cm exchange microguidewire (0.014-in Transend EX, Boston Scientific) was then placed in the true lumen, and the microcatheter was withdrawn by the exchange technique. The balloons in the CCA and ECA were filled, respectively. A 2.0 × 20 mm percutaneous transluminal angiography (PTA) balloon catheter (Boston Scientific) was used to expand the occluded segment from the distal occluded ICA to the proximal portion.

After the first pre-expansion, several larger PTA balloon catheters were used to expand the occluded segment. After the pre-expansions, 50–60 mL of blood was aspirated to extract any emboli through the catheter of the proximal balloon protection device placed in the CCA and ECA. Gentle angiography was performed to examine residual stenosis or dissection. Self-expanding stents (Precise, Cordis, or Wallstent, Boston Scientific) were then placed in the narrow portion. If the ICA’s petrous or cavernous sinus portion was occluded, balloon expansion was performed, or self-expandable stents (Neuroform EZ Stent System, Stryker) were released for the lesion. When the dissections were observed in the intracranial segments of the ICA, self-expandable stents (Neuroform EZ Stent System, Stryker) for intracranial arteries were deployed. Emboli were again aspirated with 60–120 mL of blood. The balloons in the ECA and CCA were released to allow blood to pass through the recanalized ICA. Catheter angiography was performed to measure the patency of the recanalized ICA. Endovascular recanalization was performed under full heparinization. Heparin was injected to control the activation time to between 250 and 350 s.

**Statistical analysis**

SPSS version 22.0 was used for the statistical analysis. A *t*-test was used to analyze the clinical variables that were continuously recorded. A chi-square test was used to analyze the categorical variables. A *p*-value of <0.05 was considered statistically significant.

