Intraoperative Computed Tomography (CT) for Treating Giant Carotid Intracavernous Aneurysms

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

ACE **Zhe Xue**
AG **Fuyu Wang**
BCE **Zhenghui Sun**
BD **Hui Zhang**
BD **Chen Wu**
CEF **Dongsheng Kong**
BDF **Bainan Xu**

Department of Neurosurgery, General Hospital of PLA, Beijing, P.R. China

Corresponding Authors: Bainan Xu, e-mail: BainanXuzxc@163.com, Zhenghui Sun, e-mail: ZhenghuiSunzxc@163.com
Source of support: Departmental sources

Background: Giant carotid intracavernous aneurysm refers to those lesions larger than 2.5 cm and derived from a cavernous segment, accounting for about 30% of all intracranial tumors. Dynamic CT perfusion imaging (PCT) is a common method recently employed to evaluate cerebral perfusion. This study investigated the efficacy and clinical application of intraoperative CT in the surgery for giant symptomatic carotid intracavernous aneurysm.

Material/Methods: A retrospective analysis was performed on 23 cases with giant symptomatic carotid intracavernous aneurysm. BTO testing was performed before surgery. Differential treatments were performed based on the condition of aneurysm, and some patients received intraoperative PCT. Postoperative anti-coagulation was given with DSA or CTA follow-up examinations at 3–6 months, 1 year, and 2 years after surgery.

Results: A total of 17 patients received aneurysm isolation coupled with high-flow bypass surgery. Among those, 9 developed early-onset neurological function after surgery, with gradual recover within 6 months. One coma patient died 25 months after discharge. One patient had aneurysm isolation with clapping of anterior communicating artery, and the other 5 cases received artery clapping only. In those patients, 4 had improvement at early phase, while 1 patient had numbness of the oculomotor nerve. Six patients received surgery in the CT room, including 5 cases with single proximal ligation of the internal carotid artery plus 1 aneurysm isolation combined with high-flow bypass surgery.

Conclusions: Intraoperative PCT can provide objective evidence and effective evaluation of cerebral perfusion.

MeSH Keywords: Acidosis, Renal Tubular • Aneurysm • Cavernous Sinus • Gastric Bypass • Intracranial Aneurysm

Full-text PDF: http://www.medscimonit.com/abstract/index/idArt/902225

📄 3178   ▦ 1   📊 4   📖 28

Background

Giant carotid intracavernous aneurysm refers to those lesions larger than 2.5 cm, which are derived from the cavernous segment. They account for about 30% of all giant intracranial tumors [1], with more female patients [2]. Clinically, it is manifested as headache and compression of cranial nerve III to VI, with less subarachnoid hemorrhage. Current curative indication mainly includes symptomatic aneurysm, and regular follow-ups are required for asymptomatic lesions until manifestation [2–4]. Giant symptomatic internal carotid intracavernous aneurysm can be treated by proximal blockade [5], vascular bypass conjunction with proximal blockade or aneurysm isolation [6,7], direct surgical clapping [8], or interventional therapy [9–11]. Due to the wide neck and huge volume of these aneurysms, and the protection of the cranial nerve inside the cavernous area, direct clapping is very difficult and not suitable for all patients. For giant or large intracavernous aneurysms, intervention and embolization have unsatisfactory efficacy [12]. Single proximal blockade can benefit patients and vascular bypass in conjunction with proximal blockade or aneurysm isolation is also a common treatment strategy. In recent years, flow-diverting stents (FDSs) have been developed and especially designed to reduce the flow velocity vortex within the aneurysm and can improve the laminar flow in the main artery and surrounding branches [13]. Computation hemodynamics suggests that a stent with an overall porosity of 50% to 70% (30–50% metallic coverage) will significantly reduce the inflow rate into an aneurysm [14]. In theory, FDSs could treat aneurysms no regardless of location and could be deployed covering collateral vessels that are not occluded. Initial clinical experiences with the use of FDSs in the treatment of visceral and peripheral aneurysms have yielded satisfactory results in technical success, aneurysm thrombosis and shrinkage, and branch vessel patency. Better results are achieved 12 months after the procedure rather than at 6 months in aortic aneurysms. Importantly, there have been no aneurysm ruptures reported after treatment with an FDS [13].

It is critical to evaluate the compensation of lateral circulation, regardless of the treatment strategy. Balloon test occlusion (BTO) is a safe and effective way to evaluate cerebral resistance after tumor-bearing artery blockade [15]. The combination of BTO assay with semi-quantitative/quantitative evaluation for focal cerebral blood flow, such as SPECT [16-18], xenon CT [19, 20], and PET scan [21], can further lower the false-negative rate. Dynamic CT perfusion imaging (PCT) is a common method recently used to evaluate cerebral perfusion. The direct application of PCT in surgery can provide objective evidence of cerebral blood perfusion, and can work as an effective monitoring approach [22]. Our group has used PCT in aneurysm surgery.

Material and Methods

General information

We recruited a total of 23 patients with giant symptomatic carotid intracavernous aneurysm in the General Hospital of the PLA from February 2007 to March 2013, including 3 males and 20 females, ages 24–68 years (average age=54.7 years). Major manifestations of aneurysm included headache and compression of cranial nerves, including 6 cases with optical nerve affected, 12 cases with oculomotor nerve, 4 cases with trigeminal nerve, and 1 patient with abducent nerve injury. There were 8, 1, and 1 patients having headache, dizziness, and vertigo, respectively. All patients had confirmed diagnosis by DSA, showing 12 and 11 lesions at left and right hemisphere, respectively. Diameters of all lesions were larger than 2.5 cm. This study was approved by the Medical Ethics Committee of General Hospital of PLA. Informed consents were obtained from all patients prior to the study.

