

# Surgical Management of Posterior Circulation Aneurysms: Defining the Role of Microsurgery in Contemporary Endovascular Era

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## 1. Introduction

In the period between 1930 and 1960, surgical treatment of posterior circulation aneurysms were only possible by indirect trapping or parent vessel ligation. Olivecrona was said to have performed the first unplanned trapping of a posterior inferior cerebellar artery (PICA) aneurysm in 1932. In 1937, Tonnis inadvertently opened a cerebellopontine angle aneurysm having assumed that it was a tumour preoperatively<sup>1</sup>. Dandy performed the first vertebral artery ligation beneath the atlas to treat a vertebral aneurysm in 1944<sup>2</sup>. In 1948, Schwartz<sup>3</sup> reported his experience with direct surgical approach to a large basilar artery aneurysm and successfully trapped it using silver clips. Logue<sup>4</sup> and Mount<sup>5</sup> formally described the techniques of vertebral artery and basilar artery ligation in 1958 and 1962, respectively.

By the 1960s, neurosurgeons were attempting direct surgical clipping of vertebrobasilar aneurysms. Early attempts, however, were not met with great success. Dr Charles Drake from Canada published his initial experience with direct surgical clipping of four ruptured basilar bifurcation aneurysms in 1961<sup>6</sup>. Although two of his patients died postoperatively, the two survivors made dramatic functional recoveries. He concluded that 'direct surgical attack was feasible and worthwhile under exceptional circumstances, when life was threatened by repeated haemorrhages'. Dr Ken Jamieson from Australia reported 19 surgical cases in 1964, 10 of whom had died and 5 were left with severe morbidity<sup>7</sup>. He commented 'it is clear that the basilar bifurcation is no place for the faint of heart. Only time and greater experience will indicate whether it is a place for neurosurgeons at all.'

The introduction of the surgical microscope to neurosurgery in the late 1960s and their propagation in the 1970s, 1980s and through to the 1990s greatly influenced the results of aneurysm surgery. Perhaps the greatest impact of the operating microscope was not just in enhancing the results of experienced aneurysm surgeons, but in accelerating the learning curve of young neurosurgeons that enabled them to master microsurgical skills and achieved competitive results within a shorter period of time. Worldwide reported surgical mortality rates for posterior circulation aneurysms have dropped from 34.4% in the 1960s to

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7.5% (1970s), 5.6% (1980s), 6.0% (1990s) and 5.0% in the new millennium. Surgical morbidity averaged between 9.8% and 12.8% throughout this time period.

The invention by Guglielmi<sup>8</sup> in the early 1990s to treat intracranial aneurysms by detachable platinum coils once again revolutionised the practice of cerebrovascular neurosurgery. This change was most dramatic and rapid for aneurysms located in the posterior circulation where surgical approaches continued to impose significant morbidities to the patients. By the end of 1990s, endovascular treatments of posterior circulation aneurysms were already well established in many centres across the United States<sup>9,10,11,12</sup> and Europe<sup>13,14</sup>. The International Subarachnoid Aneurysm Trial (ISAT)<sup>15</sup>, which compared endovascular coiling to microsurgical clipping, included only 58 patients (2.7%) with posterior circulation aneurysms from their cohort of 2143 because most authors by that stage did not perceived clinical equipoise between the two treatment modalities for aneurysms in this location. Endovascular procedures were regarded as the new promises for treatment of posterior circulation aneurysms.

Two decades on, we learnt that the effectiveness of endovascular treatment, measured by its durability, is a major technical limitation. Complete obliteration is frequently not achieved. Overall, recurrent filling is seen in 15% of aneurysms on angiograms obtained at 6 months after treatment. Longer term follow up in most series suggest complete obliteration rate is possible in just over 50% of coiled posterior circulation aneurysms. This carries significant implications on retreatments, monitoring and risk of rebleeding for many patients.

Until endovascular techniques evolve to a point where recurrence and rebleeding rates are within acceptable limits, surgery remains a viable and competitive treatment option for aneurysms of the vertebrobasilar system. The challenge for contemporary vascular neurosurgeons is to understand the differing but complementary role each treatment modality currently has to offer, and to maintain the proficiency and technical skills to deal with an emergence of complex and recurrence of previously coiled aneurysms.

## **2. The role of endovascular coiling for posterior circulation aneurysms**

Endovascular therapy has changed the way we practice cerebrovascular neurosurgery. In the past, endovascular techniques were used to occlude aneurysms when there is 'anticipated surgical difficulty', 'failed clipping', 'patient or physician preference', and 'poor medical condition'. Today, the reverse appears to be true. Endovascular therapy has largely replaced microsurgery as the firstline treatment modality for aneurysms located in the posterior circulation. In many neurosurgical centres in recent years, this trend is even more evident for unruptured posterior circulation aneurysms.

The essential characteristic and therapeutic goal of the endovascular procedure is to induce thrombosis within the aneurysm by the deployment of platinum microcoils. From a neurointerventional perspective, the key determinant for success is aneurysmal morphology, not so much location. Small aneurysms with small necks and those at a right angle to blood flow are considered appropriate for endovascular procedures. Because of the complexity or the infrequency (therefore negative impact upon confidence of competence) of surgical access to the posterior circulation, endovascular repair has gained dominant mode of treatment in this location. Other important factors to consider whether to treat or

not and which mode of treatment to employ include the patient's clinical status and the available institutional expertise. Elderly patients, or those in poor clinical grade post subarachnoid haemorrhages, may be better treated using endovascular techniques irrespective of aneurysm morphology.

Although good data is available regarding endovascular repair by means of coiling, many aneurysms are now repaired with more complex techniques including additional stents, bioactive coils, balloon re-modelling, and the addition of ethylene-vinyl alcohol copolymer and flow diversion stents. Each of these techniques offers promise to deal with problems that the simple coiling procedure was found wanting. However, with complexity comes complications, and their risks and expectations of treatment await further experience and analysis.

Not all aneurysms are amenable to endovascular treatment. For large or wide-necked aneurysms, or where the dome-to-neck ratio is less than 2, coiling is less effective. In this situation, aneurysm neck and parent vessel may be best reconstructed by microsurgical techniques. Other factors that may limit successful endovascular aneurysm occlusion include inadequate endovascular access or the presence of unstable intraluminal thrombus. When an arterial branch is incorporated in the neck of an aneurysm, as in the case of many basilar bifurcation lesions, effective endovascular treatment can be difficult.

