Surgical Atlas of Cerebral Revascularization

Ying Mao
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Preface

We aim to summarize the current surgical strategies for cerebral revascularization in the treatment of complex neurovascular diseases based on a single-center experience over the last 30 years. Complex intracranial (IC) aneurysms are mostly large/giant and irregular and do not have enough collateral compensation, so they are difficult to directly clip or embolize, leading to a high fatality rate of 68–85%. We have established the extracranial-intracranial (EC-IC) bypass strategy based on our clinical experience. For complex IC carotid artery aneurysms, the types of EC-IC bypass are determined based on preoperative hemodynamic evaluations. For complex middle cerebral artery (MCA) aneurysms, the types of EC-IC bypass are determined based on angioarchitecture. Furthermore, various IC-IC bypasses have been introduced into our surgical arsenal, with the advantages of not requiring graft vessel harvesting and preferable matching of donor and recipient arteries. The favorable outcome rate of complex IC aneurysm after cerebral revascularization remained ≥85–90%. In addition, the unique superficial temporal artery to MCA (STA-MCA) bypass (single or double) procedure combined with encephalo-duro-myo-synangiosis (EDMS) for Moyamoya disease has been successfully utilized in over 10,000 cases in our hospital. We believe that the cerebral revascularization technique is a basic and indispensable skill for neurosurgeons.

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Introduction

The treatment of giant aneurysms has always been a challenge in the field of neurovascular disease. Giant aneurysms are not only larger in size but are also associated with thrombosis development and calcification of the aneurysmal wall and neck, which often interfere with direct clipping. Most giant aneurysms have a wide neck with incomplete thrombus, making complete embolization almost impossible. Giant aneurysms at different sites have completely different hemodynamic characteristics. Moreover, aneurysms at the same site may exhibit very different hemodynamics among different individuals. Therefore, a careful assessment of each case is required before and during treatment to develop an individualized treatment plan.

Endovascular treatments and surgery are still the primary treatment approaches for giant aneurysms. The former includes occlusion of the parent artery, embolization of the aneurysm (including coiling and Onyx application), and stent- and balloon-assisted embolization of the aneurysm. Occlusion of the parent artery may completely occlude the aneurysm but can only be performed after careful assessment of cerebral hemodynamic and metabolic compensatory capacity. Stent- and balloon-assisted embolization techniques improve the success rate of complete aneurysmal neck embolization, but the elevated long-term recurrence rate of aneurysms is indisputable. Some patients may successfully undergo aneurysm trapping and reconstructive aneurysm clipping via craniotomy. However, in most patients, the hemodynamic and morphological features of the aneurysms make direct clipping impossible. Therefore, vascular reconstruction has become an indispensable and important approach in the treatment of giant intracranial aneurysms.

When treating giant internal carotid artery (ICA) aneurysms, the vascular reconstruction technique mainly refers to extracranial-intracranial bypass (EC-IC bypass), which includes high-flow (external carotid artery-radial artery-middle cerebral artery, ECA-RA-MCA, or external carotid artery-saphenous vein-middle cerebral artery, ECA-SV-MCA) and medium-flow (superficial temporal artery-radial artery-middle cerebral artery, STA-RA-MCA) bypass. Most researchers do not recommend the use of low-flow (STA-MCA) bypass. The preoperative hemodynamic assessment determines the selection of a bypass procedure with an appropriate flow rate. The assessment methods include the balloon occlusion test (BOT), the pressure drop test, single-photon emission computed tomography (SPECT), positron emission tomography (PET), computed tomography perfusion imaging (CTP), and xenon-enhanced CT (xenon-CT). Currently, there is not a single well-accepted test to accurately predict the tolerance of patients to permanent occlusion of the ICA. However, based on current clinical data, many centers have reported their own assessment methods for testing ICA occlusion tolerance, including BOT+PET, BOT+SPECT, and BOT+xenon-CT. We suggest using the “BOT+CTP” plan, which is simple, effective, and cost-efficient.