Pre-operative evaluation

BTO assay was performed 30 min before surgery to observe compensation of anterior/posterior circulation, coupled with neurological function evaluation. If compensation showed no symptom, blood pressure was further lowered by 20% to observe the existence of neurological dysfunction.

Aneurysm isolation coupled with high-flow bypass

Surgical indications included those with unsatisfactory compensation before surgery or those with neurological dysfunction. Using the great saphenous vein as the transplant vessel, external carotid and M2 segment of cerebral middle brain were ligated, followed by isolation of the aneurysm. During the surgery, microvascular Doppler was used to quantify blood flow velocity of recipient and implanted vessels. Neurological function was monitored by electrophysiology approach. Some patients further received ICG testing for measuring flow of transplanted vessels, while some patients were evaluated for perfusion via intraoperative PCT.

Aneurysm isolation or blockade of internal carotid artery starting point

Surgical indications included satisfactory compensation before surgery or with neurological symptoms. We performed 2–3 weeks of neck compression training before surgery with preparation for bypass surgery. The inner carotid artery was first exposed during the surgery, along with exposure of the external and common carotid arteries. The inner carotid artery was temporarily clamped for observing neurological-pathology conditions. Some patients underwent intraoperative

PCT for monitoring ischemia condition. The absence of ischemia manifestation indicated aneurysm isolation or proximal blockade; otherwise, the surgery was combined with bypass. After finishing isolation or proximal blockade operations, patients were awakened and underwent intubation for another 30-min observation to evaluate neurological function. No abnormality signalled the end of surgery; otherwise, combined bypass surgery was performed.

PCT imaging during surgery

Imaging was performed in the CT room during surgery. CT perfusion was first carried out before surgery. Re-scanning of perfusion and CTA examination were performed after temporary blockade. Areas of interests were the blood supply region from the cerebral middle artery and anterior artery closest to the basal ganglia layer. Cerebral blood flow (CBF), cerebral blood volume (CBV), and time to peak (TTP) were obtained from all areas of interests, along with relative perfusion indexes, including rCBV, rCBV, and rTTP. Perfusion indexes were compared between surgical and intact hemispheres, and relative perfusion indexes were compared before and after surgery.

Postoperative treatment and follow-ups

All patients received heparin as anti-coagulation treatment for 24 h, followed by oral ingestion of anti-platelet drugs. Bedside ultrasound was employed to test the flow of transplanted vessels. CT or MRI was used to observe the occurrence of thrombosis or hemorrhage. Before discharge, DSA or CTA was used for re-check. Patients were asked to return for re-examination by DSA or CTA at 3–6 month after discharge. Further follow-ups were performed at 1 year and 2 years. Patients who could not attend follow-ups in person were told by telephone to go to a nearby hospital for re-examination.

Results

Aneurysm isolation coupled with high-flow bypass surgery

A total of 17 patients (3 males and 14 females) presented improvements of symptoms early after surgery, including 1 case with oculomotor nerve affected, 1 patient with optic nerve dysfunction, and 1 patient with headache. Newly-formed neurological dysfunction after surgery included 1 optic nerve injury, 3 patients with oculomotor nerve injury, 1 headache, and 1 dazzle case, plus 1 transient aphasia, 1 patient having tracheotomy due to cough and fatigue (patient had choking before surgery, with bilateral spinal artery occlusion on DSA), and 1 coma patient due to occlusion of the transplanted artery (Table 1). All these cranial nerve symptoms gradually resolved by 2–6 month after surgery. The middle-to-long-term result showed

Table 1. Outcomes of patients after surgery.

Treatments	n
Aneurysm isolation coupled with high flow bypass surgery	**17**
Optic nerve injury	1
Oculomotor nerve injury	3
Headache	1
Dazzle	1
Transient aphasia	1
Tracheotomy	1
Coma	1
Aneurysm isolation or blockade of internal carotid artery starting point	**6**
Clapping of anterior communicating artery coupled with isolation of internal carotid artery aneurysm	1
Single blockade	5
Optic nerve injury	2
Oculomotor nerve	1
Headache	1

scores of 5 in GOS in 13 patients within 3 months to 6 years and at 3-month follow-up. The patient with tracheotomy had the tube removed 1 month later, followed by rehabilitation; this patient still required daily care at the time of follow-up. The coma patient received treatment in a local hospital and died 25 months later. Two patients were lost to follow-up.

