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Original Article

Extracranial–intracranial bypass in the treatment of complex or giant internal carotid artery aneurysms

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ABSTRACT

Objectives: Direct microsurgical clipping or endovascular coiling for complex and giant internal carotid artery (ICA) aneurysms is usually risky and leads to inadequate occlusion of the aneurysm. Extracranial–intracranial (EC-IC) bypass may help eliminate neurological complications.

Materials and methods: We retrospectively reviewed patients with intracranial aneurysms who were treated with the assistance of EC-IC bypass from July 2002 to February 2014. Six patients with complex ICA aneurysms were identified, and their clinical characteristics were analyzed. There were two men and four women ranging in age from 40 to 76 years. Three of these patients presented with hemorrhage, and two with compression with visual impairment. One aneurysm was an incidental finding during a physical examination.

Results: Three of the six ICA complex aneurysms were large or giant sized, one was an ICA blood blister-like aneurysm, one was a dissecting aneurysm, and one was a pseudoaneurysm due to tumor invasion. Bypass was performed with superficial temporal artery–middle cerebral artery anastomosis. The follow-up period ranged from 2 to 103 months (mean 36.67 months). The postoperative bypass patency rate was 100%. One patient had cerebellar intracerebral hemorrhage and one had temporary ptosis. There was no bypass surgery-related morbidity. The modified Rankin scale showed good outcomes in four of the six patients.

Conclusions: Cerebral revascularization plays an important role in the treatment of complex ICA aneurysms that have a significant mass effect on the optic nerve or require occlusion of the parent ICA as a salvage procedure.

1. Introduction

Intracranial aneurysms can be treated by microscopic clipping or endovascular coil embolization with good outcomes. However, both procedures have high complication rates and low success rates for aneurysm sac obliteration, such as in the case of large and giant aneurysms or aneurysms with complex anatomy. Complex anatomy can be characterized by dolichoectatic morphology, intraluminal thrombi, atherosclerotic tissue in the neck, arterial branches incorporated into the aneurysm base, or a broad neck [1,2]. Complex intracranial aneurysms may be managed by parent artery occlusion or trapping to obliterate the aneurysm or redirect blood flow, thus avoiding the high morbidities of direct clipping or coiling.

Extracranial–intracranial (EC–IC) bypass involves revascularization of the cerebral arteries through extracranial arterial grafts [3]. Although bypass was first designed for cerebral ischemic disease, it has shown potential efficacy in patients who cannot tolerate cerebral arterial occlusion, such as those with postoperative infarction or neurological damage due to prolonged ischemic time during complex or giant aneurysm clipping.

Giant and complex aneurysms of the internal carotid artery (ICA) usually present with mass effect over the optic pathway, resulting in several types of visual impairment [4]. These symptoms are closely related to characteristics such as the size of the aneurysm, duration of visual symptoms, calcification of the aneurysm

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wall, and intraluminal thrombosis [5]. Furthermore, it has not yet been confirmed whether surgical clipping or endovascular coiling achieves a better visual outcome. We reviewed patients with complex ICA aneurysms who were treated with surgical clipping or endovascular coiling. All of these procedures were supplemented by EC–IC bypass. An analysis of the characteristics of complex ICA aneurysms (e.g., visual impairment) is presented, and the role of EC–IC bypass during surgery for giant or complex aneurysms is also discussed.

2. Materials and methods

We retrospectively reviewed the medical records and imaging results of patients who underwent treatment from July 2002 to February 2014. Among the 307 patients with aneurysms treated with microsurgical clipping or endovascular coiling, bypass therapy was performed in six patients with ICA segment aneurysms (Table 1).

2.1. Patients

There were two men and four women in this study. Their ages ranged from 40 to 76 years. Four patients received two EC–IC anastomoses via the superficial temporal artery (STA) frontal and parietal branches to the middle cerebral artery (MCA). They underwent 10 EC–IC surgery procedures for complex cerebral aneurysms. Three of these patients had unruptured aneurysms and three had ruptured aneurysms, including one with active tumor bleeding. One of the three unruptured aneurysms was an incidental finding during a regular physical examination. The other two were detected during evaluation of poor vision and transient ischemic attack. One of the three patients with ruptured aneurysms had nasopharyngeal carcinoma and active nasal bleeding. Cerebral digital subtraction angiography (DSA) revealed rupture of a right ICA pseudoaneurysm due to tumor invasion. One patient received emergency EC–IC bypass owing to an aneurysm neck tear during aneurysm clipping. The third patient was diagnosed after she suffered severe headaches and became comatose.

