# Subarachnoid Hemorrhage and Intracranial Aneurysm

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**Abstract:** A subarachnoid hemorrhage (SAH) constitutes about 5% of total strokes and occurs due to a ruptured intracranial aneurysm or an AVM. Of aneurysms, 85% are constituent from anterior circulations and the remaining 15% from posterior circulation. Saccular (berry) aneurysms comprise 90% of all intracranial aneurysm morphologies. About 2% of the general population has an intracranial aneurysm, about 1% will have a rupture during their lifetime and 0.5% will die because of an SAH. A ruptured aneurysm usually presents with a sudden, severe thunderclap headache. A CT scan followed by a CTA/MRA/DSA will confirm the diagnosis. Patients are managed in the ICU and need urgent or delayed microsurgical clipping or endovascular coiling to prevent further rupture of the aneurysm. This chapter will include discussion of SAHs and the microsurgical management of different types of intracranial aneurysms in brief. The endovascular management of aneurysms will be discussed in Chapter 18.

**Abbreviations**

| | | | |
|---|---|---|---|
| AChA | anterior choroidal artery | ACOM | anterior communicating artery |
| AVM | arteriovenous malformation | ACA | anterior cerebral artery |
| AICA | anterior inferior cerebellar artery | BTO | balloon test occlusion |
| CCF | caroticocavernous fistula | CSF | cerebrospinal fluid |
| CT | computed tomography | CTA | CT angiogram |
| DACA | distal anterior cerebral artery | DIND | delayed ischemic neurological deficit |
| DSA | digital subtraction angiogram | DVT | deep vein thrombosis |
| EI-IC | Intracranial–extracranial | GCS | Glasgow Coma Scale |
| ICA | internal carotid artery | IC-IC | intracranial-intracranial |
| ICMA | intracranial mycotic aneurysm | ICP | intracranial pressure |
| ICU | intensive care unit | IE | infective endocarditis |
| IMAX | internal maxillary artery | LOC | loss of consciousness |
| MCA | middle cerebral artery | MRA | magnetic resonance angiogram |
| MRI | magnetic resonance imaging | OA | occipital artery |
| OFZ | orbito-froto-zygomatic | OZ | orbito-zygomatic |
| PCA | posterior cerebral artery | PCOM | posterior communicating artery |
| PDR | proximal dural ring | PICA | posterior inferior cerebellar artery |
| PMF | pterigo-maxillary fissure | PWoM | posterior wall of maxilla |
| SAH | subarachnoid hemorrhage | SCA | superior cerebellar artery |
| STA | MCA-superficial temporal artery–middle cerebral artery | TM | temporalis muscle |
| VA | vertebral artery | WFNS | world federation of neurosurgical society |

## 1. Introduction

A subarachnoid hemorrhage constitutes about 5% of total strokes, which occurs commonly from a ruptured aneurysm of either anterior or posterior circulation. Of aneurysms, 85% are constituent from anterior circulations and the remaining 15% from posterior circulation. Saccular (berry) aneurysms comprise 90% of all aneurysm morphologies, and their rupture is the leading etiology of SAHs. Fusiform aneurysms are responsible for roughly 10%, with posterior circulation being the most prevalent area. An epidemiological study shows that about 2% of the general population has an intracranial aneurysm, about 1% will have rupture during their lifetime and 0.5% will die because of an SAH (Williams and Brown 2013; Greenberg 2010).

## 2. Etiologies, Types and Frequencies of SAHs

Etiologies:

(a) Aneurysms (70–75%);
(b) Arteriovenous malformation (AVM) (4–5%);
(c) Vasculitides;
(d) Tumor (rarely);
(e) Cerebral artery dissection;
(f) Coagulation disorders;
(g) Dural sinus thrombosis;
(h) Pituitary apoplexy (Greenberg 2010).

Types of aneurysms causing SAH are listed in Table 1.

