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HOW I DO IT - VASCULAR NEUROSURGERY - ANEURYSM

# Fourth-generation bypass and flow reversal to treat a symptomatic giant dolichoectatic basilar trunk aneurysm

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## Abstract

**Background** Giant dolichoectatic basilar trunk aneurysms have an unfavorable natural history and are associated with high morbidity, but their neurosurgical treatment is complex and challenging.

**Methods** Flow reversal reconstruction with fourth-generation bypass and proximal vertebral artery clip occlusion is performed via orbitozygomatic craniotomy with the Kawase approach under rapid ventricular pacing.

**Conclusion** Fourth-generation bypass is an innovative, technically challenging, and clinically effective tool in the treatment armamentarium for giant dolichoectatic basilar trunk aneurysms.

**Keywords** Cerebrovascular bypass · Complex cranial · Dolichoectasia · Fourth-generation bypass · Kawase · Skull base · Vertebrobasilar aneurysm · Vertebrobasilar junction

### Abbreviations

| | |
|---|---|
| MCA | Middle cerebral artery |
| OZ | Orbitozygomatic |
| RAG | Radial artery graft |
| SCA | Superior cerebellar artery |

## Relevant surgical anatomy

Treating giant dolichoectatic basilar trunk aneurysms is technically challenging [3–5, 10]. Individualized treatment planning is mandatory, often requires multidisciplinary teams and benefits from skull base techniques (e.g., or-bi-to-zy-go-mat-ic. [OZ] craniotomy, Kawase approach, or transcavernous approach) [1, 2]. Very large basilar aneurysms or those involved with perforators are not amenable to clip reconstruction and require a combined approach, with distal bypass and proximal occlusion to induce flow reversal within the aneurysm [6–9]. Flow reversal attempts to balance aneurysm thrombosis and perforator patency; although the complication risk is high, it offers a compelling treatment strategy for an often fatal disease. We discuss our technical approach to flow reversal treatment of a patient with a complex dolichoectatic vertebrobasilar aneurysm (Figs. 1 and 2; Video 1). The surgical plan included left OZ craniotomy, anterior clinoidectomy, anterior transpetrosal approach (Kawase), M2 middle cerebral artery (MCA) to s2 superior cerebellar artery (SCA) interpositional bypass using a fourth-generation intraluminal suturing technique (type 4A), and proximal clip occlusion of the giant dolichoectatic basilar trunk aneurysm under rapid transventricular pacing.

## Technique description

After inducing general anesthesia, the cardiology team placed a rapid transvenous ventricular pacing apparatus. The patient was positioned supine with the right forearm accessible for radial artery graft (RAG) harvest by the plastic surgery team. A standard left-sided OZ craniotomy was performed, including subfascial dissection for frontalis branch preservation (Fig. 3).

A complete extradural anterior clinoidectomy was performed. Fibrin glue was injected via the carotid-oculomotor membrane to case the cavernous sinus for hemostatic

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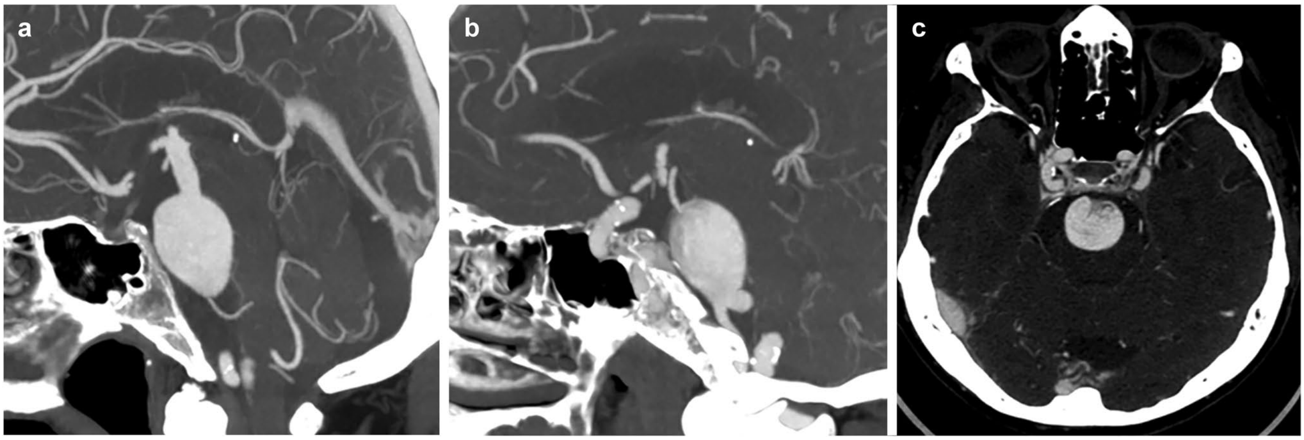