**Results**

Baseline characteristics and outcomes of all patients are summarized in Table 2. Of the 30 patients, 22 were males and eight females, with a mean age of 68.8 years (range, 55–79 years). Twenty-eight, 13, 8, and 15 of the 30 patients had a history of hypertension, diabetes, hyperlipidemia, and smoking, respectively. Ipsilateral cerebral infarction with hemodynamic dysfunction was observed in 25 patients and TIA in five patients. Twenty, 8, and 12 patients presented with limb paralysis, limb numbness, and aphasia, respectively. The recanalization of the CICAO was successful in 20 of the 30 patients (66.7%). The residual stenosis was <50%. The time required for successful revascularization ranged from 120 to 180 min (mean,
| Case no. | Age (yrs), sex | Qualified events | Occlusion side | Reversed ophthalmic artery flow | Classification | Stump condition | ICA type | Contrainalateral ICA stenosis | Duration | Occlusion length | Complications | Stent Type |
|---------|----------------|------------------|----------------|-------------------------------|----------------|----------------|----------|-------------------------------|-----------|----------------|--------------|------------|
| 1       | 71, F Stroke   | R Yes            | A              | Tapered                       | Cervical       | Mild           | 3 m      | >50 mm Hyperperfusion         |           | Wallstent       |              |            |
| 2       | 66, M Stroke   | R Yes            | B              | Blunt                         | Cervical       | None           | 2 W      | ≤50 mm None                   |           | Wallstent       |              |            |
| 3       | 77, M Stroke   | L Yes            | A              | Tapered                       | Cervical       | Mild           | 2 W      | ≤50 mm Embolic                |           | Precise         |              |            |
| 4       | 55, F Stroke   | R Yes            | A              | Tapered                       | Petrous        | None           | 3 W      | ≤50 mm None                   |           | EZ             |              |            |
| 5       | 57, M TIA      | L No             | B              | Blunt                         | Undetermined   | Mild           | 7 m      | >50 mm Dissection            |           | Failed          |              |            |
| 6       | 62, M TIA      | L Yes            | A              | Tapered                       | Cervical       | None           | 1 m      | ≤50 mm None                   |           | Wallstent       |              |            |
| 7       | 75, F Stroke   | R No             | A              | Tapered                       | Undetermined   | Mild           | 6 m      | >50 mm None                   |           | Failed          |              |            |
| 8       | 77, M Stroke   | R Yes            | A              | Tapered                       | Cervical       | None           | 3 M      | ≤50 mm None                   |           | Wallstent       |              |            |
| 9       | 79, M TIA      | R Yes            | B              | Blunt                         | Undetermined   | None           | 5 m      | >50 mm None                   |           | Failed          |              |            |
| 10      | 70, M Stroke   | L Yes            | B              | Blunt                         | Undetermined   | None           | 3 W      | >50 mm Dissection            |           | Failed          |              |            |
| 11      | 68, F Stroke   | R Yes            | C              | No Stump                      | Cervical       | Mild           | 4 m      | ≤50 mm GIB                    |           | Precise         |              |            |
| 12      | 75, M Stroke   | R Yes            | A              | Tapered                       | Cavernous      | Severe         | 6 m      | ≤50 mm None                   |           | PTA            |              |            |
| 13      | 79, M Stroke   | R Yes            | A              | Tapered                       | Petrous        | Moderate       | 3 W      | ≤50 mm GIB                    |           | EZ             |              |            |
| 14      | 73, M Stroke   | R Yes            | B              | Blunt                         | Cervical       | None           | 2 W      | >50 mm Hyperperfusion         |           | Wallstent       |              |            |
| 15      | 67, M Stroke   | R No             | B              | Blunt                         | Petrous        | Severe         | 3 m      | >50 mm None                   |           | EZ             |              |            |
| 16      | 66, F Stroke   | L No             | B              | Blunt                         | Cervical       | None           | 1 m      | ≤50 mm None                   |           | Wallstent       |              |            |
| 17      | 69, M Stroke   | R Yes            | C              | No Stump                      | Undetermined   | Severe         | 2 W      | >50 mm Hyperperfusion         |           | Failed          |              |            |
| 18      | 71, M Stroke   | R No             | D              | No Stump                      | Cavernous      | Mild           | 1 m      | >50 mm Embolic                |           | PTA            |              |            |
| 19      | 57, M Stroke   | L Yes            | C              | No Stump                      | Petrous        | None           | 2 m      | >50 mm None                   |           | EZ             |              |            |
| 20      | 63, F TIA      | R Yes            | A              | Tapered                       | Undetermined   | None           | 3 m      | >50 mm None                   |           | Failed          |              |            |
| 21      | 59, M Stroke   | L No             | D              | No Stump                      | Undetermined   | Moderate       | 1 m      | >50 mm None                   |           | Failed          |              |            |
| 22      | 67, F Stroke   | L Yes            | A              | Tapered                       | Cervical       | None           | 1 m      | >50 mm None                   |           | Wallstent       |              |            |
| 23      | 77, M Stroke   | R Yes            | A              | Tapered                       | Cervical       | None           | 2 W      | ≤50 mm None                   |           | Precise         |              |            |
| 24      | 72, M Stroke   | R No             | A              | Tapered                       | Undetermined   | Severe         | 3 m      | >50 mm Dissection            |           | Failed          |              |            |
| 25      | 71, M TIA      | R Yes            | A              | Tapered                       | Cervical       | None           | 3 W      | >50 mm None                   |           | Precise         |              |            |
| 26      | 70, F Stroke   | L No             | B              | Blunt                         | Cervical       | Moderate       | 6 m      | ≤50 mm Dissection            |           | Wallstent + EZ   |              |            |
| 27      | 77, M Stroke   | R No             | B              | Blunt                         | Undetermined   | Severe         | 9 m      | >50 m None                    |           | Failed          |              |            |
| 28      | 66, M Stroke   | R Yes            | A              | Tapered                       | Cervical       | Moderate       | 2 W      | ≤50 mm None                   |           | Wallstent       |              |            |
| 29      | 59, M Stroke   | R No             | A              | Tapered                       | Cervical       | Severe         | 3 m      | ≤50 mm None                   |           | Wallstent       |              |            |
| 30      | 69, M Stroke   | R No             | B              | Blunt                         | Undetermined   | Severe         | 1 m      | ≤50 mm None                   |           | Failed          |              |            |