**Table 1.** Types of aneurysms causing an SAH.

| Types |
| --- |
| Saccular |
| Fusiform (atherosclerotic) |
| Traumatic |
| Dissecting |
| Mycotic |
| Miliary |

Source: Authors' compilation based on data from Cruz and Hopkins (1999).

Intracranial arteries lie in the subarachnoid space and lack an external elastic laminate and have a very thin tunica adventitia. The histological section at the neck of an aneurysm shows a lack of muscle coat and internal elastic lamina (Yamazoe et al. 1990). Frequency distribution of intracranial aneurysms are shown in Table 2.

**Table 2.** Frequency of aneurysms.

| Type of Aneurysm | Frequency (%) |
| --- | --- |
| ACOM | 35 |
| PCOM | 25 |
| MCA | 20 |
| Basilar top | 10 |
| Vertebral artery | 5 |
| Others | 5 |
| Very few are from an ophthalmic segment aneurysm and ICA bifurcation aneurysm | |

Source: Authors' compilation based on data from Greenberg (2010).

When an SAH occurs, blood spreads all over the brain surface and to the cistern; hence, the brain becomes red and swollen (Figure 1). A fresh blood clot found in the basal cistern, interhemispheric fissure and Sylvian fissure. Chemical inflammation from clotting blood surrounding the brain can lead cerebral arteries to spasm in the days after the hemorrhage. An arterial spasm can result in further brain injury.

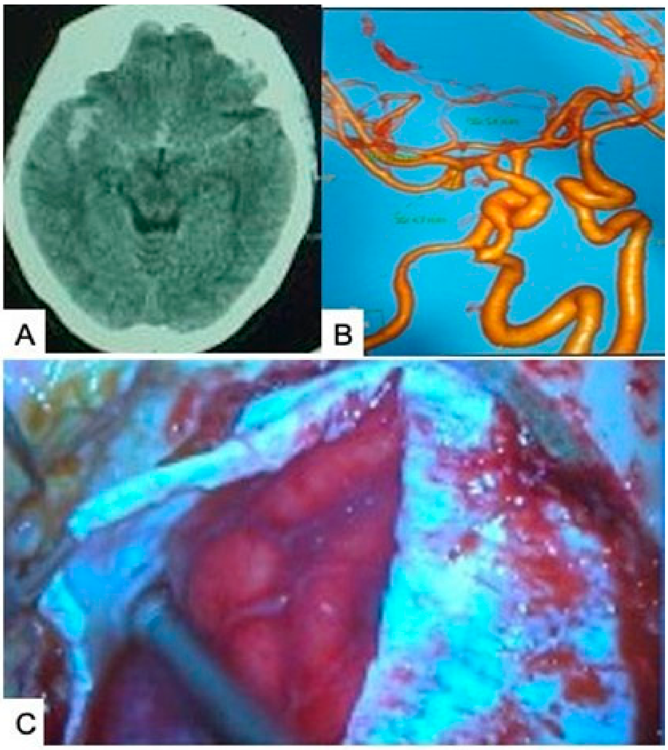



**Figure 1.** (**A**) CT scan showing an SAH likely from a ruptured right MCA aneurysm. (**B**) CTA showing a small right MCA aneurysm. (**C**) Blood in the subarachnoid space following an opening of the dura in an acute subarachnoid hemorrhage patient. Source: Figure by authors.

It is difficult to finalize which aneurysm has ruptured by only identifying it by seeing a plain CT scan. In the case of an anterior communicating artery aneurysm, there will be bleeding in the anterior circle of Willis, and in the case of a posterior communicating artery aneurysm, there will be bleeding along the tentorial edge. In the case of a middle cerebral artery aneurysm, there will be bleeding in the Sylvian fissure, even in the temporal lobe. A CT angiogram, MR angiogram, digital subtraction angiogram or direct puncture angiogram is the key to diagnose the cause of a subarachnoid hemorrhage. We can only carry out a CT angiogram, and in some cases, we go for a DSA when the aneurysm is giant or complex. An MR angiogram is a good tool for the diagnosis of a ruptured and unruptured aneurysm in the outpatient department (Greenberg 2010).