For MCA aneurysms, the hemodynamic differences are significant among giant aneurysms located in different MCA segments, and the treatment strategy should be adjusted accordingly. M1 aneurysms that involve important perforating branches such as lenticulostriate arteries cannot be directly clipped. In the case of a patient with a selectively positive BOT (BOT in the M1 segment), a medium- or high-flow EC-IC bypass (ECA-RA-MCA or STA-RA-MCA) can be combined with ipsilateral chronic ICA occlusion as treatment. The gradual decrease in intra-aneurysm blood flow is beneficial for establishing collateral lenticulostriate artery circulation and promoting ischemic tolerance in the supply area. Due to early thrombosis development in the giant aneurysm and the gradual decrease in intra-aneurysm blood flow, complete thrombosis of the aneurysm can be achieved in most cases. Moderate-flow (STA-RA-M3) bypass and trapping of the aneurysmal parent arteries can be used to treat aneurysms in the M2 segment (including the M2 bifurcation). Trapping of the aneurysmal parent arteries can be directly performed in most giant aneurysms beyond the M3 segment. However, cerebral ischemia may be present if the parent artery is the central artery or the artery of the angular gyrus. If necessary, aneurysm trapping should be performed after vascular reconstruction. In particular, intraoperative electrophysiological monitoring (including for motor evoked potentials, MEPs, and somatosensory evoked potentials, SEPs) plays an important role in assessing the tolerance to vascular occlusion and the timely identification of motor dysfunction due to various causes. Such monitoring is an essential safeguard for MCA aneurysm procedures. In addition, due to the variety of angioarchitectures and morphologies of MCA aneurysms and the large number of accompanying arteries, more rapid, minimally invasive, flexible IC-IC bypass is used. Extensive treatment approaches require further improvements in the microsurgical skills of neurosurgeons.

Most anterior communicating artery aneurysms can be directly or reconstructively clipped through the aneurysm body or neck. Vascular reconstruction is mainly used in cases in which A2 occlusion is required, including side-to-side A2-A2 or A3-A3 anastomoses in most cases.

Vascular reconstruction techniques applied for the treatment of aneurysms in the posterior circulation include EC-IC and IC-IC bypass. The main pattern is occipital artery-posterior inferior cerebellar artery (OA-PICA) bypass or superficial temporal artery-posterior cerebral artery (STA-PCA) bypass. Sometimes, due to the variable position and morphology of the posterior circulation aneurysm, it is necessary to use IC-IC bypass during surgery depending upon individual conditions. Sanai and his colleagues classified IC-IC bypass into four types to meet the requirements of vascular reconstruction in various situations: in situ bypass, reimplantation, reanastomosis, and IC bypass with graft. A high degree of surgical skills is required for these procedures because the operating sites of the posterior circulation aneurysm are close to important tissues and the operating space is limited. In addition, because of the generally poor tolerance to posterior circulation occlusion and the lack of accurate pre- and intraoperative assessment methods, a rapid bypass speed and high degree of technical skills are required for these procedures.

Although vascular reconstruction techniques have been widely used in the surgical treatment of complex IC aneurysms, further improvements to these techniques are still needed. The most common problem is how to evaluate the blood flow volume of the reconstructed vessels, including the blood flow volume of the blood vessels associated with the parent artery before and after occlusion as well as the reconstructed vessels. This information is key for correctly choosing a vascular reconstruction technique and for ensuring the effectiveness of treatment. Amin-Hanjani and his colleagues used magnetic resonance imaging noninvasive optimal vessel analysis (NOVA) to examine the flow rate of the blood vessels used in vascular reconstruction before surgery and to directly measure the flow rate during surgery. This method helps to obtain the required flow volume of the reconstructed vessel. Ultimately, the type of vascular reconstruction can be determined based on these measured flow rates. However, changes in blood flow after IC arterial occlusion are based on changes in the overall hemodynamics of the vascular network rather than the flow of a single artery. Thus, it is still necessary to perform brain metabolism assessments and functional measurements. The evaluation scheme needs to be further improved in future research.