2.2. Preoperative survey

Cerebral computed tomography (CT) angiography and cerebral DSA were routinely carried out when spontaneous subarachnoid hemorrhage (SAH) was found.

One of the three ruptured aneurysms was Hunt and Hess (H&H) Grade 3 and the other two were Grade 5. The Fisher grades of these cases are shown in Table 1. One aneurysm was located in the petrous segment, two in the ophthalmic segment, and three in the communicating segment of the ICA. The aneurysms ranged from 2.8 mm to >50 mm.

Emergency external ventricular drainage (EVD) was done to treat patients with SAH-related hydrocephalus and consciousness disturbance. Delayed aneurysm surgery was performed for high-grade H&H cases.

Brain magnetic resonance imaging (MRI) and visual field examination were used in the two visual impairment cases. Cerebral DSA was necessary for the differential diagnosis of the suprasellar lesion, which included pituitary adenoma, craniopharyngioma, meningioma, and aneurysm.

2.3. Strategy of bypass surgery for aneurysms

Initially, a balloon occlusion test was performed prior to the bypass surgery. This test took 30 minutes. If transient ischemic symptoms such as limb weakness or consciousness deterioration were noted, the test was deemed positive. When the test was negative, ICA sacrifice without bypass was indicated. However, Case 1 passed the balloon occlusion test prior to the bypass and received ICA sacrifice without bypass. The test result had been a false negative, and the patient had a symptomatic ischemic stroke. Emergency EC–IC bypass was then performed. A 25% false negative rate for the balloon occlusion test has been reported [6]. After Case 1, we changed our strategy. If a long duration of ischemia during aneurysm surgery and a potential ICA sacrifice was planned, EC–IC bypass was performed first. Then, a balloon occlusion test was done to check if a symptomatic stroke was possible after ICA sacrifice. If the patient did not pass the test, another bypass surgery such as an anterior cerebral artery (ACA)-to-ACA bypass was performed prior to the aneurysm surgery. If the patient passed the test, aneurysm therapy was performed immediately (Fig. 1).

2.4. Postoperative evaluation

Cerebral angiography was performed postoperatively to check the bypass patency and aneurysm clipping. Brain MRI was conducted in the outpatient department to follow up the bypass and aneurysm clipping. Visual field examination was used to evaluate the patients who had preoperative visual impairment. In addition, the Rankin scale was used to evaluate the clinical outcome.

2.5. Surgical procedures

EC–IC bypass with the STA to the frontal and temporal M3 branches of the MCA was carried out first. End-to-side anastomosis of the STA to the MCA, as described in detail previously, was performed [3]. At least a 5-cm length of the frontal branch of the STA was dissected from the subcutaneous layer of the scalp on the surgical side. The branch was transected and occluded with a temporary aneurysm clip. A 1% diluted heparin solution was used to irrigate the endovascular lumen to prevent thrombus formation. Then, a $3 \times 2\text{-cm}^2$ craniotomy was performed, and the Sylvian

Table 1
Clinical characteristics of aneurysms.

Cases	Age (y)/ sex	Preoperative GCS	Presenting symptoms	Location	Aneurysm morphology	Size (mm)	Fisher grade	H&H grade	Preaneurysm tx surgery
1	46/F	E4V5M6	Incidental finding	Left ICA C7	Saccular	20	1	1	None
2	54/M	E1VTM1	Deep coma	Left ICA C7	Blister	2.8	4	5	EVD
3	53/M	E4V5M6	Right homonymous hemianopsia	Left ICA C7	Saccular	25.2	1	1	None
4	40/F	E4V5M6	Left homonymous hemianopsia	Right ICA C6	Saccular	15.3	1	1	None
5	76/F	E3VTM4	Deep coma	Right ICA C2–3	Fusiform	90	1	5	None
6	43/F	E3VTM5	Deep coma	Right ICA C6	Fusiform	5.4	4	3	EVD

EVD = external ventricular drainage; GCS = Glasgow Coma Scale; H&H grade = Hunt and Hess grade; ICA = internal carotid artery.