**3. Natural History of Disease**

An SAH represents just 5% of all strokes; however, it is associated with significant fatalities, as well as long-term impairments. Between 1984 and 2007, a retrograde cohort study in two large Norwegian populations found a 36% 30-day case fatality rate. Female sex, Japanese or Finnish ancestry, aneurysm size, shape and sites, hypertension, smoking, elderly patients and cocaine misuse are all major risk factors for an aneurysm rupture. The annual rupture rate is 1–1.5% per year and the re-rupture rate is 40–60% within 3 days and gradually decreases over a period of time. The highest risk of a re-rupture is within 24 h (often within 6–12 h) (Williams and Brown 2013; Greenberg 2010).

Neurological injury from the original hemorrhage and re-hemorrhage, and delayed cerebral ischemia (DCI) are the most common causes of death.

**4. Morphology of a Saccular Aneurysm**

Larger aneurysms are most likely to bleed, whereas individual aneurysm anatomy reveled with a daughter lobe a blend of or dome irregularities that implicate the aneurysm as a culprit of an SAH (Kirollos et al. 2019).

**5. Risk Factors for an SAH**

Systemic hypertension;
Smoking;
Contraceptive pill;
Substance abuser (cocaine, alcohol);
Pregnancy and parturition;
Advancing age;
Cerebral aneurysm;
Procedure like cerebral angiography or lumbar puncture in patients with an aneurysm (Cruz and Hopkins 1999).

**6. Clinical Features**

*6.1. Symptoms and Signs*

The symptoms and signs of an SAH include a sudden, severe, thunder-clap headache; nausea; vomiting; syncopal attack (apoplexy); and neck ache (meningismus); as well as light apprehension. If there is a loss of consciousness (LOC), patients may regain consciousness later. Cranial nerve palsy may occur (for example, oculomotor nerve palsy caused by aneurysm-induced pressure of the oculomotor nerve, resulting in double vision and/or ptosis). Dependent blood can irritate the lumbar nerve roots, causing lower back pain. A sentinel hemorrhage may cause a warning headache (Greenberg 2010; Kirollos et al. 2019).

*6.2. Meningismus*

Nuchal rigidity;
Kernig sign;
Brudzinski sign;
Ocular hemorrhage (Greenberg 2010).

*6.3. Coma Following an SAH*

May occur due to the following:

1. Raised intra cranial pressure (ICP);

2. Injury to the brain from intracerebral hemorrhage;
3. Hydrocephalus;
4. Diffuse ischemia;
5. Seizure;
6. Low blood flow (Greenberg 2010).

### *6.4. Mortality in Aneurysmal SAH*

10–15% patients succumb before reaching the hospital;

10% mortality within the subsequent few days;

In general, the mortality is 45% (32–67%);

25% die due to medical complications of an SAH;

8% die from progressive deterioration from the initial hemorrhage;

55–60 years is the common age for an SAH (aneurysmal);

30% of aneurysmal SAHs happen during sleep (Greenberg 2010).

## 7. Intracranial Aneurysm

Though it is not possible to guess whether an aneurysm will rupture or not, an aneurysm is more possible to rupture when its diameter is 7 mm or over.

### *7.1. Presentation of a Ruptured Aneurysm*

- Sudden, excruciating, severe headache;
- Nausea, as well as vomiting;
- Neck stiffness;
- Blurring of vision or diplopia;
- Photophobia;
- Convulsion;
- Ptosis;
- LOC;
- Subhyaloid (preretinal) hemorrhage;
- Retinal hemorrhage (Williams and Brown 2013; Greenberg 2010; Cruz and Hopkins 1999; Yamazoe et al. 1990; Kirollos et al. 2019).

### *7.2. Presentation of an Unruptured Aneurysm*

Mass effect leads to hemiparesis and compromise vision.

### *7.3. Diagnosis*

*CT scan:* It is the most common investigation in an acute SAH, as patients are either restless or unconscious, and it takes much less time to get the image.

