Acta Neurochir (2014) 156:2071–2077
DOI 10.1007/s00701-014-2212-8

HOW I DO IT - VASCULAR

How I do it: treatment of blood blister-like aneurysms of the supraclinoid internal carotid artery by extracranial-to-intracranial bypass and trapping

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Received: 14 May 2014 / Accepted: 20 August 2014 / Published online: 9 September 2014

Abstract

Background Blood blister-like aneurysms (BBAs) pose a significant challenge to neurosurgeons and neuro-interventionalists. These fragile broad-based aneurysms have a propensity to rupture with minimal manipulation during surgical or endovascular explorations because, unlike saccular aneurysms, they lack all layers of the arterial wall. Aneurysm trapping with extracranial-intracranial (EC-IC) bypass is a safe and durable treatment for BBAs.

Methods We describe our technique and the guiding principles for surgical bypass and trapping of BBAs of the supraclinoid internal carotid artery (ICA).

Conclusions Treatment of BBAs of the supraclinoid ICA remains difficult. Aneurysm trapping with EC-IC bypass treats BBAs definitively by eliminating the diseased segment of the ICA. We have found the technique and principles described here to be safe and durable in our hands.

Keywords Blood blister-like aneurysm · Bypass surgery · Surgical technique

Abbreviations

ACA	Anterior cerebral artery
AchoA	Anterior choroidal artery
BBAs	Blood blister-like aneurysms
BTO	Balloon test occlusion
EEG	Electroencephalography
ECA	External carotid artery
ICA	Internal carotid artery
ICG-VA	Indocyanine green videoangiography
MCA	Middle cerebral artery
PCA	Posterior cerebral artery
PcomA	Posterior communicating artery
RA	Radial artery
SAH	Subarachnoid hemorrhage
SCM	Sternocleidomastoid

Electronic supplementary material The online version of this article (doi:10.1007/s00701-014-2212-8) contains supplementary material, which is available to authorized users.

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Introduction

Aneurysms arising from the supraclinoid internal carotid artery (ICA) at non-branching sites include both saccular and blood blister-like aneurysms (BBAs). Saccular aneurysms and BBAs can be distinguished by angiographic findings, but may require direct surgical observation for final diagnosis. These aneurysms do not have an aneurismal neck and are often quite small, making conventional open or endovascular treatment difficult. Moreover, BBAs are thin-walled and tend to rupture with minimal manipulation. Conventional clipping, which reliably treats saccular aneurysms, may be dangerous with BBAs given the thin, fragile wall and poorly defined neck.

Here, we describe the principles of EC-IC bypass surgery with aneurysm trapping in treatment of BBAs. This has been a safe and durable treatment for this unique and challenging aneurysm [1].

Relevant surgical anatomy

The intradural ICA extends from the distal dural ring to the bifurcation of the anterior cerebral (ACA) and middle cerebral arteries (MCA). BBAs are aneurysms arising from the anteromedial wall of the supraclinoid ICA where no branch arises [2–5]. These are distinct from saccular aneurysms, and are more like dissecting aneurysms or pseudoaneurysms without a true neck; however, there is no intimal flap as seen in true dissecting aneurysms. The normal ICA wall is absent, and only fragmented adventitia and fibrous tissue prevent rupture of these fragile aneurysms. The branches of the supraclinoid ICA, particularly the anterior choroidal artery (AchoA), the posterior communicating artery (PcomA), and the PcomA perforators must be considered carefully when choosing treatment options.

Description of the technique

Regardless of the chosen treatment for BBAs, whether with trapping, clipping, or wrapping, whether performed with or without bypass, the management of BBAs should be guided by detailed knowledge of the vascular anatomy, the unique pathology of this aneurysm, and knowledge of the specific risks and benefits of the different surgical techniques.

Opening

We elect to perform a modified orbitozygomatic approach to maximize the exposure and to minimize brain retraction. The head is rotated to the contralateral side 20–30 degrees, with the patient in a supine position. Care should be taken to preserve the superficial temporal artery during initial opening as a backup plan if radial artery bypass cannot be completed successfully. The subfascial dissection is used to elevate the temporalis fascia and muscle to preserve facial nerve branches. As we describe elsewhere, the superolateral orbital rim is removed and the sphenoid ridge flattened to facilitate full exposure of the supraclinoid ICA; this is particularly helpful in cases of BBAs [6]. The distal Sylvian fissure is dissected widely to reduce the use of retractors. We prefer exposing all M2 branches and the very distal M1 segments of the MCA for performing bypass. Until we prove that the bypass is patent, we do not proceed with proximal Sylvian or basal cistern dissection to avoid disturbing the BBA, as premature rupture of BBA may cause a catastrophic outcome, defeating the purpose of performing the bypass (Please see the video of case 2).