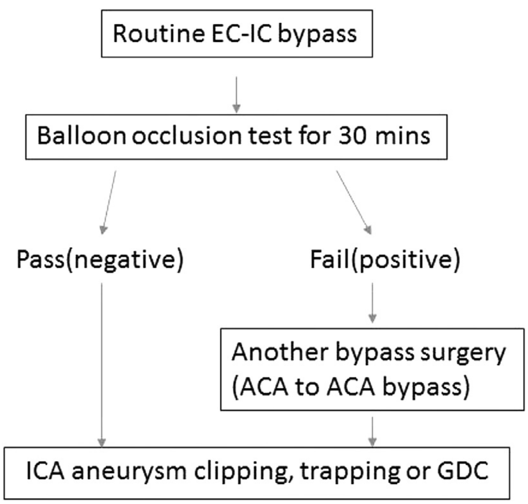

Fig. 1. Algorithm for complex and giant aneurysms in our series. If a long ischemic time or ICA sacrifice is suggested for a complex or giant aneurysm, an EC–IC bypass is first performed, followed by a balloon occlusion test. If the patient passes the balloon occlusion test, aneurysm surgery is performed. If the patient does not pass the balloon occlusion test, another bypass, such as ACA-to-ACA bypass surgery is carried out, and then the aneurysm is performed. ACA = anterior cerebral artery; EC–IC = extracranial–intracranial; ICA = internal carotid artery.

fissure was opened to identify the M3 or M4 branch of the MCA for anastomosis. The recipient vessel was freed from the arachnoid membrane and trapped with two temporary clips placed 1 cm apart. A 6-mm longitudinal incision was made in the recipient vessel, and the incision was irrigated with 1% diluted heparin solution. The stump of the donor vessel was shaved obliquely to 6 mm in length to fit the recipient side. Anastomosis was accomplished using 10–0 nylon sutures originating at the proximal and distal ends of the orifices. Approximately seven to eight interrupted sutures were made on each side for a total of 14 to 16 sutures per anastomosis. The patency of the anastomosis was validated during surgery by a transcranial Doppler test (DWL Multi Dop X4; Singen, Baden-Württemberg, Germany) using a 16-MHz transducer attached to the donor artery and both ends of the anastomosis of the recipient artery. A balloon occlusion test of the ICA was then performed for 30 minutes to check if there was a neurologic deficit.

For direct clipping and surgical arterial trapping, we performed a standard pterional craniotomy with a trans-Sylvian approach, including removal of the anterior clinoid process. After opening the basal cistern and Sylvian fissure, the ICA, optic nerve, and posterior communication artery could be seen. The ICA was traced to the bifurcation to find the distal aneurysm neck and dissect it for temporary clipping. Then, Indocyanine Green angiography was used to check the complete clipping and patency of the ICA.

3. Results

3.1. Surgical results

Ten EC–IC bypasses were performed to treat six aneurysms. The follow-up periods ranged from 2 to 103 months (mean 36.67 months). There were no wound infections, meningitis, or subdural hematomas due to anastomotic leakage. We used direct aneurysm clipping in two cases, surgical ICA trapping in two cases, and endovascular proximal occlusion with Guglielmi detachable coiling (GDC) for the other two cases. Direct aneurysm clipping with angiography was performed for two patients with visual impairment who had unruptured large and giant aneurysms (Cases 3 and 4). Emergency bypasses were carried out for two patients with surgical ICA trapping. One patient had a postoperative infarction (Case 1). The other patient had an ICA blister aneurysm, which we clipped directly first; during this procedure, an aneurysm neck tear was noted (Case 2). Following this, we performed proximal ICA trapping and did an emergency EC–IC bypass. The other two GDC proximal occlusion cases included one pseudoaneurysm due to tumor invasion of the ICA and one ICA fusiform case. Postoperative DSA revealed a 100% bypass patency rate and good aneurysm obliteration.