*CT angiogram (CTA):* It is a more popular investigation method for an SAH for the defect of an aneurysm of any location. Here, an intravenous contrast agent is pushed by a syringe pump to get the vascular image.

*MR angiogram (MRA):* It is the best chosen when patients are having a headache without an impaired consciousness level. Here, the contrast agent is not required to get vascular images.

*Digital subtraction angiogram (DSA):* it is performed for a complex aneurysm.

*Direct puncture angiogram*

A lumbar puncture can confirm the presence of an SAH even when the hemorrhage is small to declare its presence on a CT scan. Blood mixed CSF comes in SAH in spinal tap (Williams and Brown 2013; Greenberg 2010; Cruz and Hopkins 1999; Yamazoe et al. 1990; Kirollos et al. 2019).

### *7.4. Gradings*

#### 7.4.1. Hunt and Hess Grading

The Hunt and Hess (Hunt and Hess 1968) grading is a predictor of survival that defines the degree of an SAH caused by the burst of an intracranial aneurysm.

(1) Grade 1

(a) Without symptoms or a mild headache, as well as slight stiffness of the neck;
(b) 70% survival.

(2) Grade 2

(a) Moderate-to-severe headache plus neck stiffness, but no neuro-deficit other than cranial nerve palsy;
(b) 60% survival.

(3) Grade 3

(a) Drowsy and minimal neurological deficit;
(b) 50% survival.

(4) Grade 4

(a) Stuporous and moderate-to-severe hemiparesis, with possible early decerebrate rigidity, as well as vegetative disturbances;
(b) 20% survival.

(5) Grade 5

(a) Deep coma and decerebrate rigidity, moribund;
(b) 10% survival.

#### 7.4.2. Fisher Grading

SAH severity and location are important prognostic variables. An SAH is classified utilizing the Fisher grading scale, as follows:

- Grade 1—No SAH found on CT of the head;
- Grade 2—Diffuse or vertically seen SAH < 1 mm thick;
- Grade 3—Diffuse and/or vertical layer of SAH > 1 mm thickness;
- Grade 4—Intraventricular or intracerebral blood with diffuse or no SAH (July and Wahjoepramono 2019).

Comparison between Barrrow Neurological Institute and Fisher grading is shown in Table 3.

**Table 3.** Analogy between the Barrow Neurological Institute (BNI) and Fisher grading.

| Scale | Grade 1 | Grade 2 | Grade 3 | Grade 4 | Grade 5 |
|---|---|---|---|---|---|
| Fisher | No blood | Clot < 1 mm thick | Clot > 1 mm thick | Grade 1 or 2 plus intracerebral or intraventricular hematoma | - |
| BNI | No blood | Clot < 5 mm thick | Clot 5 to 10 mm thick | Clot 10 to 15 mm thick | Clot > 15 mm thick |

Source: Authors' compilation based on data from July and Wahjoepramono (2019) and Greenberg (2010).

#### 7.4.3. WFNS Grading

The World Federation of Neurosurgical Societies (WFNS) grading system utilizes the Glasgow Coma Scale (GCS) and existence of focal neurological deficits for grading the severity of an SAH.

WFNS Classification:

- Grade 1: GCS 15, no neuro-deficits;
- Grade 2: GCS 13–14 without neuro-deficits;
- Grade 3: GCS 13–14 with focal neuro-deficits;
- Grade 4: GCS 7–12, with or without deficits;
- Grade 5: GCS < 7, with or without neuro-deficits (July and Wahjoepramono 2019).

The predisposing factors for the rupture of an aneurysm are shown in Table 4.

**Table 4.** Risk factors for the rupture of an aneurysm.

| | |
|---|---|
| **PHASES significant risk factors** | P—Population–Japanese or Finnish<br>H—Hypertension<br>A—Age > 70 years<br>E—Earlier subarachnoid hemorrhage from another aneurysm<br>S—Site anatomical location of aneurysm |
| **Other postulated risk factors** | Female gender<br>Tobacco smoking<br>Familial aneurysm<br>Growth on serial imaging<br>Symptomatic aneurysm |

Source: Authors' compilation based on data from Kirollos et al. (2019).