Proximal anastomosis

Subsequently, we then direct our attention to the vascular exposure in the neck. After making a vertical incision over the anterior border of the sternocleidomastoid (SCM) muscle, the platysma and the superficial cervical fascia are opened, and the carotid sheath is identified under the SCM. The common, external, and internal carotid arteries are all exposed. This exposure should develop circumferential control of the ICA in the neck for proximal control if needed in the case of early intraoperative rupture. We prefer using the ECA for proximal anastomosis in an end-to-side fashion. Sometimes, however, this may not be possible due to short graft length or an unfavorable configuration. In these circumstances, end-to-end anastomosis is preferred, as demonstrated in the presented case (Please see the video of case 1).

Arterial bypass graft harvesting

The radial artery is our preferred bypass graft. An Allen's test is performed preoperatively and the non-dominant extremity is selected as the harvest site, if possible. The arm is abducted and externally rotated. The incision is made on the volar aspect of the arm for an open procurement. A Harmonic scalpel (Ethicon, Cincinnati, OH, USA) is preferred for dissection and cautery of the side branches. The RA is procured as a pedicle. The RA is taken first, and backflow through the palmar arch and RA is demonstrated. The proximal and distal ends, as well as the ventral surface of the RA are marked. After procurement, the RA is placed in a solution of blood (40 ml), heparin (5,000 Units), papaverine (60 mg), and verapamil (30 mg).

Bypass

Adventisectomy is performed on the ECA and on both ends of the RA graft. We perform the distal anastomosis prior to the proximal anastomosis. A 14-gauge pediatric chest tube is used to create a preauricular tunnel between the cervical and the cranial incisions through which the RA graft is passed. After tunneling the RA graft, we wrap any exposed portions with papaverine-soaked Gelfoam and cotton patties.

An M2 branch that is size-compatible and resting in a good configuration for distal anastomosis is selected. If there is no size mismatch, we prefer using the non-dominant M2 branch to avoid more prominent ischemic events in case of thrombosis of the recipient artery. Prior to the temporary clipping of the M2 for the anastomosis, we obtain baseline electroencephalography (EEG) and increase the FiO_2 to 100 % and the arterial blood pressure by 10–15 mmHg. Just prior to performing the arteriotomy, we place temporal and frontal self-retaining retractors to protect the brain during anastomosis, and we give 2,000–3,000 units of intravenous heparin. Also, we load the patient with 300 mg of rectal aspirin immediately prior to the bypass procedure (once we are certain that we are performing bypass). The arteriotomy is made with an arachnoid or ophthalmic knife and extended with microscissors. The lumen of the M2 branch is irrigated with heparinized saline. The RA graft is anchored at each corner of

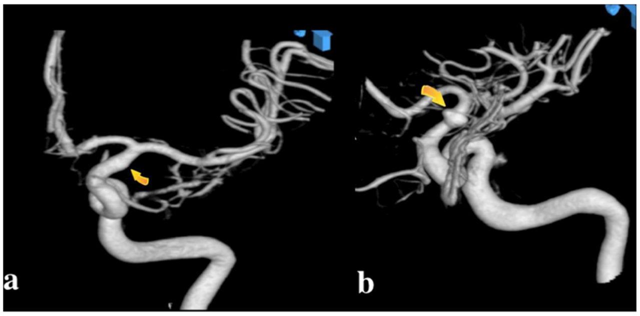


Fig. 1 An initial 3D angiogram shows a questionable, very subtle bump (*arrow*) on the antero-medial wall of the supraclinoid ICA without any obvious aneurysmal features (**a**) and post-bleed day 9 repeat angiogram shows a BBA (*arrow*) on the same localization (**b**)

the arteriotomy using 10–0 nylon suture. The back wall of the anastomosis is then secured with interrupted 10–0 nylon stitches. The front wall is secured in the same fashion. We generally put 6–8 sutures on each side of the anastomosis. After removing the temporary clips, good backflow should be observed.