The development of IC vascular reconstruction techniques began in 1969 when Yasargil first reported STA-MCA bypass. After several decades of development, this technique has been used to cure many complicated IC aneurysms that were previously incurable. However, the advancement of medical technology is endless. As people pay more attention to quality of life, more advanced vascular reconstruction techniques that are minimally invasive, rapid, and effective are needed to treat aneurysms. Thus, highly technical microsurgery skills are required. Lawton and his colleagues suggested that, in the future, vascular reconstruction for the treatment of IC aneurysms will focus on IC-IC bypass and even proposed that the "IC-IC bypass era" is coming. Such expectations require that our country's neurosurgeons not be satisfied with the current techniques but constantly improve upon existing treatment strategies and skills to benefit additional domestic patients.

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1

External Carotid Artery-Radial Artery-Middle Cerebral Artery Bypass

Jianping Song, Wei Zhu, and Ying Mao

Abstract

The management of complex internal carotid artery (ICA) aneurysms remains a challenge for vascular neurosurgeons. Because of the giant aneurysm size, fusiform or dissecting morphology, or the presence of many intramural thrombi in some cases, neither endovascular coiling nor microsurgical clipping is optimal, and sacrificing the parent artery may be a better way to treat the aneurysm. Additionally, extracranial–intracranial (EC-IC) vascular bypass is required to reconstruct the blood flow of the middle cerebral artery (MCA) before completely obliterating or trapping the parent artery for the patients with complex aneurysms involving the ICA. The high-flow bypass approach is suitable for treating large or giant ICA aneurysms that cannot be cured by routine endovascular coiling or surgical clipping, especially those originating from the paraclinoid segment, ophthalmic artery (OA), posterior communicating artery (PcomA), or cavernous sinus (CS) segment of the ICA.

Here, we present a case of a giant ICA aneurysms that were treated by an external carotid artery–radial artery-MCA bypass combined with aneurysm trapping.

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Keywords

Extracranial–intracranial bypass · Internal carotid artery · Intracranial aneurysm Middle cerebral artery · Radial artery Revascularization

1.1 Introduction

The management of complex internal carotid artery (ICA) aneurysms remains a challenge for vascular neurosurgeons. Because of the giant aneurysm size, fusiform or dissecting morphology, or the presence of many intramural thrombi in some cases, neither endovascular coiling nor microsurgical clipping is optimal, and sacrificing the parent artery may be a better way to treat the aneurysm. Additionally, extracranial–intracranial (EC-IC) vascular bypass is required to reconstruct the blood flow of the middle cerebral artery (MCA) before completely obliterating or trapping the parent artery for the patients with complex aneurysms involving the ICA [1].

This high-flow bypass approach is suitable for treating large or giant ICA aneurysms that cannot be cured by routine endovascular coiling or surgical clipping, especially those originating from the paraclinoid segment, ophthalmic artery (OA), posterior communicating artery (PcomA), or cavernous sinus (CS) segment of the ICA. The com-

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monly used bypass techniques include high-flow EC-IC (external carotid artery–radial artery–middle cerebral artery, ECA-RA-MCA or external carotid artery–saphenous vein–middle cerebral artery, ECA-SV-MCA) bypass and medium-flow (superficial temporal artery–radial artery–middle cerebral artery, STA-RA-MCA) bypass. Most researchers do not recommend the use of low-flow (STA-MCA) bypass.

We believe that ECA-RA-MCA bypass is the most efficient and safe revascularization technique for giant ICA aneurysms [2].

1.2 Case

A 57-year-old man presented with blurred vision and facial numbness on the left side for 3 months. Physical examination did not reveal hemiparesis, with VOS 0.2 and VOD 0.6. Magnetic resonance imaging (MRI) showed a giant lesion with a prominent flow void sign located in the left CS. Digital subtraction angiography (DSA) revealed a giant left ICA aneurysm (C4 segment) (Fig. 1.1). He could not tolerate a preoperative balloon occlusion test (BOT). Endovascular