CICAO: chronic internal carotid artery occlusion; EZ: Neuroform EZ Stent System; F: female; GIB: gastrointestinal tract bleeding; L: left; M: male; m: month; R: right; TIA: transient ischemic attack; yrs: years.
150 min). Of the 20 successful patients, 14 were at the cervical ICAs, and six were at the intracranial ICAs. Two of the 20 patients were patent only using PTA without stenting. The occlusions were located on the left and right sides in nine and 21 patients, respectively. Reversed ophthalmic artery flow was observed in 15 of the 20 successful patients, and four of the 10 failed patients. Tapered stumps with stump angles \(<45^\circ\) were observed in 12 of the 20 successful patients and three of the 10 failed patients. The occlusion length was categorized by a cutoff of 50 mm. An occlusion length of \(\leq 50\) mm was seen in 13 of the 20 successful patients. There were six, four, seven, and zero cases with mild stenosis (\(<50\%\)), moderate stenosis (50–70%), severe stenosis (\(\geq 70\%\)), and significant occlusion contralaterally, respectively. In three of the 10 failed cases, micro-guidewires failed to enter the distal true lumen after repeated attempts. In one of the 10 failed cases, the procedure was terminated because of hyperperfusion syndrome (headache and vomiting), although the microcatheter may have crossed the occluded segment. Guidewires failed to cross the origin of the occluded ICA in the remaining six failed cases.

The 10 unsuccessful patients were administered aspirin 100 mg and clopidogrel 75 mg or cilostazol 200 mg combined with the introduction of statins (atorvastatin calcium tablets; rosvastatin) daily for 90 days.

**Major complications**

The most common complications related to the procedure were cerebral hyperperfusion syndrome and embolism of the MCA or anterior cerebral artery branch. Cerebral hyperperfusion syndrome without intracranial hemorrhage was observed in one patient with cervico-petrous occlusion and one patient with cervical occlusion. The syndrome also occurred in one failed patient because the microcatheter may have crossed the occluded segment. We terminated the procedure due to the risk of fatal complications. New neurologic deficits did not occur in any of the patients. However, asymptomatic ischemic lesions occurred in two of the 20 successful patients. Another patient suffered from a small subarachnoid hemorrhage related to micro-guidewire extravasation during the exchange of the microcatheter. Angiography was immediately performed, but the extravasation of contrast medium was not observed in the neck. Two patients had gastrointestinal tract bleeding. Dissection was observed in one of the 20 successful patients and three of the failed patients. Once the dissection occurred during the procedure, a 300 cm exchange micro-guidewire (0.014 in Transend EX, Boston Scientific) was placed in the true lumen, and a self-expandable stent was deployed to fix the dissection. Hypoperfusion syndrome did not occur in any of the patients.

**Follow-up results**

We followed up the patients for a mean duration of 18.3 months (range, 12–24 months). Ischemic symptoms related to the ICAO did not occur during the follow-up period in all 20 patients who underwent successful revascularization.
Cerebral hemodynamics were measured with brain CTP to demonstrate the improvement in ipsilateral CBF 6 months after the revascularization. Cerebral hemodynamics of the nine successful patients who underwent brain CTP were normalized on postoperative CTP. All 20 recanalized patients were patent on CTA or carotid duplex sonography, and no cases with restenosis >50% were observed. Three of the 10 patients with failed recanalization suffered from a stroke during the follow-up period.

**Case reports**

Case 6: A 62-year-old man with TIA underwent successful recanalization for symptomatic CICAO 1 month after diagnosis (Figure 1).

Case 14: A 73-year-old man with stroke underwent successful recanalization for symptomatic CICAO 2 weeks after diagnosis (Figure 2).