After confirming the patency of the distal anastomosis, the proximal anastomosis is performed. A segment of the ECA that is sufficiently long and branch-free is prepared for proximal anastomosis. The proximal ECA is anastomosed to the RA graft with 8–0 interrupted nylon suture. The technique is similar to that performed at the distal anastomosis. Care is taken to back-bleed the RA graft and the ECA to prevent thrombotic or air embolism. We prefer to confirm the patency of the graft both with indocyanine green video angiography (ICG-VA) and micro-Doppler when the bypass is complete.

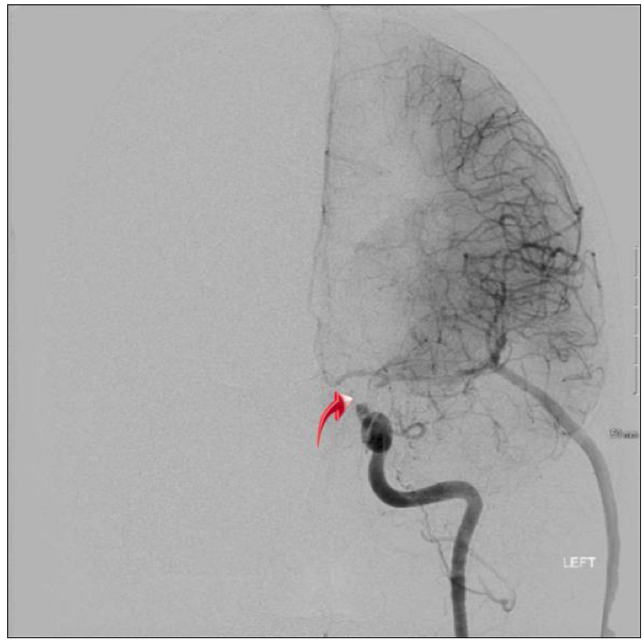
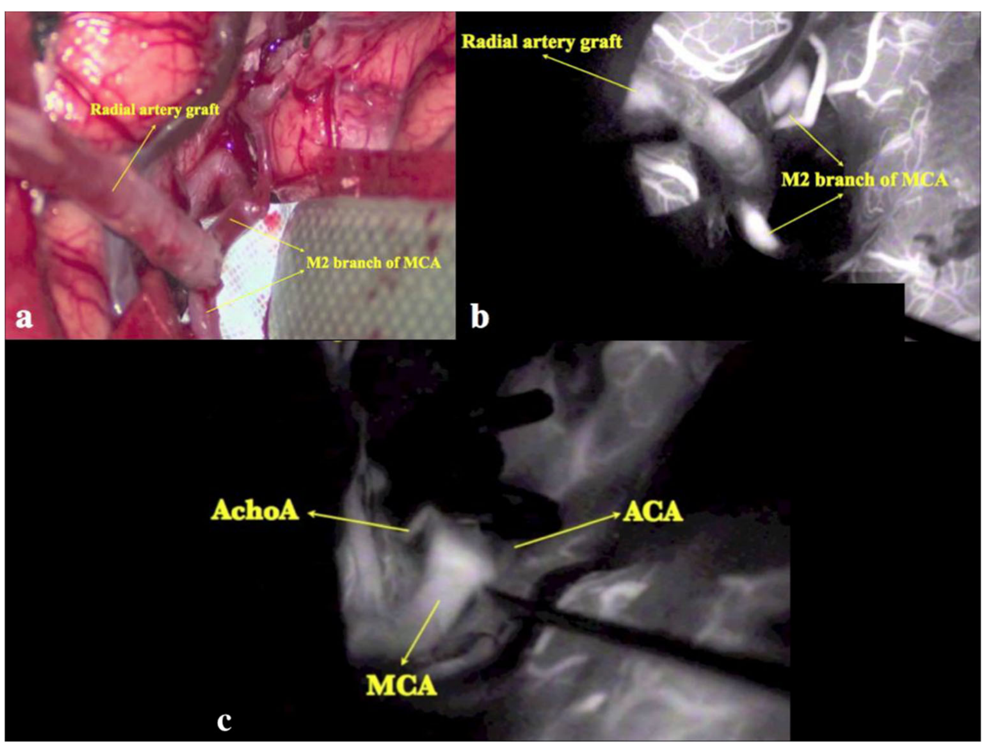


Fig. 3 Postoperative angiogram shows complete elimination of the diseased segment of the ICA and back-filling of the supraclinoid ICA and patent bypass with good filling of the MCA and ACA territories

Trapping

Microsurgical subarachnoid dissection, proceeding from the proximal Sylvian cistern to the carotid and chiasmatic cisterns, is performed carefully under high magnification. Sharp dissection is preferred due to the fragile aneurismal wall and the increased propensity for intraoperative rupture with BBAs. At