Observational studies suggest that endovascular occlusion of ruptured aneurysms is comparable to that of conventional microsurgery in the short term and can prevent early rebleeding. These studies suggest that endovascular techniques provide protection against rebleeding in the first few months, when rebleeding occurs most frequently. A review of the literature on endovascular treatment outcomes for both ruptured and unruptured posterior circulation aneurysms is demonstrated in Table 1.

In summary, around 70 to 91% of patients with posterior circulation aneurysms achieve independence (mean 85%) if treated by endovascular techniques. The overall morbidity is 4.4% (range 0 to 9.6%) and mortality is 9.1% (range 0 to 18.2). The risk of post coiling haemorrhage is 1.5% out of the 961 reported cases between 1990 to 2005 (Table 1).

The rate of complete occlusions is 52.1% (compared to >90% in most surgical series)<sup>16 17</sup>. The degree of initial occlusion has important ramifications on retreatments, monitoring, and risks of rehemorrhages. Long-term results of the ISAT suggested that rebleeding rate is 3 times more likely in patients who have recurrent aneurysms from incomplete coiling than patients with completely treated aneurysms. Of those patients that experienced rebleeds, mortality rate was up to 70%<sup>18</sup>. It is therefore prudent that younger patients with unruptured posterior circulation aneurysms be recommended for surgical management where long-term durability by this technique is an advantage.

### **3. The role of microsurgery for posterior circulation aneurysms**

According to the International Study of Unruptured Intracranial Aneurysms (ISUIA), unruptured posterior circulation aneurysms, particularly at the basilar bifurcation, carry a more aggressive risk of rupture than that of similarly sized lesion located in the anterior circulation<sup>19</sup>. Over a five-year period, aneurysms over 6mm diameter bear a cumulative risk of rupture of at least 15%. This compares to 2.6% for those in the anterior circulation.

Therefore, Younger patients (age <50 years) with unruptured posterior circulation aneurysms should be treated, given the accumulated risk of rupture during a period of many years. Although endovascular treatment options must be considered in all cases, higher partial obliteration rates and recurrence rates make microsurgical obliteration more favourable in relatively young patients without extenuating medical circumstances.

Author/Year	Study Period	No. of patients	% SAH	Mean follow up (months)	% Complete occlusion	Post GDC haemorrhage	Independent (%)	Morbidity (%)	Mortality (%)
Guglielmi 1992 <sup>20</sup>	1990-1991	43	56	2	40	1/43	83	4.8	7
McDougall 1996 <sup>21</sup>	1991-1995	33	70	15	21	1/33	NA	3	12.1
Pierot 1996 <sup>22</sup>	1993-1994	35	91	4.8	73	0/35	91	0	8.8
Klein 1997 <sup>23</sup>	1993-1996	21	76	9.8	67	0/21	91	4.8	4.8
Nichols 1997 <sup>24</sup>	1992-1995	28	100	6	61	0/28	80	0	15.4
Raymond 1997 <sup>25</sup>	1992-1995	31	74	15.5	42	0/31	87	3.2	6.5
Vinuela 1997 <sup>26</sup>	1990-1995	403	100	NA	NA	NA	84.3	9.6	6.1
Eskridge 1998 <sup>27</sup>	1991-1995	150	49	12	75*	4/150	78	6.7	18.2
Bavinzski 1999 <sup>28</sup>	1992-1998	45	75	27.4	54	1/45	73	4.4	15.5
Gruber 1999 <sup>29</sup>	1993-1996	21	52	26	14	0/21	90	9.5	0
Steiger 1999 <sup>30</sup>	1990-1998	16	69	6	69	0/16	88	6.3	6.3
Lempart 2000 <sup>31</sup>	1991-1998	112	100	13.1	54	1/112	83	2.8	15
Tateshima 2000 <sup>32</sup>	1990-1999	75	58	31.3	45	1/75	86	4.1	8.4
Birchall 2001 <sup>33</sup>	1992-1998	35	46	42.7	46	1/35	86	3.4	8.6
Uda 2001 <sup>34</sup>	1990-1999	41	69	21	32	1/41	90	2.6	7.7
Pandey 2007 <sup>35</sup>	1995-2005	275	61.5	31.8	87.8**	3/275	87.4	5.1	4.9
<b>Summary</b>		<b>1364</b>	<b>71.7</b>	<b>17.6</b>	<b>52.1</b>	<b>1.5 (14/961)</b>	<b>85.2</b>	<b>4.4</b>	<b>9.1</b>

\*% complete occlusion defined as >90% by source author; \*\*% complete occlusion defined as >95% by source author

Table 1. Endovascular treatment outcomes of posterior circulation aneurysms: analysis of published series.

Unlike endovascular treatment that depends on aneurysmal morphology, microsurgical success relies critically on

1. The specific aneurysmal location along the vertebrobasilar system.
2. Aneurysm size and patient's age

### **Location**

Location determines surgical approaches, which largely affects the outcomes. In general, surgical approaches to posterior circulation aneurysms are difficult because:

1. Surgical exposure is deep. This translates into long surgical corridor with narrow confines, thus limiting manoeuvrability and the proficiency to which a clip can be optimally placed on the aneurysm. The ability to attain good proximal and distal control may be restricted, further increasing the operative risk in the presence of subarachnoid haemorrhage.
2. The margin of error is small. The close proximity of posterior circulation aneurysms to the brainstem with interposing cranial nerves and perforator arteries makes the anatomy around this region complex and unforgiving.
3. The infrequency of these lesions. Posterior circulation aneurysms account for approximately 10 to 15% of all intracranial aneurysms, thereby giving few surgeons the opportunity to gain the necessary experience to manage them well. The emergence of endovascular therapy in the last 20 years further reduces the number of posterior circulation aneurysms available for surgical repair.