**Fig. 1** Computed tomography angiogram demonstrating the giant fusiform dolichoectatic basilar trunk aneurysm, seen in mid-sagittal (**a**), parasagittal (**b**), and axial (**c**) views. **a** The basilar apex is high-riding. The aneurysm is noted to cause mass effect and compression on the pons. **b** The vertebrobasilar junction is noted to be approximately at the level of the internal auditory canal. Bilateral posterior communicating arteries were absent. *Used with permission from Barrow Neurological Institute, Phoenix, AZ*

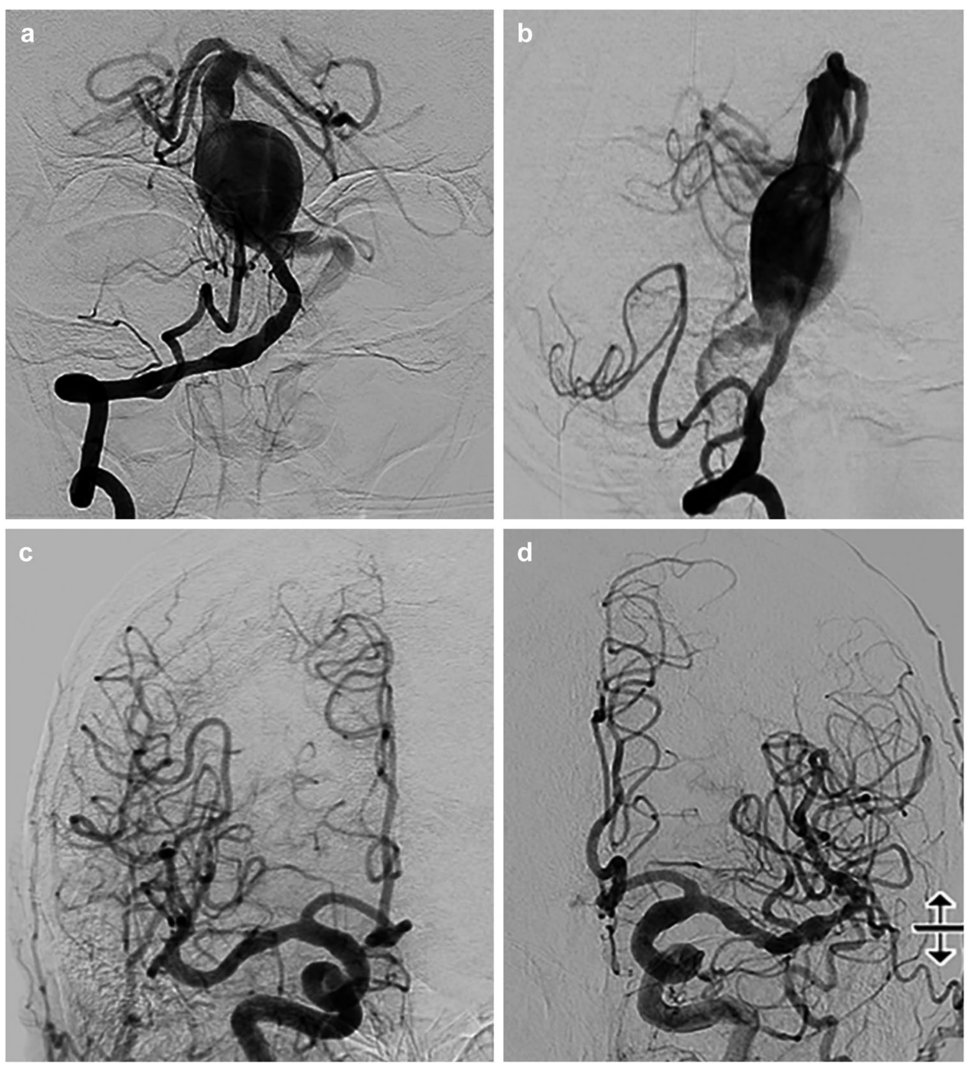


**Fig. 2** Diagnostic cerebral angiogram demonstrating the giant fusiform dolichoectatic basilar trunk aneurysm. **a** Posterior-anterior projection, transfacial view of a right vertebral artery injection demonstrates dominant flow into the aneurysm via the left vertebral artery, with considerable contribution from the right vertebral artery as well. Note the umbrella-like angulation of the basilar quadrifurcation, consistent with the high-riding basilar apex. **b** Lateral projection, right vertebral artery injection, corroborates this