**Discussion**

Symptomatic CICAO with hemodynamic impairment is associated with annual recurrent rates of 6–20%, despite intensive medical therapies. For some patients with moyamoya disease, extracranial-intracranial bypass surgery may improve the blood flow of the related brain territory and reduce the recurrence rate of ischemic events, but its efficacy and safety are still controversial. The COSS study, was a multicenter, prospective, randomized controlled study that aimed to verify whether EC-IC bypass was superior to the best drug treatment for symptomatic CICAO patients with severe hemodynamic disorders. They concluded that the EC-IC bypass was not superior to the best drug treatment. The detailed results of another EC-IC bypass study (JET) have not yet been published, so we cannot draw a clear conclusion from this study. Volovici et al. introduced an encephalo-duro-galeo-synangiosis technique to facilitate extracranial-to-intracranial collateralization. For most patients with CICAO, the intracranial segments of the ICA and MCA are patent. If the occluded ICA is recanalized, the intracranial blood supply can be effectively improved. EC-IC bypass may be appropriate for patients with CICAO combined with MCA occlusion or unsuccessfully recanalized patients. Recently, Jiang et al. reported that a hybrid operation significantly improves the technical success and is associated with low related complications and favorable outcomes. However, further studies with a larger sample size and more conditions are needed. With the development of nerve interventional materials and techniques, endovascular interventional recanalization has become a hot topic in the treatment of CICAO. Kao et al. reported that the endovascular recanalization of symptomatic chronic ICAO was technically feasible, with a success rate of 73%. Terada et al. reported that endovascular recanalization of symptomatic chronic ICAO was successful in 14 of 15 patients. Cagnazzo et al. discussed the technical details and feasibility of the endovascular revascularization technique for long-type chronic ICA occlusion, but the protection device was not mentioned in the article.
A 62-year-old male with TIA underwent successful recanalization for a symptomatic chronic internal carotid artery occlusion 1 month after diagnosis: (a) the mean time to peak of the left hemisphere was prolonged on preoperative computed tomographic perfusion, (b) left chronic internal carotid artery (ICA) occlusion was confirmed by preprocedural catheter angiography, with a tapered stump, (c) collateral circulation via the ophthalmic artery, the reconstruction level of the distal ICA blood flow was the petrous part, (d) collateral circulation via the posterior communicating artery, (e) the balloons of the proximal balloon protection device (Mo.Ma) located at the origin of the external carotid artery (ECA) and common carotid artery (CCA) were filled to block the blood flow completely, (f) after the first pre-expansion, 50–60 mL of blood was aspirated from the catheter of the proximal balloon protection device placed in the CCA and ECA. Catheter angiography was done to measure the residual stenosis and patency of the recanalized internal artery, (g) after the first pre-expansion, several larger percutaneous transluminal angiography balloon catheters were used to expand the narrow segment, (h and i) a self-expanding stent (Wallstent, Boston Scientific) was deployed at the narrow portion. The residual stenosis was <50%, (j) the thrombolysis in cerebral infarction score was grade three on catheter angiography at the end of the procedure, (k) intimal hyperplasia in the stent was observed at 1 year of follow-up, and (l) the left ICA was patent on computed tomographic angiography at 1 year of follow-up.
Figure 2. A 73-year-old male with stroke underwent successful recanalization for a symptomatic chronic internal carotid artery occlusion 2 weeks after diagnosis: (a) right internal carotid artery occlusion was confirmed by preprocedural catheter angiography, with a little blunt stump, (b) collateral circulation via the ophthalmic artery, (c) the reconstruction level of the distal ICA blood flow was the petrous part, (d) the balloons of the proximal balloon protection device (Mo.Ma) located at the origin of the external carotid artery (ECA) and common carotid artery (CCA) were filled to block the blood flow completely, (e) after the first pre-expansion, catheter angiography was done to measure the residual stenosis and patency of the recanalized internal carotid artery (ICA), (f) after the first pre-expansion, several larger PTA balloon catheters were used to expand the narrow segment, (g) a self-expanding stent (Wallstent, Boston Scientific) was placed at the narrow portion, (h) the thrombolysis in cerebral infarction score was grade three on catheter angiography at the end of the procedure, (i) the right ICA was patent on catheter angiography at 1 year of follow-up. The residual stenosis was <30%, and (j) the mean time to peak of the right hemisphere was prolonged on preoperative computed tomographic perfusion (CTP) and normalized on postoperative CTP (K).
After successful recanalization, cerebral perfusion can be maintained, and cognitive function can be improved to a greater extent than with medical treatment.\textsuperscript{23–25} Endovascular recanalization for symptomatic chronic ICAO may offer similar reperfusion benefits with less hemodynamic fluctuation. However, endovascular recanalization of CICAO is technically challenging, and serious complications are fatal. All patients should be evaluated carefully before this procedure. The occlusion length is not clear before the procedure, which increases its difficulty. A systematic preprocedural evaluation helps identify patients.\textsuperscript{11}