### **Size and patient's age**

Raaymakers et al<sup>36</sup>, in a meta-analysis of case series published between 1966 and 1996 found that the morbidity and mortality of surgery for non-giant unruptured posterior circulation aneurysms was 12.9% and 3.0% respectively. They found that age; aneurysm size and location of the aneurysms (anterior versus posterior) were factors that predicted a greater chance of a favourable outcome. In ISUIA II, patients' age was an important factor in overall surgical outcome. Other predictors of poor outcome included large aneurysmal size, history of ischaemic cerebrovascular disease, and presence of aneurysmal symptoms other than rupture. In Ogilvy and Carter's logistic regression model<sup>37</sup>, posterior circulation, size of aneurysm and age of the patient were associated with poor outcome. Eftekhar et al<sup>38</sup> reminded us of the overall low risk associated with surgical clipping at dedicated cerebrovascular centres, when treating patients with small unruptured posterior circulation aneurysms. In their surgical treatment of 136 unruptured vertebrobasilar aneurysms in 120 patients, the combined surgical mortality and morbidity for aneurysms <9mm in size was 3.2%. They emphasized that younger age patients and smaller sized aneurysms were favourable surgical predictive factors. This view is well supported by the works at other dedicated cerebrovascular centres<sup>39</sup>.

In general, aneurysms that are most suitable to surgical clipping are:

1. Superior cerebellar artery (SCA) aneurysms
2. P1 Posterior cerebral artery (PCA) aneurysms
3. Distal anterior inferior cerebellar artery (AICA) aneurysms
4. PICA aneurysms

Aneurysms that are difficult to approach microsurgically are:

1. P2 Posterior cerebral artery aneurysms
2. Basilar trunk
3. Proximal AICA
4. Vertebral-basilar junctions

#### 4. Preoperative consideration

A wide variety of operative approaches exist and the surgeon must select the most appropriate for the aneurysm location, size and projection. A number of critical factors must be considered prior to making the decision to operate.

1. *Imaging*: An angiogram combined with bone imaging reveals important anatomical features, of value not just in determining the optimal approach but also in indicating the operative risks. Note the
  - a. Height of the aneurysm neck in relation to the posterior clinoids or clivus
  - b. Size and direction of the aneurysm fundus.
  - c. Any associated crucial perforator anatomy
  - d. Any co-existent anterior circulation aneurysms that may alter the side of intended approach
2. *Neuro-anesthesia and cerebral protection*: Mild hypothermia and barbiturate-induced electroencephalographic burst suppression are necessary for complex basilar bifurcation and trunk aneurysms. Both techniques are essential when considering using temporary clipping as an adjunct to final aneurysm dissection and permanent clipping. It is important that these are thoroughly communicated with the anaesthetists and the rest of the neurosurgical team throughout the case.
3. *Side of approach*: In general, access to the parent artery immediately prior to the aneurysm dictates the side. For midline locations, a right-sided approach is preferable if either side provides equal access to the parent artery. Other factors may be taken into consideration but only if access to the parent artery is ensured. These factors include:
  - a. Coexistent left-sided anterior circulation aneurysm.
  - b. Hearing loss where a medial petrosectomy is required.
4. *Types of approach*: In considering the approach, it is important to keep in mind the principles underlying most cranial base surgical strategies including
  - a. Shortest trajectory to the lesion
  - b. Bone removal rather than brain retraction
  - c. Maximization of extradural exposure
  - d. Skeletonization/decompression of cranial nerves and vascular structures
  - e. Reconstitution of all dural openings.

From an anatomical perspective, it is useful to subdivide the vertebrobasilar arterial system into 3 compartments (Table 2).

1. *Upper vertebrobasilar*: incorporating basilar bifurcation, posterior cerebral artery (PCA) and superior cerebellar artery (SCA).
2. *Middle vertebrobasilar*: incorporating low-lying basilar bifurcation, basilar trunk, proximal Anterior Inferior Cerebellar Artery (AICA), and vertebra-basilar junction (VBJ).

3. *Lower vertebrobasilar*: incorporating vertebral and PICA arteries aneurysms.

The selection of a particular approach depends on a number of important factors

1. Location of aneurysm along the vertebrobasilar system
2. Size and projection of fundus of aneurysm
3. Surgeon's familiarity with specific approaches

Compartments	Aneurysms	Surgical corridor Approach Options	
Upper vertebrobasilar	Basilar bifurcation Posterior cerebral artery Superior cerebellar artery Upper basilar trunk	Anterolateral	Pterional approach Orbitozygomatic approach Subtemporal approach
Middle vertebrobasilar	Midbasilar trunk Anterior inferior cerebellar artery	Lateral	Transpetrosal approach Combined supra- and infratentorial approach Extended middle fossa approach Transoral approach
Lower vertebrobasilar	Vertebrobasilar junction Vertebral artery Posterior inferior cerebellar artery	Posterolaterally	Far-lateral approach Extended far-lateral approach Midline suboccipital approach

Table 2. Surgical approaches to posterior circulation aneurysms

## 5. Skull base approaches for aneurysm occlusion

In vascular neurosurgery, exposure is extremely important. Only with adequate exposure can neurosurgeons directly visualize vascular anatomy, obtain proximal and distal control, apply meticulous microsurgical technique, and manoeuvre a clip to occlude an aneurysm successfully with a good outcome.

In the last 3 decades, skull base neurosurgeons have disassembled and reassembled the skull in every possible way with the intention to maximise exposure and minimise neurological injury. These techniques have been designed to reduce the distance between the surgeon and the aneurysm, increase surgical manoeuvrability, and reduce retraction on neighbouring neurovascular structures to improve safe aneurysm clipping. In this section, we described only a selected few approaches that are practised by the senior author (MKM) in approaches to aneurysms of the posterior circulation.

### Orbitozygomatic approach

The *orbitozygomatic* (OBZ) approach dramatically enhances the standard pterional craniotomy. It allows exposure of, and access to, the medial end of the sphenoid wing and

middle fossa floor, providing a much greater scope for manoeuvre in the vertical dimension than through conventional anterolateral techniques.

The “orbito” aspect involves removing the superior and lateral orbit, which opens up the roof of the operative corridor when the patient’s head is rotated away from the aneurysm and extended. In addition, extending the zygomatic removal by removing the zygomatic arch is utilised when there is an advantage in creating a flat trajectory with the middle cranial fossa floor (e.g. for medial petrosectomy). A widened operative corridor improves illumination, eliminates the need for brain retraction, and optimises manoeuvrability. A good OBZ approach gives the neurosurgeon a wide sweep of surgical trajectories ranging from supraorbital to transsylvian to pretemporal to subtemporal. Surgical trajectory can then be tailored to the pathology at hand.