Aneurysm isolation or blockade of internal carotid artery starting point

A total of 6 patients (all females) received such treatment. Among these, 1 patient had clapping of the anterior communicating artery coupled with isolation of the internal carotid artery aneurysm. This patient presented transient indifference, which was improved after elevating blood pressure and vasodilation. All 5 patients received single blockade, and symptom improvements were observed, including 2 cases with optic nerve injury, 1 case with oculomotor nerve affected, and 1 headache case (Table 1). Newly-formed neurological dysfunction occurred after surgery, including 1 patient with oculomotor nerve injury, which gradually recovered after 2 months, and 1 patient with headache improved by vasodilation. Long-term, all 6 patients had GOS scores of 5 within the follow-up period (9–15 months).
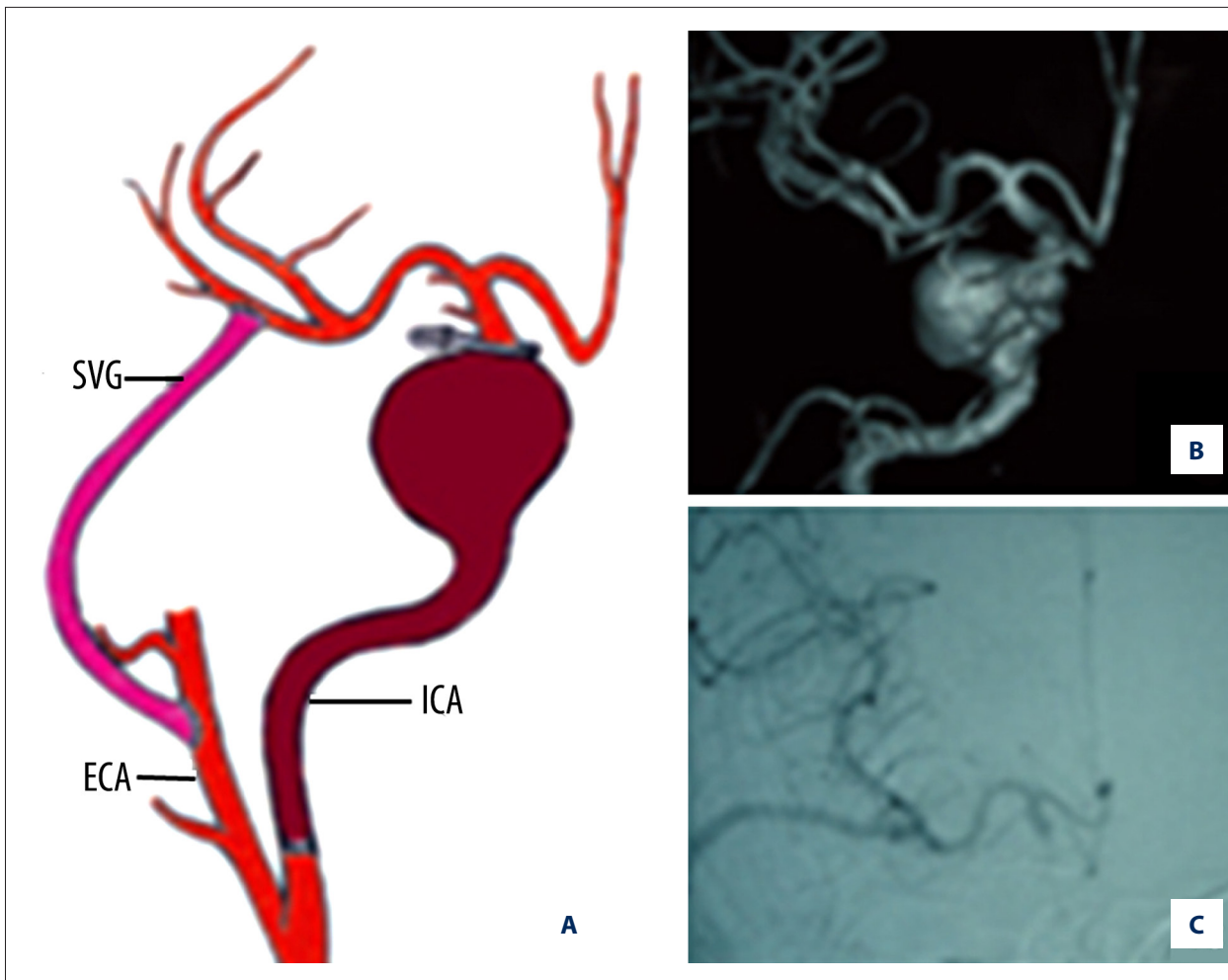
Figure 1. Report of patient A, with isolation of giant intracavernous aneurysm on right side plus high-flow bypass surgery. (**A**) Illustration of aneurysm isolation combined with high-flow bypass surgery. (**B**) DSA image of giant intracavernous aneurysm before surgery. (**C**) Postoperative DSA results showed no indication of aneurysm, good hemodynamics of transplanted vessel, and satisfactory images of right cerebral middle/anterior artery.

PCT imaging results

Six patients received PCT during the surgery. Among these, 5 had proximal ligation of the internal carotid artery, and 1 had aneurysm isolation coupled with high-flow vessel bypass surgery. One patient had an approximately 50% decrease in somatosensory-induced potential after temporary blockade of the proximal internal carotid artery, and PCT showed improved perfusion after surgery, indicating direct proximal blockade. One case showed a minor (less than 50%) decrease in somatosensory-induced potential after temporary blockade of the proximal internal carotid artery, and PCT showed no change in perfusion after surgery, indicating direct proximal blockade.