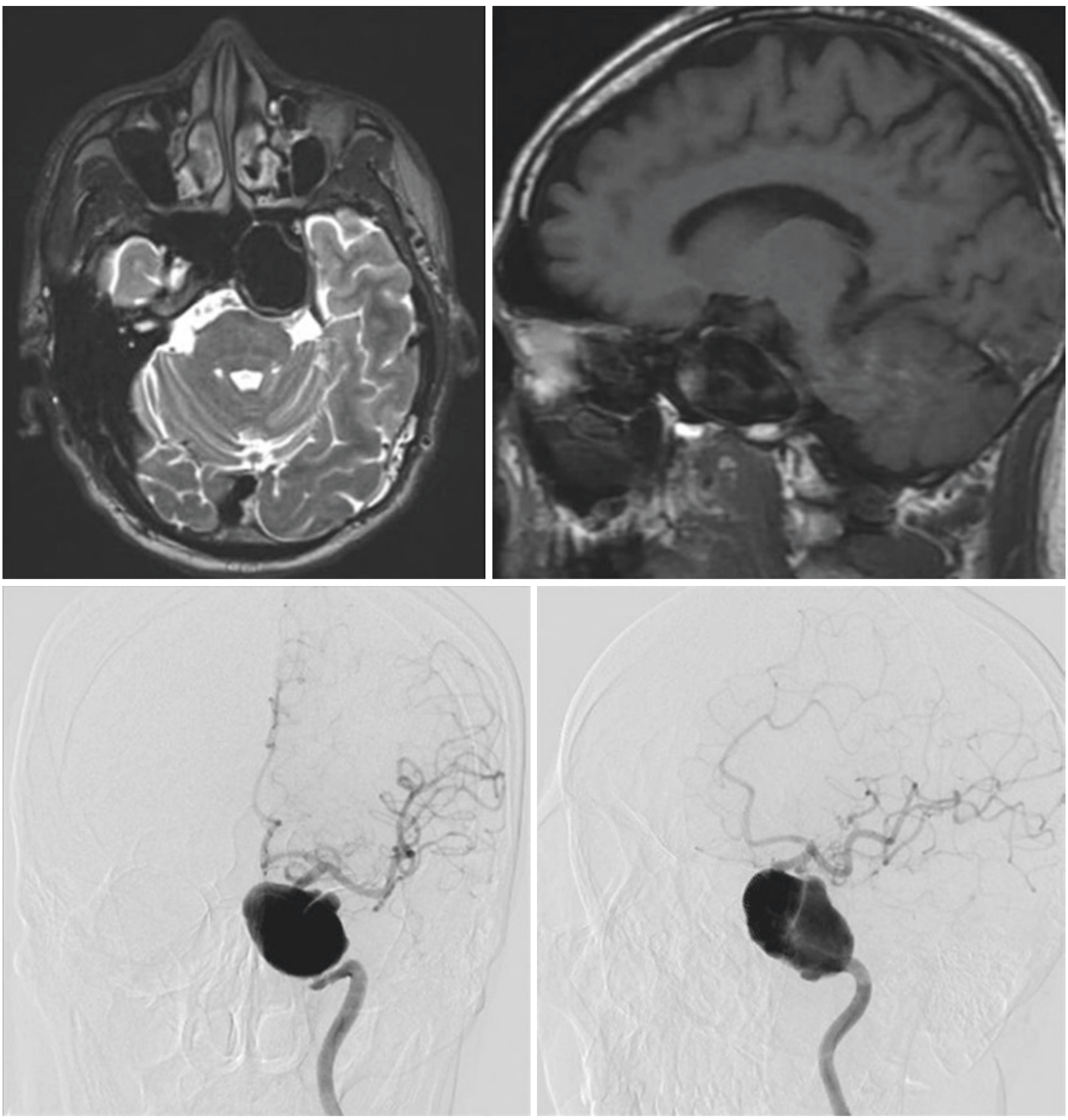

Fig. 1.1 Preoperative imaging: MRI and DSA demonstrated a giant aneurysm in the C4 segment of the left ICA

treatment was difficult for this patient. Therefore, to secure the aneurysm, a left ECA–RA–MCA bypass was planned before occluding the left ICA (Fig. 1.2).