There are a number of important limitations to this technique, although the risks are low:

1. Cosmetic concerns including
  - a. Temporalis atrophy
  - b. Subtle orbital asymmetries that bother some patients
  - c. Frontalis nerve injury,
  - d. Pulsatile enophthalmos,
2. Orbital problems such as
  - a. Orbital entrapment,
  - b. Diplopia from extraocular muscle or nerve injury,
  - c. Blindness
3. Infection: communication with the frontal or ethmoidal sinus may increase the risk of infection or cerebrospinal fluid leakage.

#### **Key steps in an orbitozygomatic approach**

1. Patient’s head is placed in a 3-point fixation head frame in slight extension such that the malar process is upper most. An imaginary line, starting from the lateral canthus of the ipsilateral eye to the external occipital protuberance, should be positioned perpendicular to the floor. This will ensure the Sylvian fissure remains vertical, such that after wide splitting of the fissure, the frontal and temporal lobe fall away from the operative field.
2. A curvilinear incision is planned from just anterior to the ipsilateral tragus up to the superior temporal line. The incision then gently curves to terminate at the hairline superior to the contralateral midpupillary line. A small strip of hair is shaved with clippers along the course of the planned incision.
3. The skin is incised and haemostasis is obtained with Raney clips. The inferior limb of the incision is complete after the scalp is dissected from the temporalis fascia with a periosteal elevator.
4. The scalp flap is mobilised anteriorly and the temporalis fascia is exposed. The fascia is sharply incised and elevated separately in a subfascial dissection to protect the frontalis branch of the facial nerve running along the superficial surface of this fascial plane.
5. Dissection continues anteriorly to expose the orbital rim, malar eminence, and the zygomatic arch.
6. The temporalis muscle is raised separately, exposing the zygomatic root and pterion. The muscle flap is left attached to the cranium at its vascular pedicle in the infratemporal fossa.



7. The scalp flaps and temporalis muscle are retracted anteriorly and inferiorly using surgical hooks.
8. The periorbital is a delicate lining and can be carefully stripped from the undersurface of the orbit with a Mitchell dissector. Periorbita can be preserved by beginning the dissection where it is thickest inferolaterally near the inferior orbital fissure, by using side-to-side sweeps with a round-tipped dissector, and by advancing circumferentially along the orbital roof and the lateral wall. This dissection gradually deepens towards the orbital apex.
9. Two burrholes are placed over the temporal bone near the root of the zygoma and a pterional craniotomy is performed.
10. The OBZ unit consists of the orbital rim, orbital roof, lateral orbital wall, and zygomatic arch. Removal of the zygoma is optional. The OBZ unit can be removed with the cranial flap as one integrated piece, which provides a better cosmetic result than a two-piece technique, although more difficult.
11. Additional bone is removed around the orbital apex, resecting what remains of the orbital roof, lateral orbital wall, and medial sphenoid wing, back to superior orbital fissure.
12. The dura is then opened in a semicircular incision, and reflected anteriorly and inferiorly over the periorbita and temporalis and tacked to the over lying scalp. This way, the profile of the periorbital contents is flattened to enhance the exposure.

### **Arachnoid dissection**

The Sylvian fissure is the gateway to aneurysms along the circle of Willis. Separating the frontal and temporal lobes with the fissure split is one of the most important skills a vascular neurosurgeon needs to master. It is important, when performing the Sylvian fissure split, to keep the following principles in mind:

1. No retraction should be used.
2. Superficial Sylvian veins are the guardians of the Sylvian fissure. Knowing which way to dissect beyond the veins is an important skill. In general, superficial Sylvian veins course inferiorly and bridge to the sphenoparietal sinus under the sphenoid ridge. Dissection, therefore, should be along the frontal side to preserve these connections. However, it is important to maintain the venous connections of the larger veins in the region of the frontal operculum to minimise the risk of venous infarction in this region.
3. Cortical and deep arachnoid dissection must always be sharp, precise and controlled, using only the inverted tip of a No. 11 scalpel blade. Blunt dissection places stress on arachnoid-bound structures and increases the risk of complications from bleeding and neural injuries.
4. The Sylvian fissure is entered from distal to medial, and from deep to superficial along the direction of the middle cerebral artery branches.
5. All cisterns must be opened maximally to allow CSF egression and optimise brain relaxation. This manoeuvre eliminates the need for fix brain retraction. The Sylvian cistern is entered first, followed by the opticocarotid and the chiasmatal cisterns. Fenestration of the lamina terminalis is encouraged to allow more CSF drainage from the third ventricle in cases where CSF outflow obstruction due to haemorrhage may be present. This further enhances brain relaxation.
6. The deep Sylvian cistern is opened and the carotico-oculomotor triangle is dissected.

7. Arachnoid adhesions to the oculomotor nerve lying along the edge of the tentorium are dissected as the temporal lobe is retracted gently. The course of the posterior communicating artery is then visible as it pierces the membrane of Lilliequist. Incising the attachment of the tentorium at the posterior clinoid process is usually not of help in further facilitating exposure of the distal basilar complex. In the senior author's experience, this has not been a necessary manoeuvre.
8. Lilliequist's membrane is opened sharply with a no. 11 blade. Through this space the course of the posterior communicating artery (PCoA) can be observed to its junction with the ipsilateral PCA.
9. Further dissection along the PCA towards midline will expose the basilar bifurcation and the four-vessel complex, exposing the distal basilar compartment in the interpeduncular cistern.

### **Skull base extension for low-lying distal basilar complex aneurysms**

For low-lying basilar apex aneurysms or SCA aneurysms, skull base extensions may be performed through the transcavernous route as originally described by Dolenc<sup>40</sup>. This extended basal approach widens the distal surgical corridor near the lesion, and allows exposure of the basilar artery and its proximal branches as far as the AICAs, with minimal retraction of the brain. The demands of this approach involve drilling of the anterior clinoid, freeing the ICA from the proximal and distal dural rings, opening of the cavernous sinus and drilling of the posterior clinoid process. This manoeuvre enhances the corridor between the ICA and the oculomotor nerve, and is useful for low-lying distal basilar complex lesions, and giant or recurrent BA aneurysms in which proximal control may be necessary during aneurysm dissection and clip placement.