Report of typical cases

Case 1

Female, 65 years old, admitted as "Intermittent headache and double vision for 1 year". Physical exam showed blepharoptosis of the right upper eyelid. Head MRI indicated a round-shaped parasellar lesion on the right hemisphere, and DSA suggested a giant aneurysm in the cavernous segment of the right internal carotid artery. Isolation of the aneurysm combined with high-flow bypass surgery was performed. During the surgery, the internal carotid artery was exposed, along with external and common carotid arteries. A front temporal approach was used. Using the great saphenous vein as the transplant vessel, the external carotid and M2 segment of cerebral middle brain were ligated, followed by isolation of the aneurysm. After surgery, headache was improved, along with
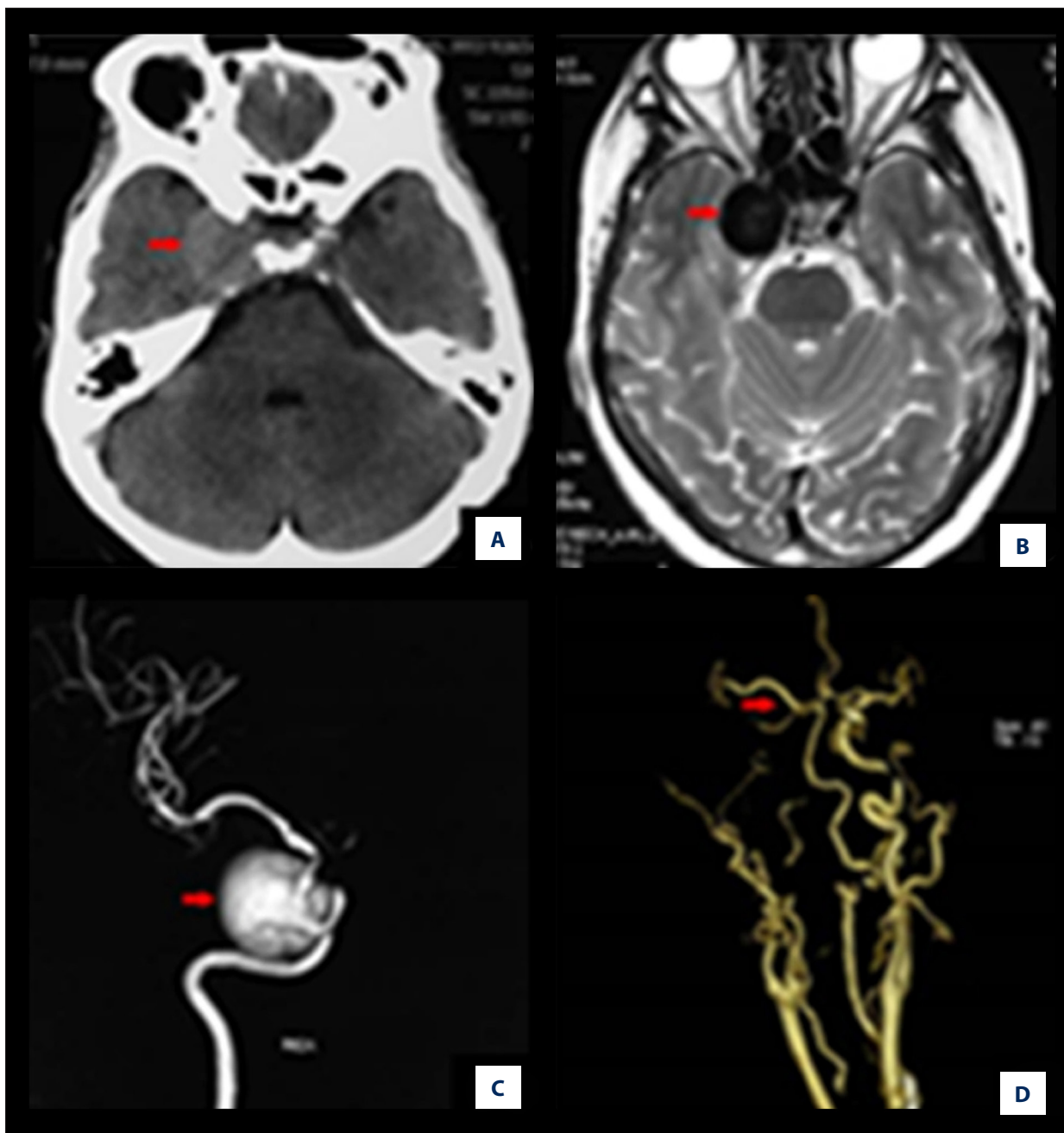
Figure 2. Patient B undergoing blockade at starting point of right giant intracavernous aneurysm of inner carotid artery. (**A**) Pre-operative head CT showed high-density round lesion on right parasellar region (red arrow). (**B**) Head CT showed round vacuoles at right parasellar region (red arrow). (**C**) Pre-operative DSA indicated giant aneurysm of intracavernous segment in inner carotid artery (red arrow). (**D**) After blocking of inner carotid artery initiating point, intraoperative CTA showed no imaging of distal end in inner carotid artery, while right cerebral middle artery (red arrow) and anterior artery had good imaging.

recovered numbness of the oculomotor nerve. No sign of aneurysm was found in postoperative DSA, indicating satisfactory hemodynamics of the transplanted vessel. Imagining of the right cerebral middle artery and anterior artery showed no abnormalities (Figure 1).