3.2. Clinical results

The Rankin scale scores for the unruptured cases were 0–1 prior to the aneurysm therapy and 1–2 afterward (Table 2). The Rankin scores for the ruptured cases were 4–5 prior to the aneurysm therapy and 3–5 afterward. Case 1 had a postoperative infarction, and right hemiparesis and aphasia were noted. Case 2 had an ICA blister aneurysm and the patient was in a deep coma both on arrival in the ER and postoperatively. A postoperative visual field examination revealed obvious improvement in the visual impairment of Cases 3 and 4 after direct aneurysm clipping of giant and large aneurysms. Bypass and GDC were carried out in Case 5 (pseudoaneurysm) to control bleeding and prevent postoperative infarction. After GDC, no obvious active bleeding or neurological defect was noted. Case 6 had an H&H Grade 3 aneurysm, and EVD surgery was performed initially. Cerebral DSA revealed a fusiform aneurysm of the ICA ophthalmic segment. Bypass surgery and GDC were then performed. Postoperatively, the patient's consciousness was clear, and no obvious neurological defect was noted. One postoperative delayed cerebellar intracerebral hemorrhage was noted and an emergency suboccipital craniectomy was performed. Postoperatively, the patient's consciousness cleared and the limb weakness resolved. One patient had temporary ptosis postoperatively due to third nerve dissection.

3.3. Illustrative cases

Case 2

A 54-year-old man complained of a severe headache, which deteriorated to a deep coma (Glasgow Coma Scale: E1VTM1) upon arrival at the hospital. Brain CT revealed a diffuse SAH and intraventricular hemorrhage. Emergency EVD was performed, and the aneurysm was downgraded to H&H Grade 4. A cerebral DSA revealed a left ICA C7 segment aneurysm (Fig. 2). We performed a standard left pterional craniotomy with the trans-Sylvian approach, including removal of the anterior clinoid process. During application of the clip, an inadvertent tearing of the neck of the aneurysm was noted and the ICA had to be trapped with another two clips. Collateral arterial blood flow via the ACA, posterior communicating artery, or extracranial meningeal artery is the major blood supply after the ICA is sacrificed. However, we could not ascertain that the collateral blood supply would suffice to prevent ischemic stroke. Therefore, an emergency EC–IC bypass was conducted to increase the blood supply and decrease the chance of ischemic stroke after ICA trapping. Then, we dissected the STA, and an EC–IC bypass (left STA to MCA M3 segment) was performed immediately. Postoperative cerebral DSA revealed good patency from the STA to the MCA (Fig. 3).

Case 3

A 53-year-old woman with hypertension had progressive blurred vision for 4 months. The visual impairment deteriorated to blindness on the right side of the visual area 1 week before she came to the hospital. The visual field examination showed

Table 2
Treatment outcome of aneurysm.

Case no.	Aneurysm treatment	Bypass timing	Bypass type	Ischemic time	EC–IC patent	Postoperative GCS	Postoperative condition	Preoperative Rankin score	Postoperative Rankin score	Hirai[a]
1	Trapping	Emergent (4 d)	STA–MCA	None	+	E4V5M6	Right hemiparesis	0	2	Mild
2	Trapping	Emergent (intraoperative)	STA–MCA	30 min	+	E2VTM3	Deep coma	5	5	Extensive
3	Clipping	Prior to clipping	STA–MCA*2	360 s	+	E4V5M6		1	1	Moderate
4	Clipping	Prior to clipping	STA–MCA*2	400 s	+	E4V5M6		1	1	Moderate
5	GDC	Pre-GDC	STA–MCA*2	None	+	E3VTM4	Deep coma	5	5	Moderate
6	GDC	Pre-GDC	STA–MCA*2	None	+	E4V5M6		4	1	Mild

EC–IC = extracranial– intracranial; GDC = Guglielmi detachable coils; GOS = Glasgow Outcome Scale; STA–MCA = superficial temporal artery–middle cerebral artery.
[a] Hirai: the type of reestablished vasculature.

homonymous hemianopsia (Fig. 4A). Brain MRI showed one giant ICA aneurysm with a mural thrombus over the suprasellar region with compression of the optic apparatus (Fig. 4B, 4C, and 4D).

After she was admitted to the neurosurgical department, a cerebral DSA confirmed a giant aneurysm in the communicating segment of the left ICA (Fig. 4E and 4F). We planned direct clipping to secure the aneurysm and decompress its mass effect.

In the first stage, EC–IC bypass was performed with the left STA to the frontal and temporal M3 branches of the MCA. A balloon occlusion test of the left ICA demonstrated no neurologic deficit after 30 minutes. In the second stage, we performed a standard left pterional craniotomy with a trans-Sylvian approach. The optic apparatus was compressed by the giant aneurysm. We applied four temporary clips on the proximal and distal ICA, and posterior communication (Pcom) artery. Following our preoperative design, we applied the first fenestrated clip, which was near the Pcom. Then, we applied the T-bar fenestrated clip in tandem. Next, we used the third fenestrated clip to preserve the MCA and ACA (Fig. 5). Then we removed the temporal clip. The total ischemic time was about 6 minutes. We used Indocyanine Green angiography to check for complete obliteration of the aneurysm and patency of the ICA. Then, we opened the aneurysm sac for decompression. The patient recovered uneventfully, and the defect in the visual field improved remarkably. Postoperative visual field examination revealed nearly complete resolution of visual impairment (Fig. 6A). The follow-up DSA also showed good arterial filling over the MCA branches and good patency of the bypass (Fig. 6B, 6C, 6D, and 6E).