### **Far-lateral approach**

The *far-lateral approach* is also known as the lateral suboccipital approach, the extreme lateral approach, and the extreme lateral inferior transcondylar exposure (ELITE). These approaches are best suited for aneurysms along the lower third of the basilar artery.

### **Key steps in a Far-lateral approach**

1. The patient is positioned semi-prone (or lateral), with the head held in 3-pin fixation and square to the shoulders and the chin tucked in to tighten the nuchal ligament.
2. A 'hockey-stick' incision is made beginning in the cervical midline over the C4 spinous process. It extends cranially to theinion, courses laterally along the superior nuchal line to finish immediately above the ear.
3. The paraspinal muscle is split in the avascular plane of the nuchal ligament.
4. Retraction of soft tissue is facilitated by exposure down to and around the C2 spinous process.
5. The vertebral artery (VA) is identified and protected as it courses from the transverse foramen of the lateral mass of C1, through the sulcus arteriosus of the C1 vertebral arch, to its dural entry point.
6. The lateral epidural venous plexus can cause troublesome bleeding and is best preserved by blunt dissection and packing with surgical.
7. Bone removal consists of 3 parts
  - a. Lateral occipital craniotomy,

- b. C1 laminotomy, and
  - c. Partial condylectomy
8. A suboccipital craniotomy is extended unilaterally from the foramen magnum in the midline, up to the muscle cuff at the level of the transverse sinus, as far laterally as possible, and then back around the foramen magnum. In elderly patients with adherent dura, a suboccipital burrhole with subsequent cut-downs to the foramen magnum may help to preserve dura. The rim of the foramen magnum is rongeuared to extend the opening across the midline and laterally toward the occipital condyle.
  9. The craniectomy extends from the midline to the edge of the transverse/sigmoid sinus and includes a rim of foramen magnum.
  10. The arch of C1 is removed with the drill, making a cut just medial to the sulcus arteriosus and another across the contralateral arch. These cuts are made in a rostral-to-caudal direction to keep any lurching of the drill away from the VA. Additional atlantal bone can be removed under the VA laterally to the transverse foramen.
  11. The lateral aspect of the foramen magnum and the postero-medial two thirds of the occipital condyle are removed. The anterior extent of the condylar resection is defined either by the condylar emissary vein or by dura that begins to curve antero-medially, giving a tangential view along this dural plane.
  12. Condyilar resection enables the dural flap reflected against the condyle to be completely flat.
  13. The dural incision curves from the cervical midline, across the circular sinus, to the lateral edge of the craniotomy. An inferior dural incision laterally under C1 mobilizes the flap further laterally against the margin of the craniotomy.
  14. Multiple dural packing sutures hold the flap against the condyle under tension. Condylectomy is sufficient if there is no bony prominence obstructing the view of the lateral medulla.
  15. The arachnoid of the cisterna magna is preserved until the microscope is brought into the field to keep blood out of the subarachnoid space.
  16. After opening the arachnoid layer and taking care to minimize any retraction of the nerves, the vertebral artery is followed rostrally until the origin of the PICA. Alternatively PICA may be easily identified running around and under the cerebellar tonsils and this can be followed down to its origin and the aneurysm.

## 6. Revascularization

Direct surgical clipping remains the best treatment of aneurysms. It approximates normal arterial walls to promote endothelialisation that seals the aneurysm orifice. Parent vessels can be reconstructed and normal blood flow restored around the base of the aneurysm. However, not all aneurysms can be treated by direct clipping. Giant saccular aneurysm and complex fusiform or dolichoectactic aneurysms may lack a clippable neck. In these situations, it has been advocated that surgical bypass and trapping of the aneurysms would be a less invasive alternative treatment option.

In revascularization procedures to treat complex aneurysms in the posterior circulation, it is important to understand that the surgical approach is largely dependent on the exposure required to perform the arterial bypass. In most cases, this is often a less extensive exposure than that needed for direct clipping, making the overall surgery less traumatic for the

patients. In addition, endovascular occlusion of parent vessel is a safe and feasible option in most centres, thus reducing the exposure required to only that needed for the bypass.

The surgical approaches for posterior circulation revascularisation are no different from the techniques discussed above. However, the strategy is important, and depends on:

1. Which aspect of the posterior circulation requires revascularization (i.e. upper, middle or lower vertebrobasilar territory)
2. How much blood flow is required - high or low flow strategies.

Possible posterior circulation bypasses to treat complex aneurysms are listed in Table 3.

Compartments	EC-IC low flow	EC-IC high flow	IC-IC low flow	Approach
Upper Basilar	STA-SCA STA-PCA	ECA-SCA ECA-PCA	PCA-SCA	Orbitozygomatic
Mid Basilar	OA-AICA	ECA-AICA	AICA-PICA	Retrosigmoid Retrolabyrinthine
Low Basilar	OA-PICA	VA-VA VA-PICA	PICA-PICA	Far-Lateral

Adapted from Youman's Neurological Surgery, 5<sup>th</sup> edition.

Table 3. Surgical bypass options for posterior circulation aneurysms

## 7. Postoperative care

1. Patients are managed in a dedicated neurosurgical intensive care unit for a minimum of 24-hours post-operatively.
2. Patients should be kept in a euvolemic state, with blood pressure allowed to rise to the patient's high normal pressure without the use of inotropes or vasopressors unless the patient shows clinical evidence of vasospasm.
3. Corticosteroids and anticonvulsants medications are not routinely used.
4. A CT/CT-angiogram is performed on day 1 post-operatively. If clipping is incomplete, surgical as well as endovascular options should be considered to obliterate the aneurysm remnant.
5. CSF leak can be treated with bed rest and lumbar CSF drainage; in cases where this fails to resolve, surgical re-exploration and repair of CSF fistula may be required.
6. A dedicated digital subtraction angiography (DSA) should be performed for cerebral revascularization cases to assess the adequacy of flow in the bypass.

## 8. Complications and their treatment

### 8.1 Cranial nerve damage

*Upper basilar territory:* The most common complication after surgical clipping of aneurysms in this region is an ipsilateral third nerve palsy, which may occur transiently in as many as 70 percent of patients. Damage may be peripheral which has an excellent chance of recovery. For central third nerve palsy, mostly from injury to the oculomotor nucleus in the brainstem, complete recovery is rare.