Case 2

Female, 63 years old, admitted as "Blepharoptosis of right upper eyelid for 3 months". Physical exam showed blepharoptosis of the right upper eyelid. Head CT and MRI indicated a round
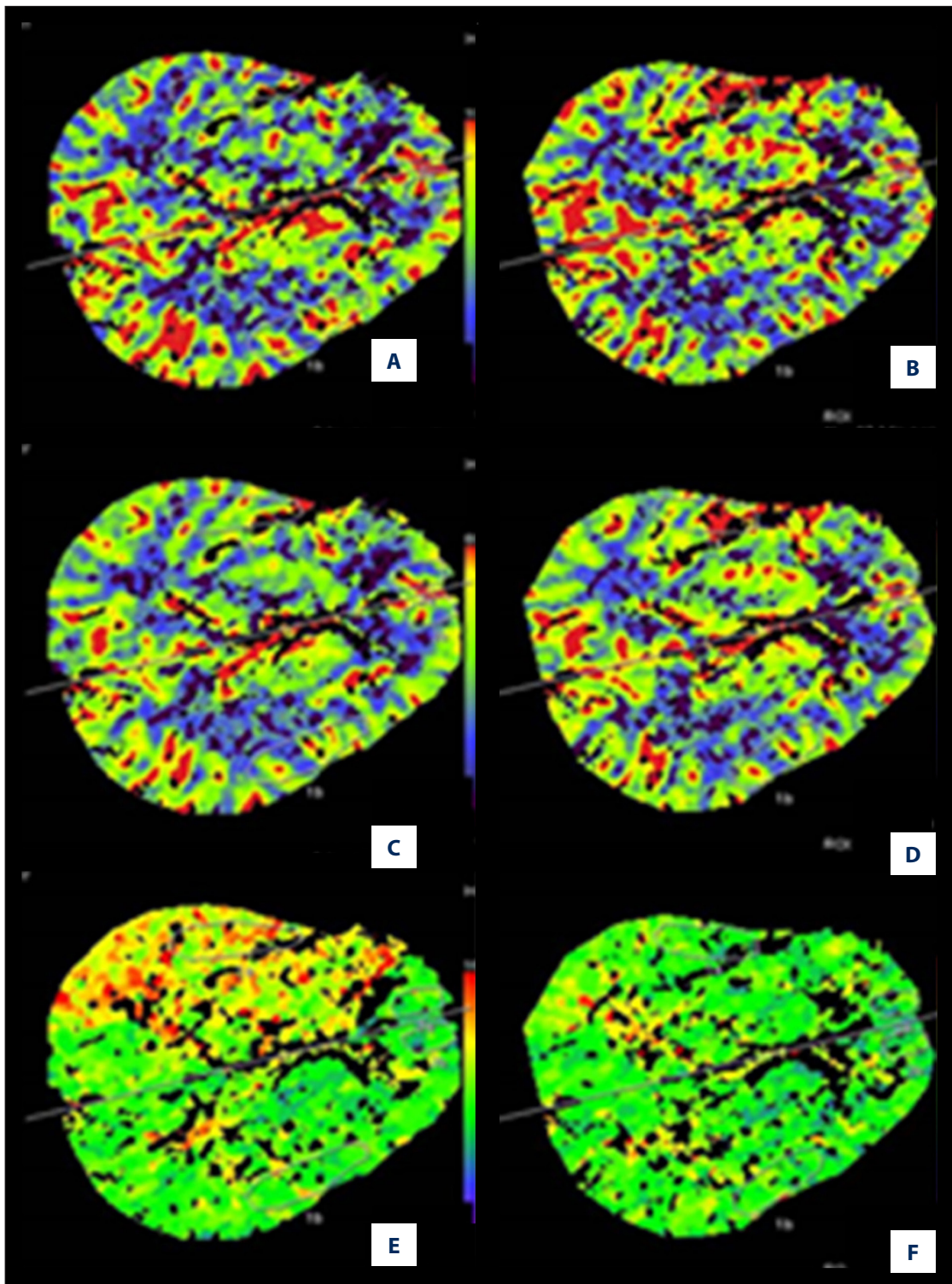
Figure 3. Pseudo-colored image of intraoperative PCT in patient B. (**A**) Lower rCBF value (0.81) of right temporal lobe before surgery. (**B**) Higher CBF value (1.41) in right temporal lobe during the surgery after temporal blockade of right inner carotid artery. (**C**) Similar rCBV value (1.01) between right and left temporal lobe before surgery. (**D**) Higher rCBV value (1.31) in right temporal lobe during the surgery after temporal blockade of right inner carotid artery. (**E**) Significantly elongated TTP in right temporal lobe compared to left hemisphere before surgery (rTTP value=1.39). (**F**) Similar TTP (rTTP=1.00) between right and left temporal lobe in surgery after temporal blockade of right inner carotid artery.
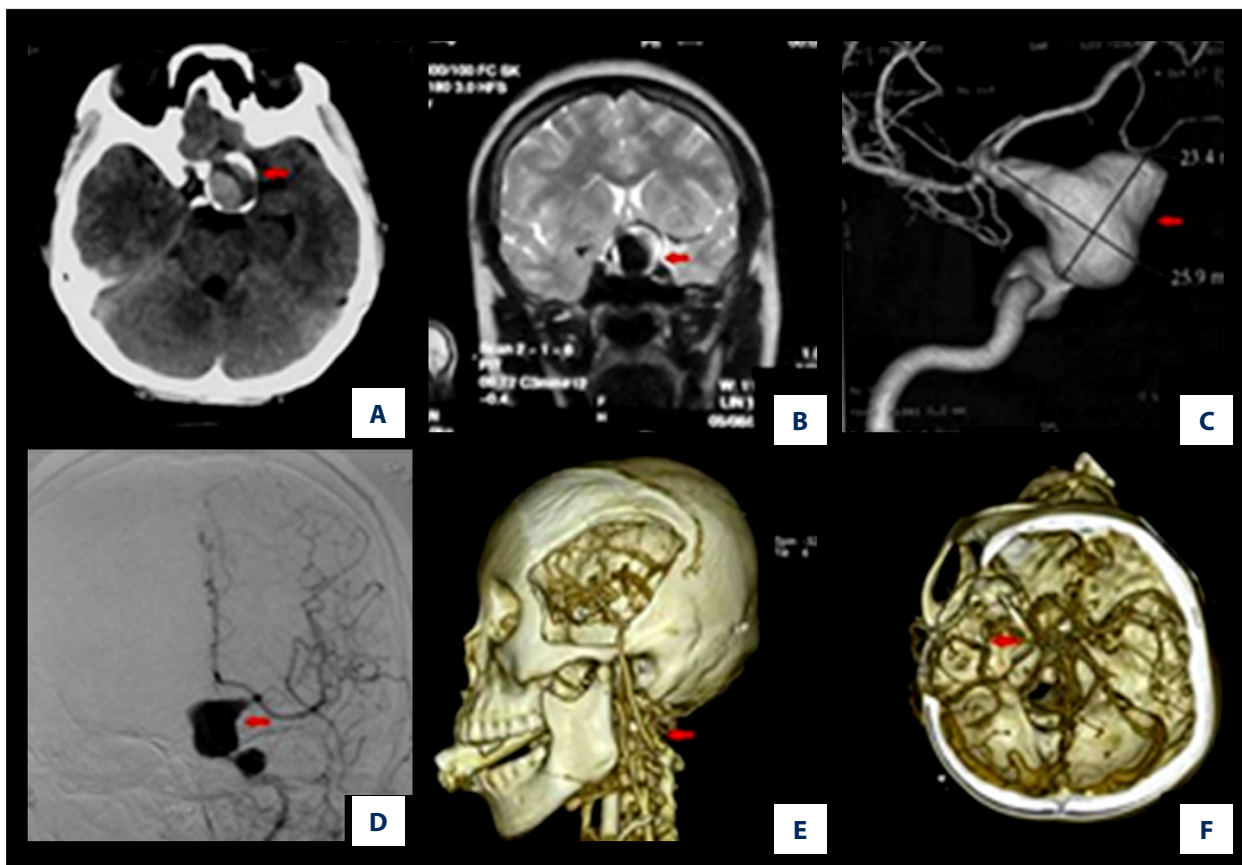
Figure 4. Isolation of left inner carotid artery intracavernous aneurysm coupled with high-flow vessel bypass surgery using giant saphenous vein. (**A**) Pre-operative head CT showed a round high-density region in the left parasellar area, accompanied with calcification (red arrow). (**B**) Head MRI indicated a round vacuole in the left parasellar region, accompanied with thrombosis formation (red arrow). (**C**) CTA indicated a giant aneurysm within the intracavernous segment of the left inner carotid artery (maximal diameter, 25.9 mm). (**D**) Pre-operative DSA indicated a giant aneurysm in the intracavernous segment of the left inner carotid artery. (**E**) Intraoperative CTA showed good hemodynamics of bridge vessels (read arrow), and no image at initiating point of left inner carotid artery. (**F**) Intraoperative CTA showed good imaging of left cerebral artery (red arrow) and anterior artery after bypass surgery.