finding. **c** Right and **d** left common carotid injections, posterior-anterior view, demonstrating the bilateral absence of posterior communicating arteries. In cases where a posterior communicating artery can be identified, an Allcock test may be performed to determine the viability of this artery to supply the posterior circulation. *Used with permission from Barrow Neurological Institute, Phoenix, AZ*

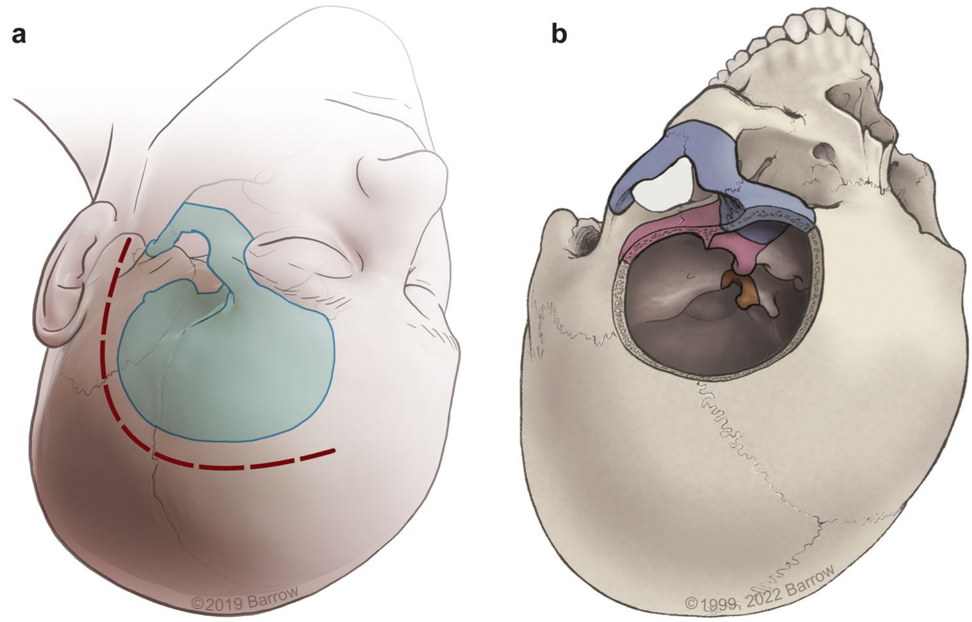


**Fig. 3** Steps of the surgical approach. **a** A curvilinear incision (*red dashed line*) is made along the left frontotemporal region, with the head positioned for an orbitozygomatic-pterional approach (*green shaded area*), clinically completed using the two-piece technique. **b** Following pterional craniotomy, the orbitozygomatic osteotomy is completed (*blue shaded area*), with lateral drilling down to the middle fossa floor, as well as extradural anterior clinoidectomy (*purple shaded area*). Following initial intradural dissection, the posterior clinoid was also removed (*orange shaded area*). *Used with permission from Barrow Neurological Institute, Phoenix, AZ*