In the transylvian approach, the third nerve needs to be dissected away from the tent to avoid retraction injury. The opposite should be employed in a subtemporal approach, where third nerve needs to be protected and tugged under the temporal lobe to avoid direct injury during retraction.

*Mid basilar territory:* The transtentorial approach to the basilar trunk risks damage to the 4<sup>th</sup> and 5<sup>th</sup> and 6<sup>th</sup> nerves and the combined petrosal approach also risk damage to the 7<sup>th</sup> and 8<sup>th</sup> nerves.

*Lower basilar territory:* Approaches in this region risk damage to the lower cranial nerves, particularly when dissecting and clipping PICA aneurysms. Great care and delicacy is required when retracting these nerves to gain access. Damage can lead to potentially fatal aspiration pneumonia.

## **8.2 Perforator injuries**

The most common cause of permanent morbidity for surgical management of posterior circulation aneurysms is perforator injury or occlusion. The importance of recognizing and preserving perforator damages at all case was well recognised by Dr Drake early on in his experience. Depending on the level of perforator involvement, patient may have significant cranial nerve deficits due to damage of cranial nuclei. Other complications may involve pseudobulbar palsy, ataxia, memory loss, a variable degree of hemiparesis and, in severe cases, disturbance of consciousness.

## **8.3 Venous infarction**

Inadequate surgical exposure or inappropriate approach inevitably leads to the need for brain retraction. This significantly increases the risk of venous infarction, particularly for the subtemporal and petrosal route, where the vein of Labbe may be at risk. It is therefore important that when not necessary, retraction should be avoided at all cost. Furthermore, coagulating veins should be avoided during the approach as much as possible. If bleeding occurs, particular at the point where the vein of Labbe inserts into the sinus, do not coagulate; pack, irrigate, and dissect elsewhere until bleeding spontaneously stopped.

## **8.4 Vessel occlusion**

An important lesson that neurosurgeons must learn from our endovascular colleagues is that it is always safer to compromise on the aneurysm sac than the parent artery. The pursuit of perfect clipping across an aneurysm neck at the compromise of constricting the parent artery and inflicting postoperative ischaemia is not acceptable. A microdoppler probe can provide a guide to patency, but intraoperative indocyanine green (ICG) fluorescence videoangiography if available should be used to ensure that the aneurysm is safely clipped. ICG fluorescence videoangiography can also reveal perforator occlusion.

## **8.5 Failure to use temporary clipping**

Inadequate surgical exposure can compromise the ability to proximal and distal vessel control with temporary clipping. While the confines of the surgical corridor are limited, the role of temporary clipping for posterior circulation aneurysms is critical. Temporary

clipping of the proximal vessel softens the aneurysmal wall, minimises the risk of clip closure, prevent proximal clip migration, and allows manipulation of the sac to identify critical perforators and adjacent vessels. Over the years, several authors have reported the use of circulatory arrest in the treatment of giant intracranial aneurysms<sup>41</sup>. These techniques enable longer period of temporary clipping up to 60 minutes, thus helping both the dissection and clipping of such complex aneurysms.

## 9. Outcome and prognosis (including results of author's series)

There is a popular trend in contemporary published surgical series to combine all treatment outcomes of posterior circulation aneurysms into one category. This method of classification conceals the unique features, management strategies, surgical approaches and outcomes that are distinctive to the individual aneurysm along the various parts of the vertebrobasilar system.

Like anterior circulation aneurysms, the outcome following direct clipping of aneurysms in the posterior circulation depends on a number of key factors:

1. Patient's preoperative grade
2. Aneurysm size and shape and related factors (e.g. degree of atheroma at the neck, extent of mural thrombosis, direction of the fundus)
3. Specific anatomical location along the vertebrobasilar system
4. Surgical expertise

In the senior author's aneurysm series (MKM) over a 20-year period from 1989 to 2010, 256 aneurysms in the posterior circulation were operated in 239 operations. 120 (46.9%) of the aneurysms were ruptured and 136 (53.1%) unruptured. Mean age was 51.2 +/- 13.1 years (range 9 to 77). There were 144 basilar bifurcation, 30 basilar trunk and 82 vertebral-PICA aneurysms. Aneurysms sizes were <7mm in 132 cases (53%), 7 to 12mm in 60 (24.1%), 13-24mm in 37 (14.9%) and >24mm in 20 (8%). The overall mortality was 9.2% and surgical morbidity was 12.9%.

Table 4 summarises the senior author's own surgical results and the results from the literature for surgical outcomes of posterior circulation aneurysms according to their location along the vertebrobasilar system.

### Basilar Bifurcation Aneurysms

	No. of studies	No. of patients	% Independent	% Morbidity	% Mortality
1960-69	6	37	48.6 (18/37)	10.8 (4/37)	37.8 (14/37)
1970-79	10	408	77.2 (315/408)	15.9 (65/408)	6.9 (28/408)
1980-89	12	1177	82.3 (969/1177)	12.6 (148/1177)	5.1 (60/1177)
1990-99	13	2859	82.4 (2357/2859)	10.8 (308/2859)	6.2 (178/2859)
2000-09	10	644	76.4 (492/644)	14.4 (93/644)	6.1 (39/644)
Author's series	1	144	77.9 (109/140)	12.5 (18/144)	5.6 (8/144)
<b>Overall</b>	<b>52</b>	<b>5269</b>	<b>80.9 (4260/5265)</b>	<b>12.1 (636/5269)</b>	<b>6.2 (327/5269)</b>

**Basilar Trunk Aneurysms**

	No. of studies	No. of patients	% Independent	% Morbidity	% Mortality
1960-69	4	18	61.1 (11/18)	16.7 (3/18)	22.2 (4/18)
1970-79	5	144	88.2 (127/144)	6.9 (10/144)	4.9 (7/144)
1980-89	7	208	84.1 (175/208)	7.2 (15/208)	8.7 (18/208)
1990-99	16	471	86.0 (405/471)	8.7 (41/471)	5.3 (25/471)
2000-09	5	59	81.4 (48/59)	13.6 (8/59)	5.1 (3/59)
Author's series	1	30	65.4 (17/26)	20.7 (6/29)	20.7 (6/29)
<b>Overall</b>	<b>38</b>	<b>930</b>	<b>84.6 (783/926)</b>	<b>8.9 (83/929)</b>	<b>6.8 (63/929)</b>