4. Discussion

EC–IC bypass was first introduced for treatment of cerebral ischemia disease but gradually lost its role when it did not prove better for stroke prevention than antiplatelet medication [7]. With refinements in revascularization techniques and the addition of anticoagulants, EC–IC bypass has proved to have long-term efficacy for complex aneurysm surgery or skull base tumors with major vessel invasion [8]. Although high flow bypass may increase blood flow in the distal circulation through bypass vessels, low flow bypass, such as that used in our cases series using STA–MCA bypass, may also provide adequate perfusion under careful

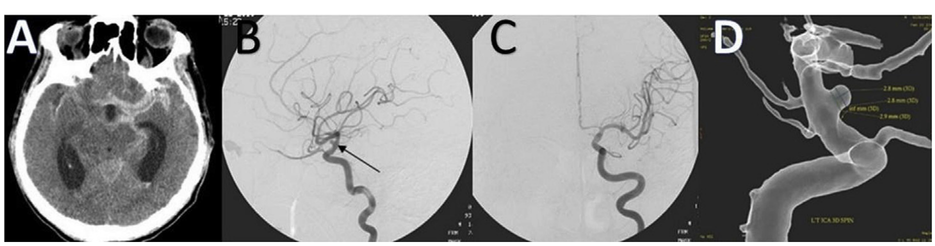

Fig. 2. Preoperative survey: (A) brain CT without contrast shows a diffuse SAH in the basal cistern and left Sylvian fissure; (B, C) DSA lateral and AP views demonstrates one blister aneurysm in the left ICA communicating segment (black arrow); and (D) spin DSA of the left ICA shows the aneurysm neck/dome are 2.9/2.8 mm. AP = anterior–posterior; CT = computed tomography; DSA = digital subtraction angiography; ICA = internal carotid artery.

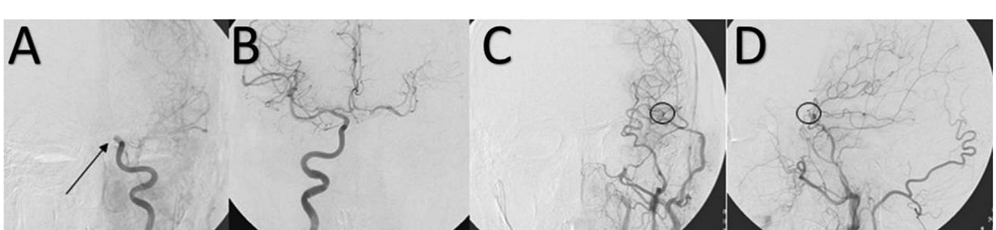

Fig. 3. Postoperative survey: (A) DSA AP view shows no blood flow in the left ICA due to proximal trapping (black arrow); (B) DSA AP view shows the left ACA and MCA branch have blood flow from the right ICA via the Pcom artery; and (C, D) DSA of the left ECA shows good patency of the low flow bypass (circles). ACA = anterior cerebral artery; AP = anterior–posterior; DSA = digital subtraction angiography; ECA = external carotid artery; MCA = middle cerebral artery; Pcom = posterior communication.