control. The dissection was carried along the middle fossa floor, and the Kawase triangle was drilled at the petrous temporal bone for posterior fossa access and proximal vertebrobasilar control (Fig. 4).

The dura was opened over the sylvian fissure, which was widely split, providing cerebrovascular exposure from the M4 branches down to the opticocarotid, interpeduncular, and crural cisterns, bringing the dolichoectatic basilar aneurysm, superior basilar trunk, and bilateral SCAs into view. Although we anticipated using the P2 segment as the bypass recipient vessel, it was poorly visualized because of the high-riding basilar apex, and the left s2 SCA was selected as the optimal recipient site.

The previously harvested RAG was pressure-distended with heparinized saline and brought up to the surgical field. The deep anastomosis was performed first to avoid obstruction from the proximal reconstruction. An end-to-side RAG-s2 SCA anastomosis was performed using an intraluminal suturing technique for the back wall, which was required due to the s2 configuration. Once the deep anastomosis was

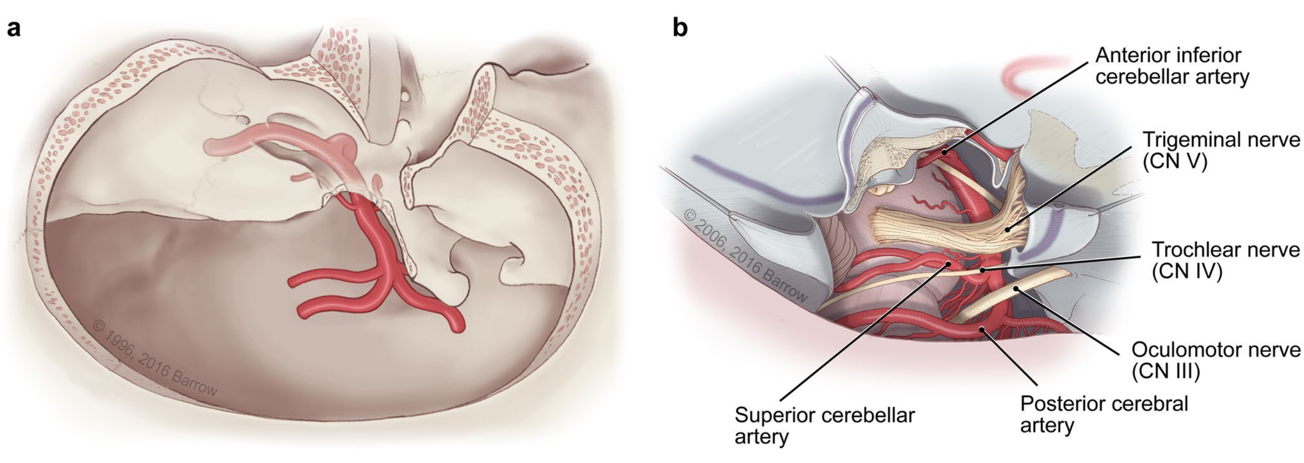


**Fig. 4** **a** The orbitozygomatic-pterional craniotomy affords access to the typical basilar apex region, whereas the addition of the Kawase triangle drilling extends the approach toward the basilar trunk and, in this particular case, to the vertebrobasilar junction. In this manner, potential difficulties posed by the high-riding basilar apex and difficult visualization of the posterior cerebral artery are compensated for by the lower-than-expected access afforded by the Kawase approach. **b** The cisternal view from the typical Kawase approach, visualizing the mid-pontine region between cranial nerve (CN) V and the superior margin of CNs VII/VIII. In this case, this space was largely occupied by the aneurysm. Transvenous rapid ventricular pacing softened the aneurysm and facilitated manipulation, improving visualization in this space. *Used with permission from Barrow Neurological Institute, Phoenix, AZ*