parasellar lesion on the right hemisphere, and DSA suggested a giant aneurysm in the cavernous segment of the right internal carotid artery. After 1-week neck compression training, blockade of the right internal carotid artery was chosen for surgery. Pre-operative PCT indicated a large hypo-perfusion area in the right temporal lobe. After temporary blocking of the right internal carotid artery, intraoperative PCT indicated significantly improved right temporal perfusion. Intraoperative CTA showed no image of right inner carotid artery from the starting points, plus satisfactory imaging of right cerebral middle/anterior arteries. Blockade of the right inner carotid artery was thus performed. No postoperative complications occurred, and there was gradual recovery of oculomotor nerve numbness (Figures 2, 3).

Case 3

Female, 29 years old, admitted as "Blurred vision in left eye for 4 years, plus headache for 2 months". Physical exam showed normal right eye vision. Head CT and MRI indicated a round lesion in the left parasellar region, accompanied by calcification. CTA and DSA suggested a giant aneurysm of the intracavernous segment of the left inner carotid artery. Surgery was performed using isolation of the left inner carotid artery intracavernous aneurysm accompanied by high-flow bypass by the great saphenous vein. Pre-operative PCT showed worse perfusion in the left cerebral hemisphere. Intraoperative PCT suggested similar results. Re-examination after bypass surgery via CTA showed good hemodynamics in bridge vessels, and imaging of left cerebral middle/anterior artery revealed good recovery after surgery (Figure 4).

Discussion

Clinical symptoms of intracavernous aneurysm include headache or compression of cranial nerves, and most cases have benign history with few suffering subarachnoid hemorrhage [2,21]. Therefore, current indications of surgery mainly refer to large or giant symptomatic aneurysm [2–4]. In our department, the choice of aneurysm treatment was stipulated by the surgical team and intervention clinicians, in consideration of the patient's opinion and economic conditions, thus benefiting patient care via individualized treatment.

BTO assay can be used before treating intracavernous aneurysm of the carotid artery. This assay is an effective and safe method for evaluating ischemia resistance of a tumor-bearing artery after blockade [15]. Combined treatment with bypass surgery is required when BTO assay indicates unsatisfactory hemodynamic compensation or symptoms. Even in BTO-negative patients, there was a 5–20% chance of cerebral infarction after blocking the artery. Therefore, BTO results alone are not completely reliable [23]. Currently, multiple methods, including SPECT [14–16], xenon CT [19,20], PET [21], and TCD [24], can evaluate focal cerebral blood flow volume quantitatively or semi-quantitatively. The combination of BTO with these assays thus can improve accuracy of quantification of cerebral tissue ischemia, but requires multiple procedures [7,24]. In this study, we used depressurization assay with 15-min observation for neurological function evaluation and monitoring after depressing blood pressure by 20~30%. The combination with BOT can help to improve predicative value of the assay. In this study, all 17 patients had unsatisfactory blood flow compensation via pre-operative BTO assay, or had good compensation but with symptoms, or the presentation of symptoms after managing hypotension. After high-flow bypass surgery, most patients had certain levels of improvements.

In recent years, intraoperative PCT has been widely used to evaluate resistance to ischemia of brain tissues [22], with satisfactory effects. A total of 6 patients received perfusion PCT imaging after surgery. Among those, 2 patients had clear depression of somatosensory-induced potential after blockading the proximal inner carotid artery, and PCT showed no change in blood supply, leading to the direct blockade of proximal vessels. Therefore, intraoperative PCT is an effective approach.