**Vertebral-PICA Aneurysms**

	No. of studies	No. of patients	% Independent	% Morbidity	% Mortality
1960-69	2	9	66.7 (6/9)	0 (0/9)	33.3 (3/9)
1970-79	5	165	86.7 (143/165)	1.8 (3/165)	11.5 (19/165)
1980-89	9	304	89.2 (248/278)	5.4 (15/278)	5.4 (15/278)
1990-99	11	370	91.6 (329/359)	3.6 (13/359)	4.7 (17/359)
2000-09	13	259	88.8 (222/250)	8.4 (21/250)	2.4 (6/250)
Author's series	1	82	78.5 (62/79)	9.1 (7/77)	8.9 (7/79)
<b>Overall</b>	<b>41</b>	<b>1189</b>	<b>88.6 (1010/1140)</b>	<b>5.2 (59/1138)</b>	<b>5.9 (67/1140)</b>

Table 4. Surgical Outcomes of Posterior Circulation Aneurysms 1960-2011

When the outcomes from major published series in both the surgical arm and the endovascular arm are combined (Table 5), a number of important points are noted:

**Posterior Circulation Aneurysms: Coiling vs Clipping**

	Study period	No. of studies	No. of patients	Independent (%)	Morbidity (%)	Mortality (%)
Endovascular	1990-2005	16	1364	85.2	4.4	9.1
Microsurgery	1960-2009	56	7132	82.8	10.5	9.1
				(5865/7086)	(747/7086)	(437/7086)

Table 5. Comparison of outcomes for coiling versus clipping of posterior circulation aneurysms.

1. Contrary to contemporary belief, endovascular treatments and surgical treatments share similar rates of mortality and independence outcomes post procedures for posterior circulation aneurysms.
2. Morbidity is significantly lower in the endovascular group (absolute 6.1% difference), reflecting the better ease of access from an endovascular view point.

3. However, reduced morbidity in the endovascular arm is compromised by inefficient coiling rate with high recurrence and rebleeding rates, which has a negative impact in the long term for younger patients.

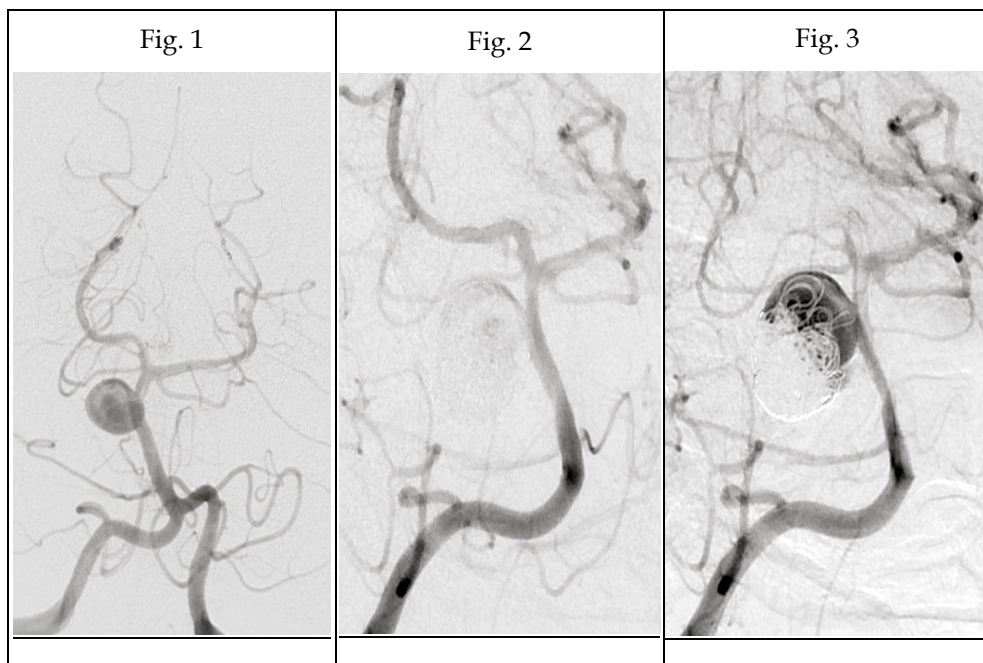
## 10. Expert suggestions

1. *Brain relaxation.* A relaxed brain is critical when operating on aneurysms in the posterior fossa. The key factors in ensuring a relaxed brain and avoid brain retraction include correct patient head positioning, maximal Sylvian fissure dissection, and optimal opening of the Sylvian and basal cisterns to promote CSF drainage.
2. *Distance of aneurysm from the clivus.* The transsylvian approaches to the basilar bifurcation involve a downward directed angle, therefore the closer the aneurysm neck is to the clivus the more hidden it becomes from the surgeon's view. Conversely, while it may be more desirable that the aneurysm is distanced from the clivus, the more posterior it is, the more likely it is adherent to the brain stem.
3. *Perforators.* A hypoplastic P1 carries as many and as vital perforators as a normal-sized P1 and therefore demands equal respect and preservation. If the ipsilateral P1 carries no perforators, then the contralateral P1 almost certainly carries perforators that supply both sides. Basilar bifurcation perforators emerge from the posterior aspect and not anteriorly. It is therefore vital to meticulously separate these perforating branches not only in the neck but also up to their adhesion to the fundus. It is possible that during clip occlusion of the neck, the resulting traction and aneurysm decompression can kink these branches distal to the clip site.
4. *Division of the posterior communicating artery.* Division of the PComA has been described in the literature and can be useful in maximising exposure to the posterior circulation. This manoeuvre, however, is often not necessary in the senior author's experience. We cautioned that division of the PComA should be done only judiciously. The anterior thalamoperforators generally leave the PComA from its medial-dorsal aspect and ascend rostrally. The decision to divide the PComA cannot be made without first confirming this and the exclusion of a fetal circulation.
5. *Aneurysm dissection.* Microdissection around the aneurysm should not be limited by a fear of intraoperative rupture. The morbidity caused by suboptimal exposure and insufficient circumferential dissection around the aneurysm can outweigh the morbidity related to a rupture. When appropriate preoperative and operative strategies are utilized, most intraoperative ruptures can be controlled.
6. *Placement of clips.* Careful selection of an appropriate aneurysm clip is important. Blade length should match the width of the aneurysm neck, which may widen as the blades close. Clips can be removed and reapplied as many times as necessary to optimally obliterate aneurysm, while preserving the parent vessels. Some aneurysms cannot be clipped directly. In such situations, it is important to recognize the challenges and consider alternative strategies.
7. *Utilize available technologies to ensure safe aneurysm surgery.* There are a number of major advances in vascular microsurgery in recent years, such as the use of ICG fluorescence videoangiography, endoscopic assisted aneurysm clipping and the utilization of intraoperative electrophysiological monitoring. These options should be exploited to reduce operative complications.