completed, the graft was tunneled up the sylvian fissure, and a recipient site was selected along the superior M2 division because of its more favorable atherosclerotic profile. We performed an end-to-side anastomosis using intraluminal technique for the posterior suture line, completing the M2 (S-E*) RAG (E-S*) s2 intracranial-intracranial interpositional bypass [9].

With the bypass in place, the Kawase approach was used to obtain proximal occlusion. The dura of the tentorium was incised just posterior to the fourth nerve. Rapid ventricular pacing was initiated to soften the aneurysm inflow via the V4 segments. To maximize occlusive strength across the vertebral arteries, large, straight Sugita clips were selected. The ipsilateral V4 segment was readily occluded with a 17-mm straight clip, after which the vertebrobasilar junction was gently mobilized using the initial clip, optimizing visualization of the contralateral vertebrobasilar junction to place another 17-mm clip. An additional 17-mm booster clip was placed on the ipsilateral V4 to secure the closure and complete the flow reversal reconstruction, after which indocyanine green videoangiography was performed to confirm absent proximal filling of the aneurysm and expected retrograde flow from the MCA via the RAG into the s2 and finally the basilar aneurysm (Fig. 5). The wound was closed in layers, with the Kawase space reconstructed using muscle graft and synthetic fibrin glue.

## Indications

The primary indications for treatment were symptomatic brainstem compression from a growing dolichoectatic basilar artery aneurysm and presumed enlargement of a potentially life-threatening lesion with a highly morbid natural history. The need for flow reversal with M2 (S-E*) RAG (E-S*) s2 bypass was indicated by bilateral posterior communicating artery atresia. Other pertinent indications for similar procedures include vertebrobasilar ischemia, insufficiency, or infarction in the setting of a dolichoectatic lesion. Although alternative strategies were considered (e.g., extracranial-intracranial bypass with an occipital artery donor), our experience indicated that successful flow reversal in this setting is empowered by a high-flow intracranial-intracranial construct. Postoperative endovascular sacrifice proximally was considered instead of direct vertebral artery ligation to potentially avoid the need for rapid ventricular pacing and to minimize the need for skull base drilling. This option would be a reasonable alternative strategy; however, our