Most common approaches for treating intracavernous aneurysm include proximal blockade or aneurysm isolation coupled with vascular bypass surgery. In this study, 17 patients received aneurysm isolation plus high-flow bypass surgery using the giant saphenous vein as the bridging vessel, which was further ligated onto the descending branch of the external carotid artery and cerebral middle artery. By this approach, no clapping of the inner carotid artery is required when clapping,

thus reducing the incidence of ischemia. During the preparation of the subcutaneous tunnel and skull window, it is necessary to keep transplanted vessels from being compressed. One patient developed cerebral ischemia and coma due to blockade of the transplanted vessel and died 2 years later, suggesting that transplanted vessel blockade is a major factor causing ischemic stroke after surgery. This is related to multiple factors, including the selection of transplanted vessels, matching of vessels, ligation technique, postoperative blood pressure management, and anti-coagulation and anti-platelet drugs. One patient had onset of dazzles and choking before surgery, as supported by blockade of the bilateral spinal artery. After surgery, this patient had worse coughing reflex and underwent tracheotomy. At 6-year follow-up, the patient was still in a wheelchair but has satisfactory results in general conditions, further indicating the importance of vascular condition before surgery for patient prognosis.

For those patients with satisfactory resistance for proximal blockade in BTO assay, isolation of the aneurysm or blockade of the proximal inner carotid artery might be effective and safe approaches. In all 6 patients with BTO resistance, surgery was performed after 2–3 weeks of continuous neck compression training. The preparation for bypass surgery was performed before surgery, in which temporally proximal blockade was first performed. One patient only received 30-min electrophysiological monitoring and the other 5 received simultaneous examinations including electrophysiology and intraoperative PCT, both of which had no abnormality. Proximal blockade was then performed. Two patients presented headache and dazzle after surgery, and were all discharged after treatment. Four patients showed improvement of symptoms. Blockade caused by thrombosis detachment is a common complication, with 5–10% incidence [25]. During this study, all 6 patients had no severe complication of thrombosis. Proximal clapping can be performed on either the common carotid artery or internal carotid artery. Some scholars believe that these 2 ischemia-related complications are different, while others disagree with this opinion. We chose blockade of the inner carotid artery, which is the tumor-bearing vessel. Therefore, direct blockade of the aneurysm accelerates the velocity of thrombosis formation and can improve symptoms. In this group, only 2 patients had headache or dazzle symptoms, and these were improved after treatment. Other scholars [5] utilized chronic clapping of carotid artery to treat intracavernous aneurysm, which, however, had relatively higher incidence of thrombosis, and incomplete blockade of aneurysm. The application of anti-coagulation and anti-platelet treatment can help to decrease the incidence of ischemic episodes. A previous report indicated potential decrease of thrombosis events by interventional blockade proximal to the tumor neck [6]. Other groups also found that proximal blockade of the inner carotid artery generates new aneurysms or enlarges original tumors [26]. This study,

however, did not find *de novo* aneurysm, indicating certain preventive effects by post-op management of blood pressure.

In addition to blockade of the proximal inner carotid artery in the treatment of aneurysm, flow-diverting stents (FDSs) are a new alternative treatment approach for aneurysms that takes into account their unique characteristics. The largest published experience to date comes from use of FDSs in visceral aneurysms, and the results are very encouraging, with a significant incidence of aneurysm thrombosis and shrinkage during follow-up and without any branch vessel occlusion. In terms of peripheral aneurysms, FDSs have been widely used in the treatment of iliac, popliteal, and subclavian aneurysms. In these anatomic areas, significant collateral branches have to be preserved, including the internal iliac artery, the genicular arteries, and the vertebral arteries, respectively [13].

This study has certain limitations. Firstly, it has a relatively smaller sample size and short follow-up periods, in which loss to follow-up gradually increased. The outcome of long-term follow-up has been found to be important for the choice between proximal ligation and aneurysm isolation combined with bypass procedure [27]. Based on previous studies, the incidence of ischemia episodes is lower in the short term, but needs further long-term evaluation in the future. Secondly, the method for evaluating hemodynamic compensation needs to be elaborated, due to the occurrence of ischemia complications even after the surgical optimization based on pre-operative evaluation [28]. In early-phase cases, we preferred the aneurysm isolation combined with bypass procedure, which is mature technique with fewer complications. However, the

use of bypass surgery in all cases is just based on safeguarding the blood supply, because some patients actually had satisfactory long-term outcomes without bypass. Therefore, the treatment strategy needs to be refined based on evaluation before and during surgery. Patients still need to be prepared for bypass surgery at the time of proximal ligation. However, new symptoms may develop after surgery, and long-term follow-up data are needed to evaluate the efficacy of proximal ligation. Intraoperative electrophysiology monitoring also has certain limitations, as it cannot reflect the consistency between clapping of aneurysm/adjacent vessels and cerebral perfusion, in addition to false-positive and false-negative results, which can be affected by anesthesia, electrical devices, and surgical operation, although intraoperative PCT combined with CTA provides more information. Factors during the surgery should be carefully controlled, including blood pressure, consistency between pre- and intraoperative scanning, dosage of imaging reagent, and radiation dosage. Moreover, large-cohort clinical studies are required to comprehensively analyze results of electrophysiology monitoring and PCT imaging.

Conclusions

The use of PCT during surgery can provide objective and timely evidence for cerebral blood perfusion and is an effective monitoring method.

Disclosure of conflict of interest

None.