Fig. 2 Intraoperative photograph (**a**) and ICG-VA (**b**) demonstrate the patent distal anastomosis. ICG-VA after final trapping demonstrates filling of the ACA, MCA, and AchoA (**c**)



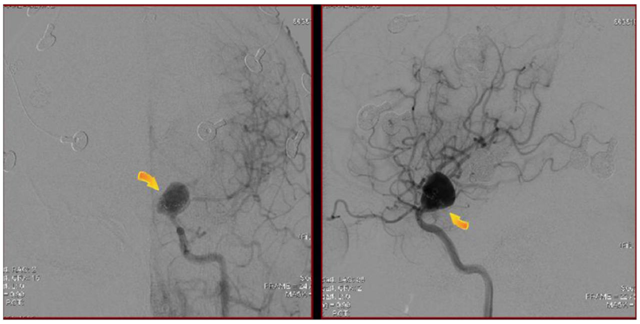


Fig. 4 Angiogram in post-bleed day 16 shows rapid recurrence of the aneurysm despite initial coiling on the day of presentation

this stage, dissection of all of the branches of the supraclinoid ICA should be performed, most importantly the AchoA, the PcomA, and the uncal artery. Any artery that is left unidentified may reduce the chances of complete trapping of the segment of the ICA and increase the risk of an ischemic complication. A permanent clip is placed on the proximal ICA distal to the ophthalmic artery. Temporary clips are then placed on the MCA and the ACA. Consideration must be given to the PcomA to completely trap the aneurysmal segment of the ICA. If the PcomA can be preserved with permanent clip placement on the ICA, this is ideal. If the PcomA cannot be preserved, a permanent clip is applied to the PcomA at its origin from the ICA, away from its perforators. ICG-VA can be used to demonstrate effective filling of the PcomA perforators from the posterior circulation. If the ipsilateral P1 segment of the posterior cerebral artery (PCA) is hypoplastic, every effort should be made to exclude the PcomA from the trapped segment of the ICA. If this is not possible, a double bypass procedure, such as from the superficial temporal artery to the PCA, should be performed. The ICA is then clipped distally to the aneurysm but proximally to the AchoA with extreme care in order to preserve AchoA. After removing the ACA and MCA temporary clips, we use ICG-VA and micro-Doppler to confirm both complete aneurismal trapping and good patency of the AchoA, the ACA, and the MCA.

Closure

A layer of Surgicel (Ethicon, North Ryde, NSW, Australia) is placed over both anastomosis sites. The dura is partially closed, leaving an opening where the RA graft enters the intradural space. The orbital rim and the bone flap are replaced with titanium plates and screws. A loose dressing is applied to the neck and the head.

Indications

We choose a definitive treatment modality, aiming to completely eliminate the BBA. The unique and threatening pathophysiology of these aneurysms makes non-operative management a less favored option.

When considering trapping of the involved segment of the ICA, balloon test occlusion (BTO) is the ideal test to evaluate whether trapping would be tolerated. However, because all of the patients with true BBAs present with subarachnoid hemorrhage (SAH), and most of these are high grade (Hunt & Hess grade 3 to 5) SAH, obtaining an optimal result from BTO may not be possible. The patient's clinical condition may not allow the cooperation necessary to undergo BTO. Because of these factors, we prefer performing EC-IC bypass with trapping only after a thorough angiographic evaluation. We place special emphasis on evaluating collateral circulation, venous phase (with and without cross-compression), and potential bypass conduits such as superficial temporal artery. If we think collateral blood supply is not sufficient, we then choose high flow bypass.

Limitations

In the case of a BBA diagnosis, treatment options should be individualized for each patient. Despite advances in contemporary surgical and endovascular treatment options, BBAs carry a significant risk in terms of treatment. The cons and