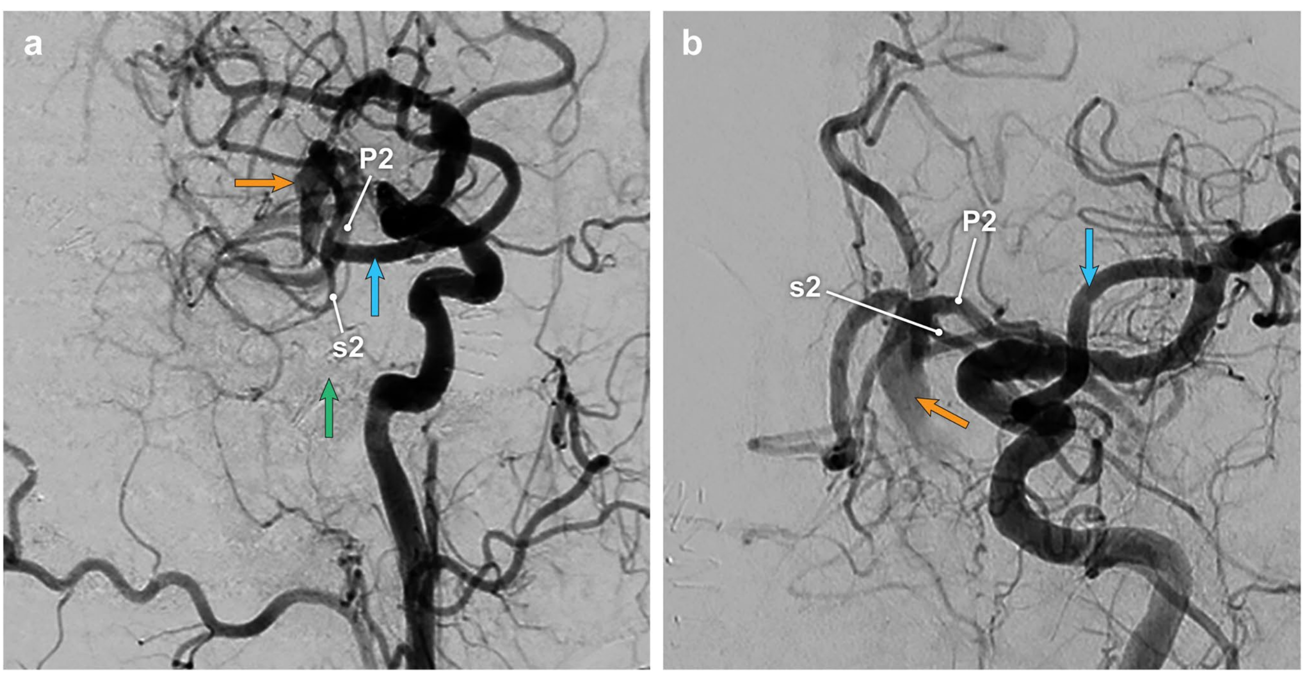


**Fig. 5** Postoperative diagnostic cerebral angiogram. **a** Left common carotid artery arteriogram, lateral view, demonstrating flow through the radial artery graft (*blue arrow*) between the M2 segment of the middle cerebral artery and the s2 segment of the superior cerebellar artery, with retrograde flow into the quadrifurcation and down the aneurysm (*orange arrow*). The inferiorly directed aneurysm clips on the vertebral arteries have been digitally subtracted but can be appreciated (*green arrow*). **b** Left common carotid artery arteriogram, posterior-anterior view, with better visualization of the basilar trunk and aneurysm. This view confirms that all 4 branches of the quadrifurcation are filling. *Used with permission from Barrow Neurological Institute, Phoenix, AZ*

experience indicates that, where feasible, immediate intraoperative proximal occlusion induces a more optimal pattern of flow reversal and coagulation.

## Limitations

Treating dolichoectatic basilar aneurysms is challenging and nuanced. Establishing a balance between aneurysm thrombosis and perforator patency is imprecise and influenced by unpredictable patient- and disease-specific factors that are difficult to control. Technical limitations of surgery include the need for deep recipient vessel suturing and the use of a fourth-generation bypass. Generally, patients with medical complications or a history of advanced cardiac disease may be unsuitable for such a procedure because prolonged anesthesia is required.

## Complication avoidance

Highly sophisticated cerebrovascular bypass or complex cranial operations are subject to a wide range of perioperative complications. Many complications are generic and pertain to specific surgical steps that collectively require manipulating or engaging critical structures (e.g., cranial nerves III and IV, dural venous sinuses, and the petrous internal carotid artery). Minor complications may be associated with RAG harvest. Bypass occlusion may result in brainstem infarction, and aneurysm rupture could result in subarachnoid hemorrhage and death.

## Specific perioperative considerations

We recommend careful preoperative study of detailed, high-quality, multiplanar, multimodality imaging, with particular attention to flow dynamics and key normal or variant structures, including the presence of a patent circle of Willis or other major collaterals. Preferred and alternative sites for donor and recipient anastomoses should be selected and high-risk variations in the patient's individual anatomy, such as persistent fetal vessels, reviewed. Patients should undergo thorough medical clearance, including cardiology assessment for rapid ventricular pacing. Multidisciplinary collaboration is key; for example, collaboration with the hand surgery team is necessary for graft planning, and collaboration with the endovascular team is needed to ensure that all desired views are included and radial access is avoided on the donor side.