References:

1. Dengler J, Maldaner N, Bijlenga P et al: Quantifying unruptured giant intracranial aneurysms by measuring diameter and volume – a comparative analysis of 69 cases. Acta Neurochir (Wien), 2015; 157: 361–68; discussion 368

2. Stiebel-Kalish H, Kalish Y, Bar-On RH et al: Presentation, natural history, and management of carotid cavernous aneurysms. Neurosurgery, 2005; 57: 850–57; discussion 857

3. Eddleman CS, Hurley MC, Bendok BR, Batjer HH: Cavernous carotid aneurysms: to treat or not to treat? Neurosurg Focus, 2009; 26: E4

4. ter Brugge KG: Cavernous sinus segment internal carotid artery aneurysms: Whether and how to treat. Am J Neuroradiol, 2012; 33: 327–28

5. Niiro M, Shimozuru T, Nakamura K et al: Long-term follow-up study of patients with cavernous sinus aneurysm treated by proximal occlusion. Neurol Med Chir (Tokyo), 2000; 40: 88–96; discussion 97

6. Field M, Jungreis CA, Chengelis NL et al: Symptomatic cavernous sinus aneurysms: Management and outcome after carotid occlusion and selective cerebral revascularization. Am J Neuroradiol, 2003; 24: 1200–7

7. Tacconi L: Extracranial-intracranial bypass for the treatment of cavernous sinus aneurysms. J Clin Neurosci, 2006; 13: 1001–5

8. Dolenc V: Direct microsurgical repair of intracavernous vascular lesions. J Neurosurg, 2009; 58: 824–31

9. van Rooij WJ: Endovascular treatment of cavernous sinus aneurysms. Am J Neuroradiol, 2012; 33: 323–26

10. Starke RM, Chalouhi N, Ali MS et al: Endovascular treatment of carotid cavernous aneurysms: Complications, outcomes and comparison of interventional strategies. J Clin Neurosci, 2014; 21: 40–46

11. Puffer RC, Piano M, Lanzino G et al: Treatment of cavernous sinus aneurysms with flow diversion: Results in 44 patients. Am J Neuroradiol, 2014; 35: 948–51

12. Morita K, Sorimachi T, Ito Y et al: Intra-aneurysmal coil embolization for large or giant carotid artery aneurysms in the cavernous sinus. Neurol Med Chir (Tokyo), 2011; 51: 762–66

13. Sfyroeras GS, Dalainas I, Giannakopoulos TG et al: Flow-diverting stents for the treatment of arterial aneurysms. J Vasc Surg, 2012; 56: 839–46

14. Liou TM, Li YC: Effects of stent porosity on hemodynamics in a sidewall aneurysm model. J Biomech, 2008; 41: 1174–83

15. Lesley WS, Rangaswamy R: Balloon test occlusion and endosurgical parent artery sacrifice for the evaluation and management of complex intracranial aneurysmal disease. J Neurointerv Surg, 2009; 1: 112–20

16. Sugawara Y, Kikuchi T, Ueda T et al: Usefulness of brain SPECT to evaluate brain tolerance and hemodynamic changes during temporary balloon occlusion test and after permanent carotid occlusion. J Nucl Med, 2002; 43: 1616–23

17. Tomura N, Omachi K, Takahashi S et al: Comparison of technetium Tc 99m hexamethylpropyleneamine oxime single-photon emission tomograph with stump pressure during the balloon occlusion test of the internal carotid artery. Am J Neuroradiol, 2005; 26: 1937–42

18. Shimizu H, Matsumoto Y, Tominaga T: Parent artery occlusion with bypass surgery for the treatment of internal carotid artery aneurysms: Clinical and hemodynamic results. Clin Neurol Neurosurg, 2010; 112: 32–39

19. Gupta DK, Young WL, Hashimoto T et al: Characterization of the cerebral blood flow response to balloon deflation after temporary internal carotid artery test occlusion. J Neurosurg Anesthesiol, 2002; 14(2): 123–29

20. Marshall RS, Young WL, Solomon RA et al: Clinical utility of quantitative cerebral blood flow measurements during internal carotid artery test occlusions. Neurosurgery, 2002; 50(5): 996–1004; discussion 1004–5

21. Brunberg JA, Horton JA, Deveikis JP et al: [15O]H2O positron emission tomography determination of cerebral blood flow during balloon test occlusion of the internal carotid artery. Am J Neuroradiol, 1994; 15: 725–32

22. Schichor C, Rachinger W, Zausinger S et al: Intraoperative computed tomography angiography with computed tomography perfusion imaging in vascular neurosurgery: Feasibility of a new concept. J Neurosurg, 2010; 112: 722–28

23. Linskey ME, Jungreis CA, Yonas H et al: Stroke risk after abrupt internal carotid artery sacrifice: Accuracy of preoperative assessment with balloon test occlusion and stable xenon-enhanced CT. Am J Neuroradiol, 1994; 15: 829–43

24. Bakke SJ, Sorteberg W. Angiographic balloon test occlusion and therapeutic sacrifice of major arteries to the brain. Neurosurgery, 2008; 63: 651–60

25. Hauck EF, Welch BG, White JA et al: Stent/coil treatment of very large and giant unruptured ophthalmic and cavernous aneurysms. Surg Neurol, 2009; 71(1): 19–24; discussion 24

26. Fujiwara S, Fujii K, Fukui M: *De novo* aneurysm formation and aneurysm growth following therapeutic carotid occlusion for intracranial internal carotid artery (ICA) aneurysms. Acta Neurochir (Wien), 1993; 120: 20–25

27. Date I, Ohmoto T: Long-term outcome of surgical treatment of intracavernous giant aneurysms. Neurol Med Chir (Tokyo), 1998; 38: 62–69

28. Souto AAD, Domingues F, Espinosa G et al: Complex paraclinoidal and giant cavernous aneurysms: importance of preoperative evaluation with temporary balloon occlusion test and SPECT. Arq Neuropsiquiatr, 2006; 64: 768–73