## 11. Explicative case

An 18 year-old girl presented with several months history of progressive left sided paraesthesia and difficulty walking. Subsequent investigations revealed a large middle basilar trunk aneurysm measuring 2cm in maximal diameter. The fundus of this aneurysm was projecting toward the right side (Figure. 1).



Due to its location, this aneurysm was initially treated by endovascular coiling with near complete occlusion (Figure. 2). At 3-month post-coiling follow-up, a repeat cerebral angiogram revealed coil compaction and recurrence of the aneurysm along (Figure. 3). A further attempt at recoiling with stent was carried out but this failed to robustly repair the aneurysm (Figure 4). At this point, surgical option was chosen for definitive treatment.

Surgery was carried out via a right sided orbitozygomatic approach with the zygomatic arch removed. A medial petrosectomy was made extradurally having first unroofed the ipsilateral internal carotid artery. The dura was then opened and reflected on to superior orbital fissure continuing the dural opening down to the superior petrosal sinus, communicating this with an opening of the dura in the posterior fossa, dividing the superior petrosal sinus and bringing the dural opening across the tentorium to the free edge of the tent behind the fourth cranial nerve.

The Sylvian fissure was then widely split, followed by isolation of the fourth nerve with intact dura drawing and placing tension on the cavernous sinus. This allowed full access to the aneurysm that was well exposed both proximally and distally. Direct clipping of the aneurysm neck was rendered problematic as the stent protruded through the basilar artery

wall as the clip was closed. At this point, the aneurysm was trapped by necessity to control bleeding. Having assessed the posterior communicating arteries were of small calibre, it was deemed appropriate to supplement the patient's posterior circulation with a vein bypass.

The vein graft was harvested from the long Saphenous below the left knee and a right anterior sternomastoid approach was made to the common carotid artery. The vein was tunnelled into a subcutaneous location and then an end-to-side anastomosis was performed between the vein and the right P2 segment of the posterior cerebral artery. Following this an end-to-side anastomosis was performed onto the common carotid artery with the fish-mouth. A post-operative computed tomography angiogram is demonstrated in Figure 5. Patient remained well postoperatively and the large basilar trunk aneurysm was cured on followed up imaging.

Fig. 4

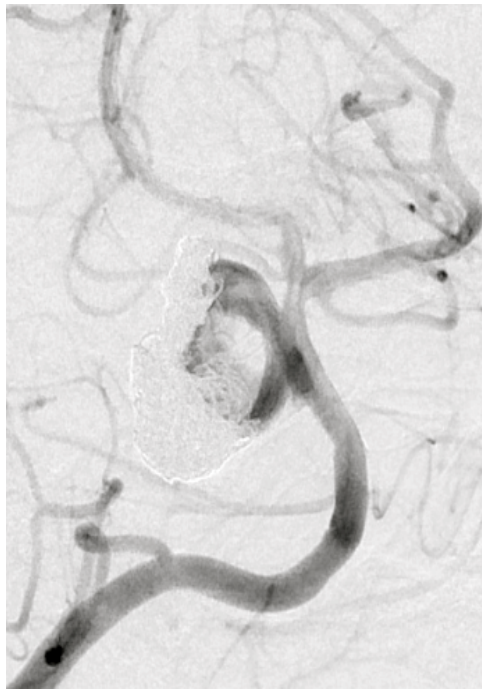
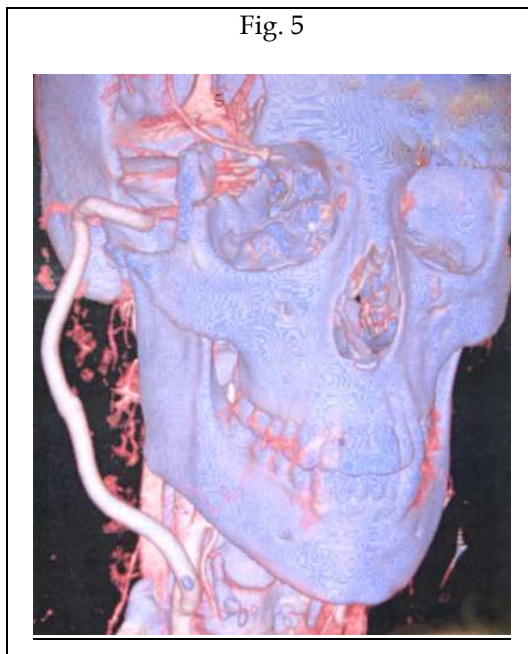


Fig. 5



## 12. Conclusions

Over the last 5 decades, neurosurgeons have worked tirelessly to tackle with aneurysms in the posterior circulation. The skull have been deconstructed and reconstructed in every feasible way to minimise neurological injuries in a territory where surgical corridors are deep, manoeuvrability is limited, and mistakes are unforgivable. At this instance, there is little room for microsurgical innovation. The next phase of breakthroughs for posterior circulation aneurysm treatments will likely transpire from endovascular and endoscopic skull base advancements. At some point, endovascular techniques will reach their limits and will not replace the role of open surgical clipping, as had previously anticipated. The responsibility for future generations of vascular neurosurgeons, therefore, is to embrace and integrate these innovations while maintaining technical proficiency in all aspects of microsurgical skull base approaches. This will be to ensure that the increasing emergence of complex aneurysms can be safely treated with microsurgical methods.

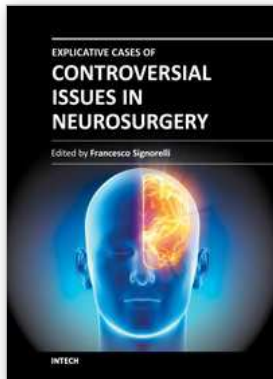
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