### *7.5. Treatments of an Intracranial Aneurysm*

Various treatments have been proposed for an intracranial aneurysm. The prime objective of treatment is the separation of an aneurysm from the parent artery with its preservation, which can be performed either by clipping or coiling. We prefer clipping rather than coiling because it has both an aneurysm occlusion under direct vision and irrigation of the brain surface and cistern by normal saline and urokinase with an aim to reduce the incidence of vasospasm.

Endovascular coiling is a treatment that is less invasive. A slender catheter with a metal coil at the end is inserted into a blood vessel by a particularly trained neuro-interventionist. The catheter or micro-catheter is inserted into the aneurysm location in the brain. The metal coil is abandoned. It prevents blood from flowing to the aneurysm.

#### 7.5.1. Initial Management Concerns

1. Rebleeding;
2. Hydrocephalus;
3. Delayed ischemic neurologic deficit (DIND);
4. Hyponatremia;
5. DVT, as well as pulmonary embolism;
6. Detecting the source of the SAH.

#### 7.5.2. Targets of Medical Management Related to Secondary Cerebral Injury

Early medical management constitutes the following:

Augmentation of CBF: To carry this out, the prime device is hyperdynamic therapy.

The goals are as follows:

(a) To increase cerebral perfusion pressure (CPP);
(b) To improve blood rheology: RBC aggregability increases after an SAH;
(c) Continuing euvolemia;
(d) Maintenance of a normal ICP (Williams and Brown 2013; Greenberg 2010; Cruz and Hopkins 1999; Hunt and Hess 1968; July and Wahjoepramono 2019; Guo et al. 2011).

#### 7.5.3. Rebleeding

Rebleeding is the most common in the first hour (between 4 and 13.6%), with >33% of patient re-rupture within 3 h and 50% within 6 h of commencement of symptoms. After the day 1, the risk is 1.5% per day for the following 13 days. Overall, 15–20% of patients will bleed again within fourteen days, and 50% will bleed again within 6 months. Furthermore, greater Hunt and Hess grades have been linked to a higher risk of rebleeding. The chance of rebleeding is higher by preoperative ventriculostomy and perhaps lumbar CSF drainage (Greenberg 2010; Kirollos et al. 2019; Guo et al. 2011).

#### 7.5.4. Prevention of Re-Hemorrhage

An optimal way of a reclusion of re-hemorrhage is early microsurgical clipping or coiling.

### 7.5.5. Hydrocephalus After an SAH

#### Acute Hydrocephalus

Blood obstructs the CSF passage through the cerebral aqueduct, the 4th ventricular output or the CSF (subarachnoid) space, as well as reabsorption at the level of arachnoid granulations. Aneurysmal rebleeding is more likely in patients who get a ventriculostomy soon after an SAH. It is recommended that an ICP be kept between 15 and 25 mm Hg and that a fast pressure drop be avoided.

#### Chronic Hydrocephalus

Chronic hydrocephalus is due to either permanent malfunctioning of the arachnoid granulations or adhesion of the pia and arachnoid.

### 7.5.6. Cerebral Vasospasm

A cerebral vasospasm is most commonly observed following an aneurysmal SAH, but it can also occur after other intracranial hemorrhages (e.g., AVM-induced intraventricular hemorrhage, idiopathic SAH), head injury (with or without SAH), cranial surgery, lumbar tap, meningitis and might even be linked to preeclampsia.

A cerebral vasospasm almost never occurs before the third day after an SAH, with a peak incidence 6–8 days following an SAH and rarely after the 17th day.

*Prime time of risk:* from 3 to 14 days after an SAH.

*Risk factors:* higher grade of SAH, more SAH on CT.