During surgery, we recommend using Doppler ultrasound and indocyanine green videoangiography intraoperatively to assess angioarchitecture and bypass reconstruction. Successfully completing a challenging intracranial-intracranial bypass depends on optimizing all factors during exposure, such as resecting the anterior clinoid process and maximal sylvian fissure dissection to provide the widest possible working corridor. We advise using rapid ventricular pacing to soften the aneurysm during manipulation and proximal occlusion, a technique with efficacy similar to hypothermic cardiac arrest but with considerably reduced procedural morbidity. Finally, Sugita clips should be used instead of Yaşargil clips, because increased opening of the blades and increased closing strength are needed across vertebral arteries.

Postoperatively, antiplatelet and anticoagulation strategies must be managed delicately. We routinely load preoperatively with 325 mg of aspirin, then add 75 mg of clopidogrel after postoperative computed tomography or computed tomography angiography has confirmed the absence of hemorrhage or other early complications. Anticoagulation is not routinely administered but may be considered if excessive early thrombus formation is noted on digital subtraction angiography.

## Patient-specific information

Although flow reversal is a high-risk treatment, a favorable outcome is more likely to be achieved with surgery than with natural history or other treatment modalities in appropriately selected patients. Possible major complications include cranial neuropathies, stroke, and death.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s00701-022-05292-w.

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**Author contribution** All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Christopher S. Graffeo, Visish M. Srinivasan, Sunil Manjila, and Michael T. Lawton. The first draft of the manuscript was written by Christopher S. Graffeo, Visish M. Srinivasan, and Sunil Manjila, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

## Declarations

**Ethical approval** This is an observational study. The Barrow Neurological Institute Research Ethics Committee has confirmed that no ethical approval is required.

**Informed consent** Patients featured in the retrospective case illustrations provided written informed consent for diagnosis and treatment.

**Conflict of interest** The authors declare no competing interests.

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**Key points**

1. Flow reversal is a preferred neurosurgical treatment for dolichoectatic vertebrobasilar aneurysms.
2. In the absence of natural collaterals (e.g., posterior communicating artery), flow reversal can be achieved satisfactorily by creating a surgical conduit using bypass techniques.
3. Access to the upper basilar trunk is best facilitated by the OZ craniotomy with a wide sylvian fissure split.
4. The addition of the Kawase approach offers a direct trajectory to the ventral pontine region, which may house the vertebrobasilar junction, distal V4 segments, or the dolichoectatic aneurysm itself.
5. Although the normal size, configuration, flow, and morphology render the posterior cerebral artery our preferred recipient vessel, the SCA is an important alternative that may have distinct advantages in certain anatomic circumstances.
6. To incorporate an immobile recipient vessel into a bypass construct, use of a fourth-generation technique is required, in particular intraluminal suturing (type 4A bypass), which facilitates a wide range of new bypass configurations.
7. For bypass operations that require multiple anastomoses, especially intracranial-intracranial interpositional bypasses, we recommend completing the deepest bypass first. This avoids interference of the superficial bypass elements with the deeper work, minimizes tension on the graft, and puts the more challenging work earlier in the operation, when fatigue is less pronounced.
8. Although its feasibility depends on the individual morphology, the Kawase approach may facilitate intraoperative proximal clipping after the bypass, potentially eliminating the additional risks associated with endovascular occlusion.
9. Antiplatelet medication is critical to maintaining a patent bypass, and we recommend preoperative loading with aspirin 325 mg followed by clopidogrel 75 mg after surgery. Anticoagulation recommendations are less well-established, but heparinization may be indicated in patients with robust early thrombosis.
10. Rapid transvenous ventricular pacing can help soften the aneurysm, which in turn facilitates visualization, clip reconstruction, and other key intraoperative maneuvers.