1.3 Details of the Procedure

During the operation, the patient was placed supine with the head turned 45° to the right, and the left shoulder was elevated. The head was elevated by 20° to facilitate venous drainage. His head, neck, and forearm were draped on the left side.

A curvilinear incision was made from the biceps tendon distally toward the wrist crease. The RA was carefully identified and isolated by ligating its branches (Fig. 1.3). After harvesting the RA, the lumen of the RA graft was irrigated with heparinized saline, and the intima edges were trimmed and marked with methylene blue. The "pressure distension" technique was performed for hydrostatic angioplasty (Fig. 1.4), and papaverine was used to treat vasospasm.

After a modified pterional craniotomy, the sylvian fissure was carefully dissected under a microscope, and the M3 branches of the MCA were exposed. One of the M3 branches without perforating vessels was temporarily clipped as the recipient artery. The RA graft was temporarily placed on the recipient M3 vessel to determine the anastomosis site's location and length (marked by methylene blue). A rubber background was placed under the isolated vessel for arteriotomy (Fig. 1.5).

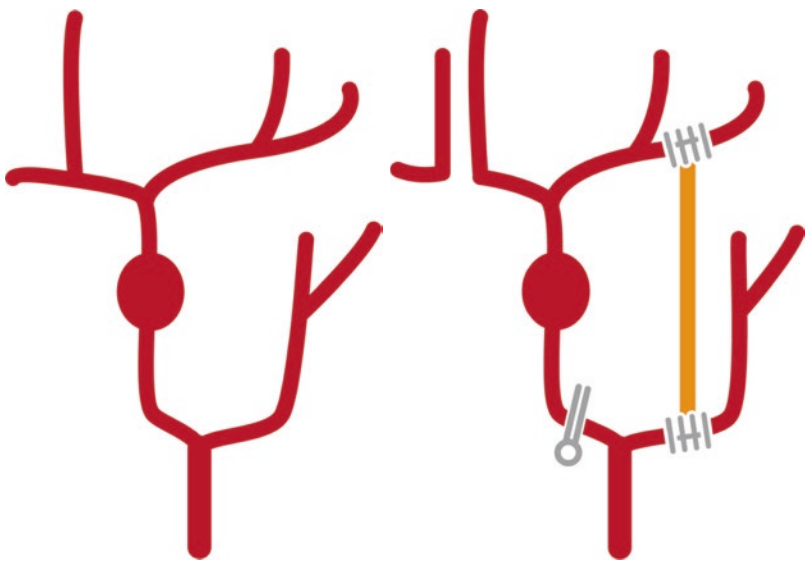

Fig. 1.2 A left ECA-RA-MCA bypass was planned before occluding the left ICA

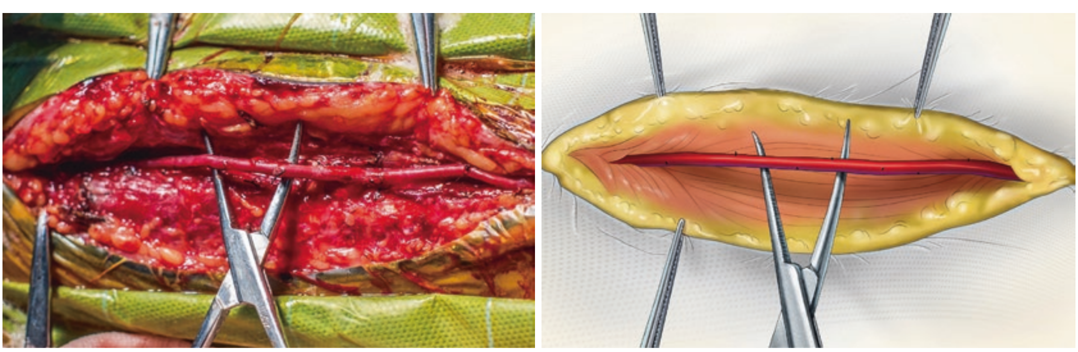

Fig. 1.3 The radial artery (RA) was harvested. The RA was carefully identified and isolated by ligating its branches