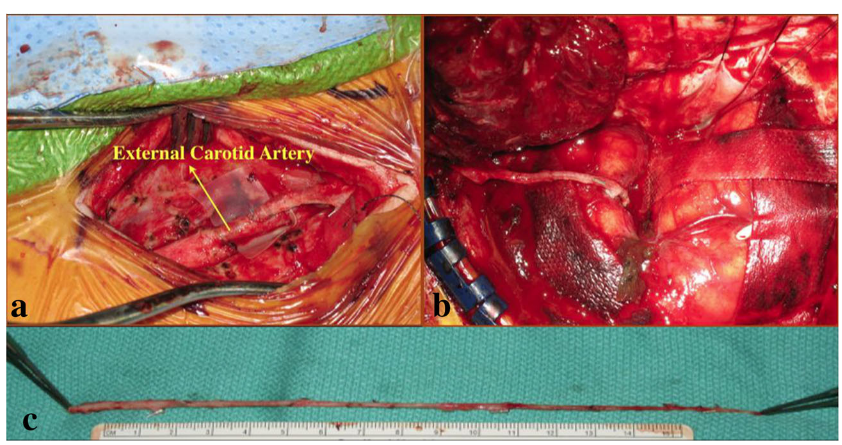


Fig. 5 Proximal end to side anastomosis with the ECA (**a**), and the distal end to side anastomosis with the M2 branch of MCA (**b**), and the arterial graft (**c**) are shown

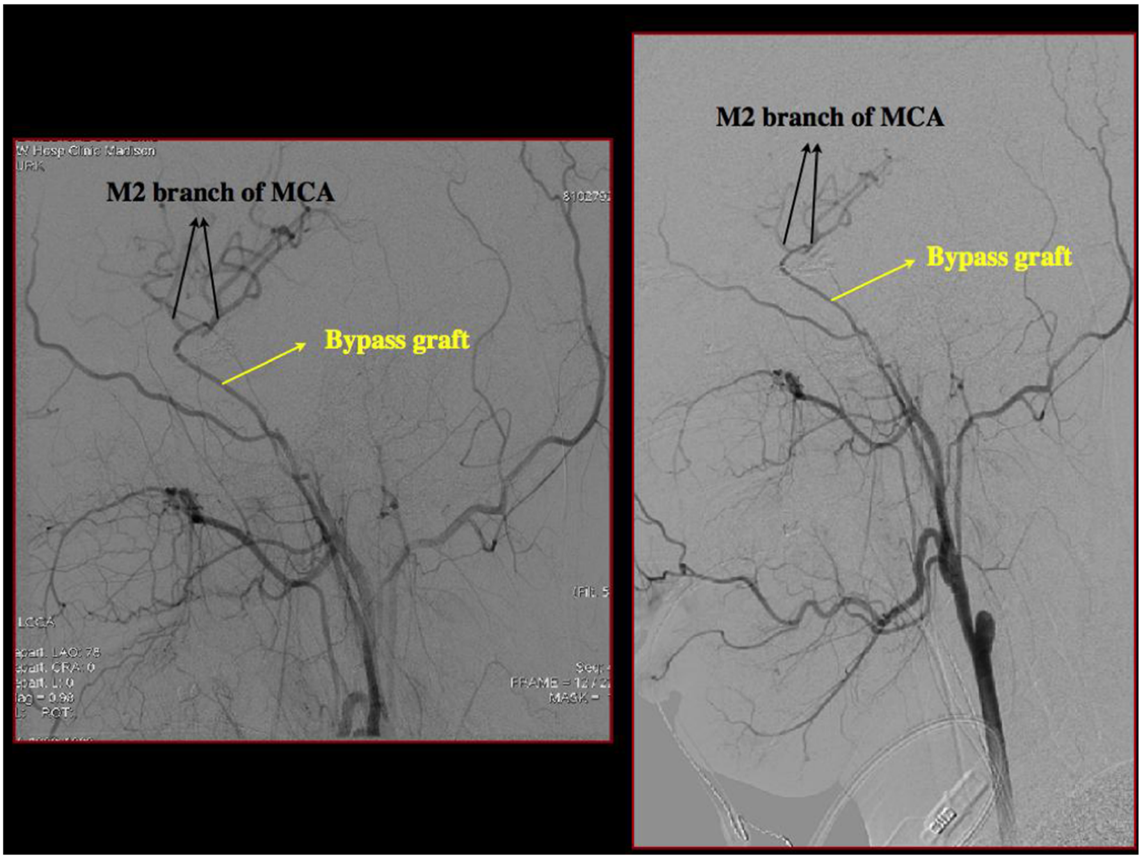


Fig. 6 Postoperative angiogram shows filling of the MCA branches via the bypass with complete aneurysm trapping

pros of every treatment option should be discussed with the patient and/or family in detail before the surgery.