*No treatment* is curative. The prime way of treatment includes euvolemia, as well as hemodynamic augmentation (formerly "triple-H" therapy: hypertension, hypervolemia and hemodilution).

*Avoidance of a vasospasm:* This can often be accomplished by avoiding hypovolemia and anemia after an SAH CVS is not prevented by early aneurysm therapy (clipping or coiling) (i.e., before the vasospasm). Nowadays, triple-H therapy is not recommended for hyperdynamic therapy (it may invite complications without benefits).

*Treatment options for a vasospasm:*

1. Pharmacological:
   (a) Smooth muscle relaxants: calcium channel blockers (usually advised for standard utilization); nimodipine (60 mg every 4 hrs continued for 21 days or if the patient is in good neurological condition) does not counteract cerebral vasospasm, but improves neurological outcomes. Endothelin receptor antagonists (still experimental): ETA antagonists (clazosentan); Ryanodine receptor blocker: Dantrolene.
   (b) Intra-arterial papaverine.
2. Intervention:

   Balloon angioplasty;
   Cervical sympathectomy;
   Removal of blood clot.
3. Monitoring all patients of SAH:
   (a) Serial neuro exam;
   (b) Daily CBC;
   (c) Transcranial Doppler monitoring.
4. Specific measures:
   Manage the patient in ICU and place on triple-H therapy.

   Triple-H therapy:

   a. Hypertension: start dopamine at 2.5 μgm/kg/min (renal dose) and titrate up to 15–20 μgm/kg/min. Alternate drugs—levophed, dobutamine.
   b. Hepervolemia: normal saline $\pm$ plamanate (200–250 mL/h).
   c. Hemodilution: target hematocrit (Hct): $\leq$33%. Transfuse for Hct < 25% (Greenberg 2010).

7.5.7. Timing of Aneurysm Surgery

A. **"Early surgery"** (usually, but not accurately defined as $\leq$48–96 h after an SAH)

*Benefits:*

1. Virtually eliminates the chance of rebleeding if effective;
2. Makes it easier to treat vasospasm;
3. Allows for the removal of possibly vaso-spasmogenic substances from vascular contact through lavage.

*Risks:*

1. Inflammation and cerebral edema are at their worst right after an SAH. (a) More cerebral retraction is required. (b) Simultaneously, the brain softens and thus brain retraction is more difficult and injurious.
2. Surgery is hampered by the existence of a firm hematoma which has not had time to disintegrate.
3. Early surgery increases the chance of intraoperative rupture.
4. An increased risk of vasospasm after early surgery for mechano-trauma to the vasculature.
5. Operative mortality is higher.

*Factors that favor choosing early surgery:*

1. Physical condition is well;
2. Neurological status is well (Hunt and Hess (H and H) grade 1, 2 and 3);
3. Huge volumes of blood in the subarachnoid space, which increases the risk and severity of a future vasospasm;
4. Situations that make management of an unclipped/coiled aneurysm more difficult (for example, uncontrollable blood pressure, frequent and/or uncontrollable convulsions);
5. SAH is associated with a big clot with a mass effect;
6. Rebleeding in the early stages, especially numerous rebleeds;
7. Signs of impending rebleeding.

B. **"Late surgery"** (generally $\geq$10–14 days after an SAH)

*Factors that favor choosing delayed surgery:*

1. The patient's poor health and/or elderly age;
2. Patient's poor neurologic condition (H and H grade 4): debatable;
3. Aneurysms that are difficult to clip due to their size or placement, requiring a loose brain intraoperatively (e.g., mid-basilar artery aneurysms or difficult basilar bifurcation, giant aneurysm);
4. CT scan reveals severe cerebral edema;
5. Active vasospasm is present.

7.5.8. Specific Treatment of Intracranial Aneurysm

Various treatments have been proposed for an intracerebral aneurysm. The main aim of the treatment is the exclusion of an aneurysm with an intact parent artery, which can be done either by clipping or coiling.