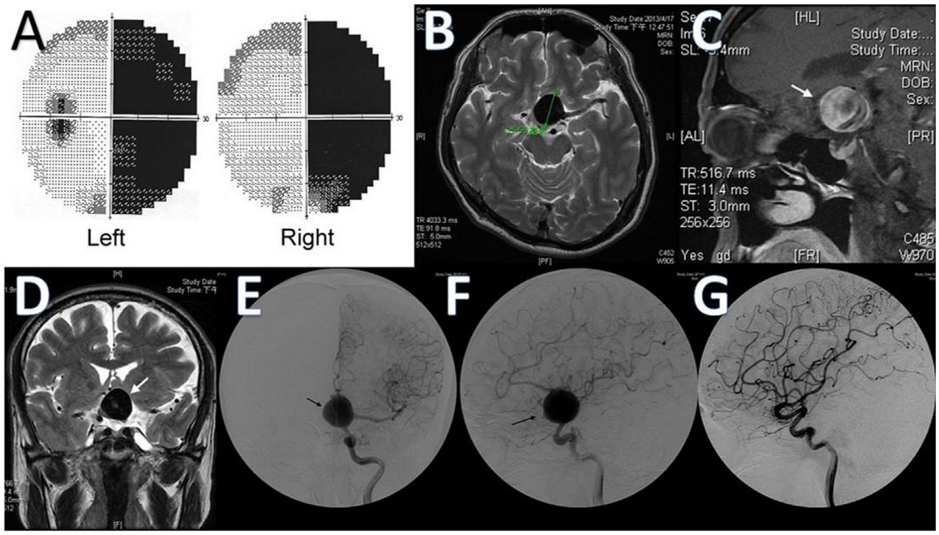

Fig. 4. Preoperative survey: (A) visual field examination shows right homonymous hemianopsia; (B, C, D) brain MRI axial, sagittal, and coronal views show one giant ICA aneurysm (25.2 mm in diameter, white arrow) over the left suprasellar region; (E, F) DSA AP and lateral views demonstrate one giant aneurysm in the communicating segment of the left ICA (black arrow) and the Pcom artery has disappeared due to aneurysm compression; and (G) DSA of the right ICA shows no abnormalities. AP = anterior–posterior; DSA = digital subtraction angiography; ICA = internal carotid artery; MRI = magnetic resonance imaging; Pcom = posterior communication.

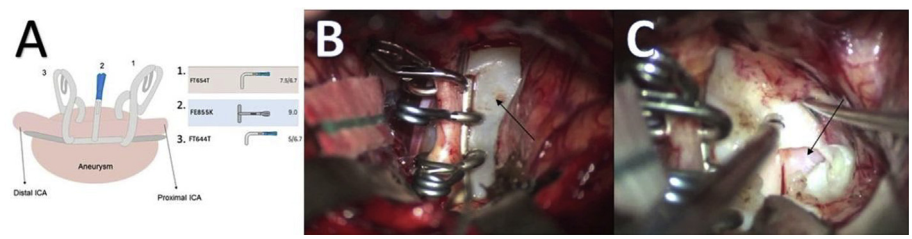

Fig. 5. Surgical plan and intraoperative findings: (A) we designed direct clipping with three Yasargil fenestrated clips for preservation of the left ICA and Pcom artery; (B) we used three fenestrated clips to perform angioplasty of the ICA. The black arrow indicates the aneurysm sac; and (C) we opened the aneurysm sac for decompression and dissected it from the optic apparatus. ICA = internal carotid artery; Pcom = posterior communication.