How to avoid complications

- Recognition of the BBA as a distinct entity from saccular aneurysms is key to complication avoidance [5]. Simple clipping may be a dangerous and inappropriate treatment of most BBAs.
- Non-invasive angiography may not adequately diagnose these dangerous aneurysms. Careful catheter-based angiography may also overlook BBAs unless dedicated oblique views are obtained. In the case of a negative angiogram, a repeat angiogram is warranted.
- Catheter-based angiography and BTO can help the surgeon understand the collateral flow available, the necessity of revascularization, and the type of revascularization.
- Ischemic hand complications should be avoided by a preoperative Allen's test.
- Careful back-bleeding and minimizing temporary clipping time are measures to reduce the risk of ischemic complications.
- Wide Sylvian fissure dissection and thorough subarachnoid cistern dissection are critical. A wide Sylvian exposure will greatly reduce the need for retractors.
- Careful dissection and identifying all of the ICA branches will ensure definitive trapping of the aneurysm without arterial inflow/outflow. Critical branches of the ICA should be preserved to prevent ischemia.
- Comfort with all methods of arachnoid dissection, particularly sharp dissection in the region of the fragile BBA, is important to minimize the risk of intraoperative rupture.
- The importance of close post-operative care cannot be stressed enough. This should include an antiplatelet agent, close neurologic monitoring, close hemodynamic monitoring, and close graft patency monitoring.

Specific perioperative considerations

Diagnosis

BBAs can be diagnosed by non-invasive or conventional digital subtraction angiography. Because BBAs are often quite small, the diagnosis can be elusive. Though digital subtraction catheter angiography remains the gold standard for diagnosis, BBAs can be difficult to detect because these aneurysms are frequently superimposed on the ICA, appearing as a shadow or double density on both AP and lateral views. A 30-degree oblique angiogram may demonstrate these aneurysms most effectively [7]. In cases of SAH of unknown etiology, the supraclinoid ICA, particularly the antero-medial wall, should be carefully evaluated to exclude a BBA. If there are subtle or non-obvious findings consistent with an aneurysm upon initial angiography, as demonstrated in our case presented here (Fig. 1), the angiogram should be repeated. Shigeta et al. reported that 30 % of initial angiograms of patients with BBAs were negative [8]. (Figs. 2, 3, 4, 5 and 6).

Postoperative course

On the same day or the following day, the patient undergoes angiographic evaluation. We take care to mark the projection on the skin of the bypass graft path to prevent undue compression of the graft from medical devices such as O_2 masks. We nurse the patients with their neck straight for several days post-operatively to prevent kinking of the bypass graft in the neck. Aspirin is given on the day of the procedure and continued post-operatively to reduce the risk of thrombosis. Close neurologic monitoring and Doppler monitoring of the bypass graft is performed in an intensive care setting for at least 3 days post-operatively. Close monitoring for vasospasm, and aggressive treatment, is necessary to prevent ischemic complications.

Specific information to give to the patient about surgery

Contemporary treatment strategies to treat these aneurysms include ICA trapping with or without bypass, parallel clip placement, clip placement with wrapping, encircling clip placement, and endovascular treatment with flow diverting stents or primary coil embolization with or without stent placement [2, 6]. Regardless of the technique used, the complication rate and mortality of BBA treatment remains high [9, 10].

A summary of ten key points

1. BBAs are a unique pathology, and paradigms for the treatment of saccular aneurysms should not be generalized to BBAs.
2. BBAs have a fragile wall and an ill-defined neck, making direct repair with clipping or endovascular techniques challenging.
3. BBAs have a tendency to rupture prematurely in the course of treatment.
4. Preoperative catheter-based angiography is helpful to define the aneurysm, the local vascular anatomy, collateral circulation, venous asymmetry, and the potential donor/graft options.
5. Be mindful of donor site complications, using an Allen's test as necessary to ensure an adequate donor and to minimize complications.
6. Wide Sylvian fissure dissection and meticulous dissection of the ICA branches are imperatives for complication avoidance in bypass and trapping.
7. Temporary clipping time should be minimized by efficient intraoperative technique and thorough preoperative preparation. Comfort with vascular anastomosis should be obtained prior to attempting this demanding surgery.
8. Manipulation of blood pressure and oxygenation along with thoughtful use of neuromonitoring techniques can reduce the risks of ischemic complications.
9. Selection of the appropriate treatment for patients with BBAs requires detailed knowledge of the vascular anatomy, the treatments, and the patient selection criteria. If this is done carefully, we have found that patients can have a very good outcome with minimal morbidity.
10. Trapping with EC-IC bypass for treatment of supraclinoid ICA BBAs is a safe, reliable, and durable treatment.

Conflict of interest None.

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