Due to the presence of thrombi in the lumen, preventing embolization is crucial during any recanalization procedure.\textsuperscript{26} Distal filter protection devices are difficult to use in patients without sufficient space of the distal true lumen. Generally, proximal balloon protection devices are preferred in the procedure, which have been described in literature by several authors. Shojima et al.\textsuperscript{26} reported endovascular revascularization of chronic and subacute total occlusion of ICA was successful in seven of eight patients (88%), but asymptomatic ischemic events occurred in six of eight patients (75%). The CCA was occluded with a 9 or 10.5 Fr occlusion balloon catheter, and the proximal portion of the ECA was occluded with various types of single-lumen balloon catheters in several articles. The proximal balloon protection device (Mo.Ma, Invatec Italia S.r.l.) used in our study is different from that. The blood flow from the ECA and its branches must be completely blocked, so as to prevent the reverse flow of blood to the internal carotid artery. Lee et al.\textsuperscript{27} confirmed that proximal balloon protection devices are more effective than distal filter protection devices in reducing the drop of microemboli during carotid artery stenting. They compared the number of patients with new cerebral infarction before and after stent implantation using a proximal balloon protection device and distal filter protection device through MRI-DWI. Stabile et al.\textsuperscript{28} found that proximal balloon protection devices can reduce the incidence of new cerebral infarction more effectively than distal filter protection devices. A meta-analysis and review recently reported that proximal balloon protection devices could provide similar protection levels from ischemic stroke as distal filter protection devices in patients undergoing carotid artery stenting.\textsuperscript{12} Without sufficient space of the distal true lumen, a proximal balloon protection device was a better choice for endovascular recanalization. The advantages are as follows: (1) the proximal balloon can completely block the blood flow to prevent embolic migration when the micro-guidewire and microcatheter pass the occluded ICA. Even if there are a large number of emboli in the blood vessel, it can be removed by repeated aspiration; (2) it uses a low-pressure compliance balloon to avoid the risk of arterial spasm and endangium injury; (3) it can be used as a guiding catheter; and (4) there is no danger of recovery difficulties. The drawbacks are as follows: (1) only the femoral artery approach can be selected; (2) ECA or CCA lesions are not applicable; and (3) some branches of the ECA may not be completely blocked, but there is still forward blood flow.

We encountered some technical challenges in performing endovascular interventional recanalization in the current study. It is difficult to cross the origin of the occluded ICA in the procedure, and using the micro-guidewire and microcatheter
to successfully cross the origin is key. If there is an obvious stump at the origin of the occluded ICA, the guiding catheter can be placed in it. The micro-guidewire can be rotated carefully along with the microcatheter. The occluded segment was carefully passed until the catheter’s distal site was confirmed in the true lumen. Guidewires may be hindered by severe calcification of the occluded segment. Calcification has been recognized as a negative predictor of success in endovascular interventional recanalization of chronic coronary occlusions. Reversed ophthalmic artery flow provides a clear path for passing the guidewires and reveals patency from the ophthalmic artery (OA) segment to the terminal ICA bifurcation. The length of occlusion affects the success rate of endovascular recanalization in chronic complete coronary artery occlusion. In theory, a shorter occlusion also predicts a higher success rate because guidewires crossing a short occlusion are relatively easy. The longer the occlusion, the more unpredictable the factors. Chen et al. reported no neurological events, non-tapered stump, distal ICA reconstitution via contralateral injection, and distal ICA reconstitution at communicating or ophthalmic segments as adverse predictors of successful endovascular recanalization. The identification of the occlusion site is important. It is difficult to define an accurate occlusion site using only angiography after complete ICA occlusion. As shown in our cases, the occlusion sites were 14 cervical ICAs and six intracranial ICAs in successfully recanalized patients. Guidewires failed to cross the origin of the occluded ICA in six of the 10 failed patients. The procedure was terminated in the other four failed patients due to partial crossing of the occlusion.