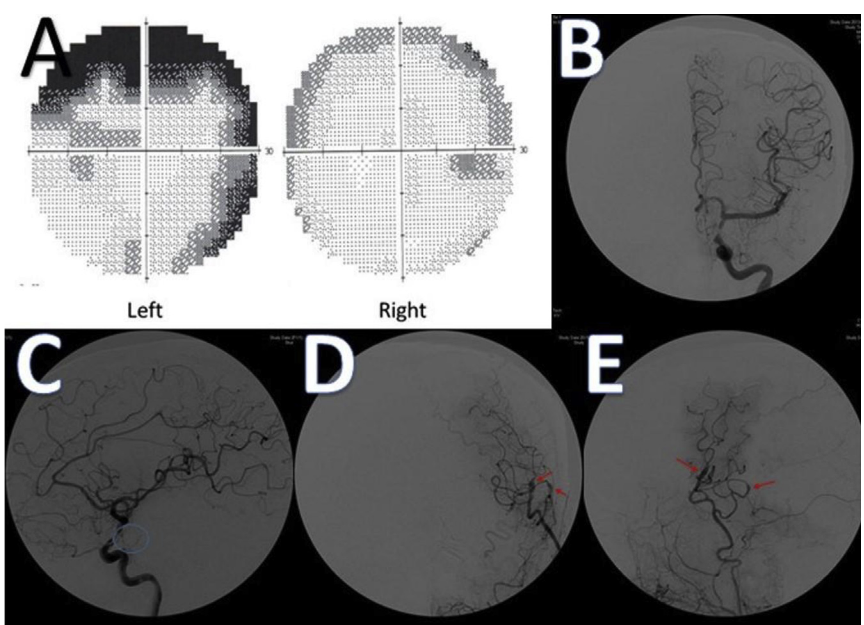

Fig. 6. Postoperative results: (A) visual field examination shows near complete resolution of preoperative impairment; (B, C) DSA of the left ICA AP and lateral views demonstrate complete obliteration of the aneurysm after clipping and patency of the ICA and Pcom artery (circle); and (D, E) DSA of the left ECA shows good patency of the low flow bypass (arrows). AP = anterior–posterior; DSA = digital subtraction angiography; ECA = external carotid artery; ICA = internal carotid artery; Pcom = posterior communication.

preparation of donor vessels [2]. STA–MCA bypass can also avoid the possibility of donor site harvest morbidity. Studies have also shown similar patency rates between low flow and high flow bypass [9]. There is a growing interest in IC–IC bypass, which has been used in an attempt to eliminate the risk of extracranial donor vessel harvesting, with shortened interposition grafts, and caliber-matched donor and recipient arteries. However, a lower patency rate for complex aneurysms in some centers has resulted in the use of IC–IC bypass for complex or giant aneurysm at specific anatomical positions, emphasizing that the choice of bypass technique should be individualized [10]. Cantore et al [11] suggested that direct clipping of complex or giant aneurysms may give better outcomes than high-flow bypass plus trapping. High-flow bypass is technically demanding and may be associated with perioperative ischemic stroke. Some studies showed that low flow bypass carries a lower risk of intraoperative ischemia [12].

Routine cerebral DSA is performed in aneurysm cases to check the quality of the reestablished vasculature. We used the Hirai classification to describe the morphological changes in the reestablished vasculature demonstrated on DSA [13]. The types were categorized as extensive, moderate, or mild. In the extensive type, abundant branches of the MCA could be seen on postanastomosis angiography. In the mild type, only the recipient vessel could be identified. In the moderate type, two or three MCA branches were seen after the bypass. The mild type was seen in two of our six cases, the moderate type in three cases, and the extensive type in one. In another of our bypass-stroke series, Chiu et al [14] showed low bypass flow velocity and mild-type reestablishment of cerebral vasculature in most patients with MCA stenosis. Our bypass-stroke series shows that bypass can obviously improve hemodynamic perfusion. In our experience, patients with Grade 4 aneurysms have the potential to recover from deep coma to full consciousness. Therefore, we perform surgery if we feel that an aneurysm can be improved from Grade 5 to Grade 4. In Case 2, the Grade 5 H&H (Grade 5) aneurysm improved to Grade 4 after EVD. Although postoperative cerebral DSA showed extensive type reestablished vasculature, the patient was still comatose. This suggests the prognostic value of the premorbid presentation [15]. In Cases 3 and 4 with giant and large aneurysms, we planned a two-stage surgery, a bypass, balloon occlusion test, and angioplasty for aneurysm clipping. For the aneurysm clipping, we planned an angioplasty with two or three fenestrated aneurysm clips and used temporary clips for proximal control. We anticipated long ischemic times during angioplasty with proximal control. Bypass has been shown to save ischemic time during complex or giant aneurysm clipping [6]. Both cases had the moderate type of post-anastomosis vasculature and had no ischemic changes after long ischemic times of 360 and 400 seconds. Case 6 had a fusiform ICA aneurysm with an initial H&H grade of 3. Direct aneurysm clipping and angioplasty have high surgical risks, so endovascular GDC occlusion of the proximal ICA was performed. The addition of bypass surgery also prevented postoperative stroke. Although postanastomosis DSA showed a mild type vasculature, the patient recovered from a coma to full consciousness. Taken together, the prognostic factors included not only the bypass surgical outcome but also the initial presentation. A 30-minute balloon occlusion test ensures that bypass flow can be used for long ischemic times or to prevent strokes in ICA trapping or occlusion cases. Some surgeons do a balloon occlusion test prior to the bypass and giant aneurysm surgery [16]. If the patient cannot tolerate this test and a neurological deficit is noted, a high flow bypass should be used. If the patient can tolerate a balloon occlusion test, and single photon emission CT demonstrates normal perfusion at rest and hypovasoreactivity of the hemisphere ipsilateral to the occlusion site during acetazolamide stress, a low flow bypass may be required. Our first patient had a false negative result on the balloon test prior to the aneurysm surgery and an emergency EC–IC bypass was performed. The balloon occlusion test has a false negative rate of approximately 25%. These patients pass the balloon occlusion test and then have symptomatic infarctions after ICA trapping in aneurysm surgery without bypass surgery. We wanted to decrease the infarction risk due to a false negative balloon occlusion test. We also had a high patency rate and low complication rate with EC–IC bypass surgery. If a long ischemic time or ICA sacrifice is suggested for complex or giant aneurysms, we perform an EC–IC bypass first and then the balloon occlusion test. Aneurysm surgery is performed if the patient passes the balloon occlusion test. If the patient fails this test, another bypass surgery, such as ACA-to-ACA bypass surgery, is done. We hope that the STA-to-MCA bypass can provide adequate blood supply with the coexisting collateral blood supply to replace the parent ICA and prevent brain ischemia after aneurysm treatment.

In 2003, the International Study of Unruptured Intracranial Aneurysms (ISUIA) showed that the risk of rupture of giant aneurysms is as high as 40% within 5 years [17,18]. The ISUIA Phase 1 and Phase 2 studies showed that posterior circulation aneurysms, especially basilar apex aneurysm, have a higher rupture rate compared with those in the anterior circulation. A similarly increased risk had also been noted for lesions arising from ICA Pcom artery segment, which is traditionally considered to be within the anterior circulation. In 2014, one prospective cohort study developed a practical score (PHASES) that predicts the risk of aneurysm rupture on the basis of the clinical condition and aneurysm characteristics, including hypertension history, age, aneurysm size, earlier SAH, and site of the aneurysm [19]. According to PHASES scores, the 5-year risk of aneurysm rupture in our study Cases 1, 3, and 4 was more than 18%. The ISUIA reported that the surgical mortality and morbidity rates of microsurgical treatment for unruptured aneurysms were 2.7% and 9.9%, respectively. However, endovascular treatment of unruptured aneurysms carries a risk of morbidity up to 5% [20]. Microsurgical treatment has a slightly higher risk of complications than endovascular treatment. However, the risk of rupture after endovascular treatment is higher than that after surgery, with annual rupture rates of 0.2% according to a large systematic review [21]. This evidence suggests microsurgical treatment for complex or giant aneurysms.

Direct clipping of paraclinoid aneurysms with mass effect over the optic apparatus is usually considered the first choice of treatment [4,22]. The goal is not only to occlude the aneurysm but also to ameliorate the mass effect from the aneurysmal sac *per se*, which usually leads to progressive visual impairment prior to decompression of the aneurysm. Microsurgical clipping has been reported to achieve a remission rate of more than 90% for patients with visual disability from the aneurysm, especially when aneurysms of the anterior circulation compress the anterior visual pathway [23,24]. Gonzalez et al [25] reported that the complete obliteration rate after endovascular therapy for giant aneurysms was only 56%. In addition, endovascular treatment provides less relief from mass effect [26]. Although endovascular coil therapy may lead to better initial occlusion of the aneurysm sac with preservation of the ICA, visual impairment does not improve after coil embolization alone, and additional salvage surgical procedures may be necessary to relieve mass effect and improve visual outcome.

Surgical clipping with an EC–IC bypass has been shown to result in a lower mortality rate than clipping without bypass if surgery for complex or giant aneurysm is necessary. However, the benefits from EC–IC bypass may be offset when the revascularization is performed without preparation, as in emergencies such as parent artery occlusion or tear of the aneurysm neck [12]. The current study Cases 1 and 2 were emergencies including a postaneurysm trapping ischemic stroke and aneurysm neck tear during aneurysm clipping surgery. Although Case 2 had better reestablished vasculature after bypass surgery, there was a long ischemic time during emergency bypass surgery. The increased morbidity is usually attributed to prolonged ischemia in the brain and insufficient brain protection procedures. Meticulous preparation and performance of EC–IC bypass prior to complex and giant aneurysm clipping not only avoids cerebrovascular ischemia but also obviates the risk of rupture of untreated aneurysms.

5. Conclusion

Avoiding neurogenic deficits attributed to hemodynamic insufficiency during complex or giant cerebral aneurysm surgery is challenging. EC–IC bypass provides additional blood flow to ensure complete occlusion of complex aneurysms and remarkable improvement of aneurysmal mass effect without producing cerebral ischemic morbidity.

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