The main complications related to the procedure include perforation of blood vessels, rupture of blood vessels, intracranial hemorrhage, subarachnoid hemorrhage, intracranial hyperperfusion, pseudoaneurysm, carotid-cavernous fistula, gastrointestinal tract bleeding, and ischemic stroke. Kao et al. reported that the complication rate of endovascular recanalization for symptomatic cervical CICA0 is relatively low. The incidence of vascular perforation and rupture is relatively low. Once extravasation of contrast medium is observed in the neck, balloons are filled to temporarily block the blood flow near the ICA’s ruptured site and play a hemostatic role. Decompressive craniectomy is feasible for treating severe intracranial hemorrhage. Generally, subarachnoid hemorrhage can be naturally absorbed. During the perioperative period, once intracranial hyperperfusion occurs, blood pressure should be strictly controlled, and dehydration should be used to reduce the intracranial pressure. Pseudoaneurysms and carotid-cavernous fistulas can be repaired using stents. Gastrointestinal hemorrhage is mostly related to antithrombotic therapy, gastrointestinal diseases, and stress, and antithrombotic drugs should be discontinued in time. The risk of ischemic stroke is low because of the use of the proximal balloon protection device. However, asymptomatic ischemic lesions occurred in two of the 20 successful patients, which might have been caused by a forceful injection of the contrast agent or small emboli. Ischemic stroke is mostly related to hemodynamic fluctuations and embolus shedding. Most of these cases are asymptomatic ischemic stroke, which was confirmed by DWI.
Endovascular interventional recanalization is technically feasible for patients with CICAO after strict screening. The success rate and incidence of complications are acceptable.\textsuperscript{30} The procedure requires standardized management, including preoperative assessment, perioperative medication, surgical strategy, postoperative monitoring, and follow-up. According to the preoperative vascular assessment results, various interventional techniques should be considered during the procedure, and the procedure should be terminated when repeated attempts fail, or patients have serious adverse reactions. With the development of interventional materials and the advancement of interventional technology, more patients may benefit in the future.

There are several limitations to our study. The number of cases is relatively small, the potential complications might be underestimated, and the technical success rate might be overestimated. In addition, the beneficial effects of the procedure against ischemic stroke and cognitive deterioration were not proven by our study due to the small number of cases. We did not make a sample size calculation before we started, and the number of cases will be expanded in following studies. The procedure was terminated in several failed patients as we were concerned about fatal complications. A hybrid operation with the combination of carotid endarterectomy (CEA) and endovascular therapy may be a better choice for failed patients. High-resolution MRI was not used in this study. Functional imaging may provide several clues for identifying patients, as the morphology of the ICA at the occluded segment can be analyzed through functional imaging.\textsuperscript{31} Future studies should seek to understand which patients may be more suited to endovascular interventional recanalization. Our study was not a randomized controlled trial, and comparisons were not made with bypass surgery or hybrid operations. Therefore, prospective randomized controlled trials based on functional imaging are needed to verify our findings.

**Conclusion**

The recanalization of the CICAO was successful in 20 of 30 patients (66.7\%). No permanent complications occurred in our study. Ischemic symptoms related to ICAO did not occur during the follow-up period in all 20 patients who underwent successful revascularization. Three of the 10 patients with failed recanalization suffered from a stroke during the follow-up period. Endovascular revascularization of symptomatic CICAO using a proximal balloon protection device is technically feasible in selected patients, and the outcomes are favorable for patients who benefit from revascularization.

**Acknowledgments**

The authors would like to thank all their colleagues who assisted them with this study.
Declaration of conflicting interests
The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding
The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was funded by the Science and Technology Development Program of Suzhou in 2018 (sys2018061).

Ethics approval
Ethical approval for this study was obtained from the Ethics Committee of the Second Affiliated Hospital of Soochow University (APPROVAL NUMBER: JD-LX-2018-022).

Informed consent
Written informed consent was obtained from all subjects or their legally authorized representatives before the study.

ORCID iD
Huaping Du https://orcid.org/0000-0002-4056-1385

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Author biographies

Guojie Zhai was born in 1981. He received a bachelor of Clinical Medicine degree from Soochow University, Suzhou, China, in 2009. He is currently pursuing the Ph.D degree at the Second Affiliated Hospital of Soochow University.

Zhichao Huang received a bachelor of Clinical Medicine degree from Soochow University, Suzhou, China, in 2012. He is currently pursuing the Ph.D degree at the Second Affiliated Hospital of Soochow University.

Huaping Du received master degree from Soochow University in 2012. His current research interests include stroke.

Yuan Xu received PhD degree from Soochow University in 2015. He is a professor at the Affiliated Wujiang Hospital of Nantong University, Suzhou, China. His current research interests include cerebral vascular disease and epilepsy.

Guodong Xiao received PhD degree from Soochow University in 2014. He is a professor at the Second Affiliated Hospital of Soochow University, Suzhou, China. His current research interests include cerebral vascular disease and interventional neurology.

Yongjun Cao is a professor at the the Second Affiliated Hospital of Soochow University, Suzhou, China. His current research interests include organisational management of stroke, clinical study of cerebral vascular disease(rt-PA thromblysis, endovascular therapy, neuro-image etc.), cerebral ischemia reperfusion injury, and molecular mechanism of cerebral atherosclerosis.