Endovascular Coiling

Endovascular coiling is a process that is less intrusive. A slender catheter with a metal coil at the end is inserted into a blood vessel by a particularly trained neuro interventionist. The catheter or micro-catheter is inserted into the aneurysm location in the brain. The metal coil is abandoned. It prevents blood from flowing to the aneurysm. Coiling will be discussed in the endovascular chapter (Chapter 18) of this book.

Microsurgical Clipping

We prefer clipping rather than coiling because it has both the aneurysm occlusion under direct vision and irrigation of the brain surface and cistern by normal saline and urokinase with an aim to decrease the incidence of a cerebral vasospasm. We will discuss the clipping of an aneurysm in this chapter. Various patterns and types of clippings are shown in Figures 2–6.

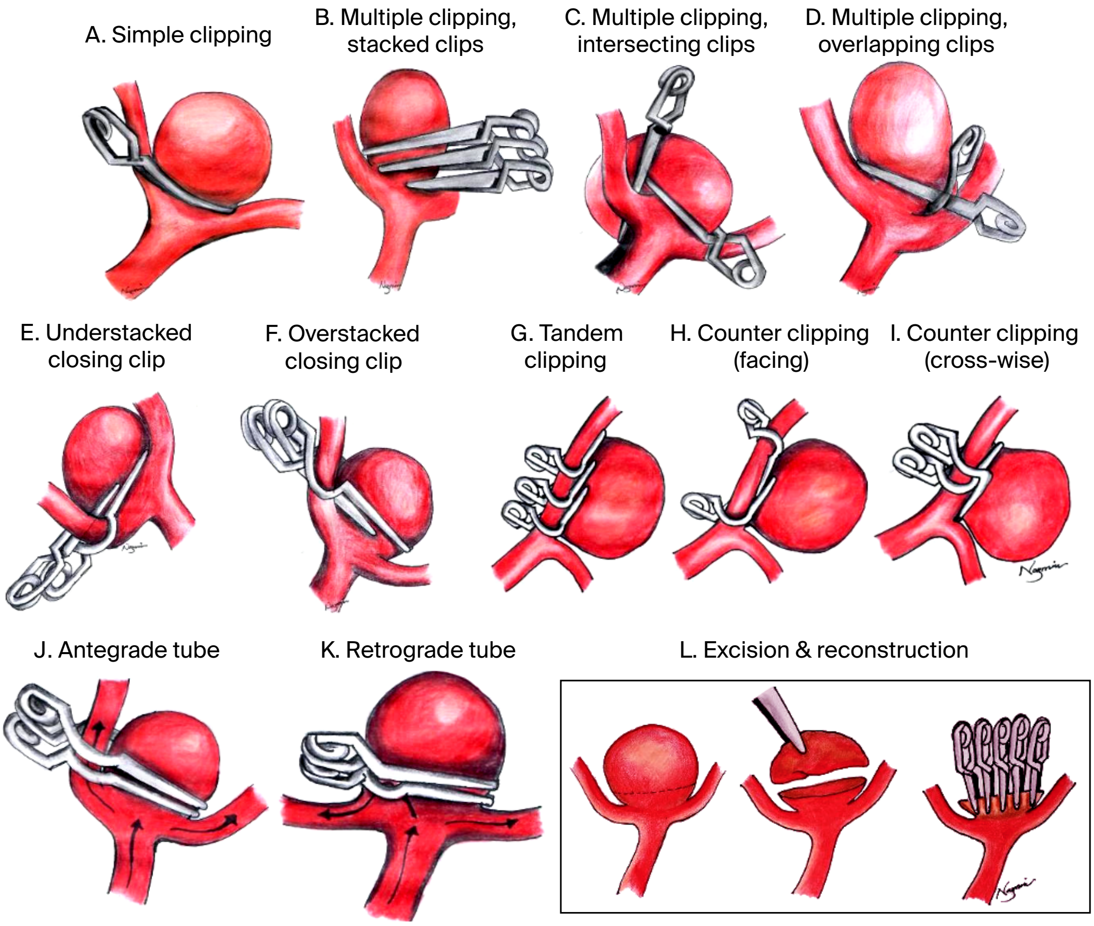



**Figure 2.** Diagram of various patterns of the clipping of different types of aneurysms. Source: Figure by authors.

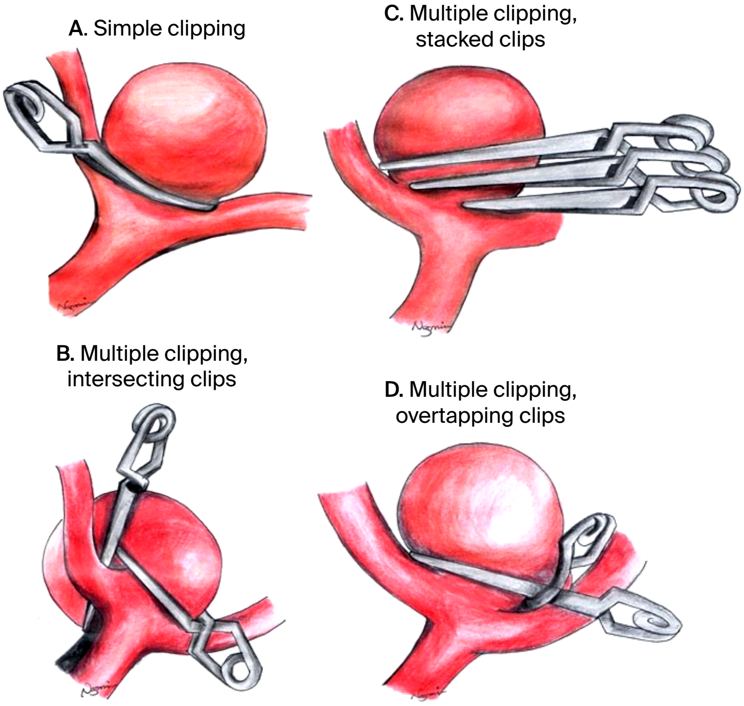



**Figure 3.** Diagram of various patterns of the clipping of different types of aneurysms. Source: Figure by authors.

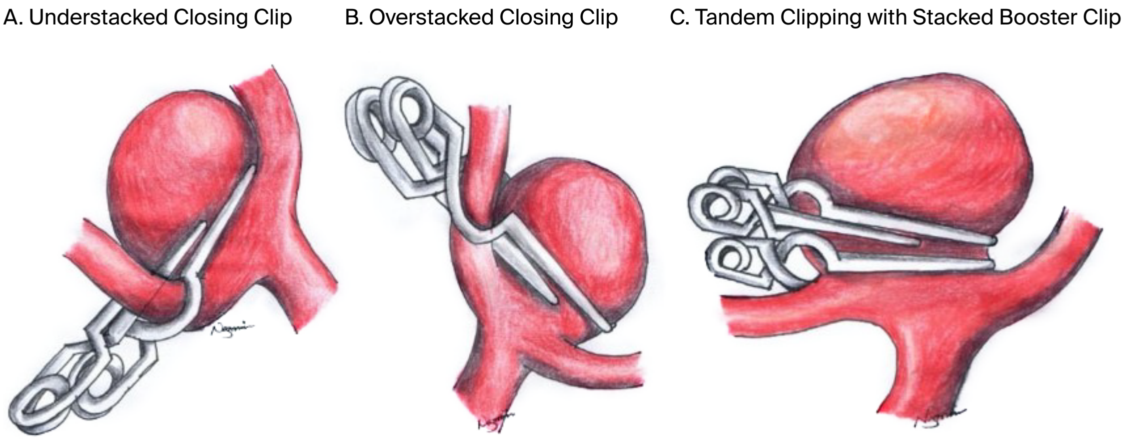



**Figure 4.** Diagram of various patterns of the clipping of different types of aneurysms (tandem clipping). Source: Figure by authors.

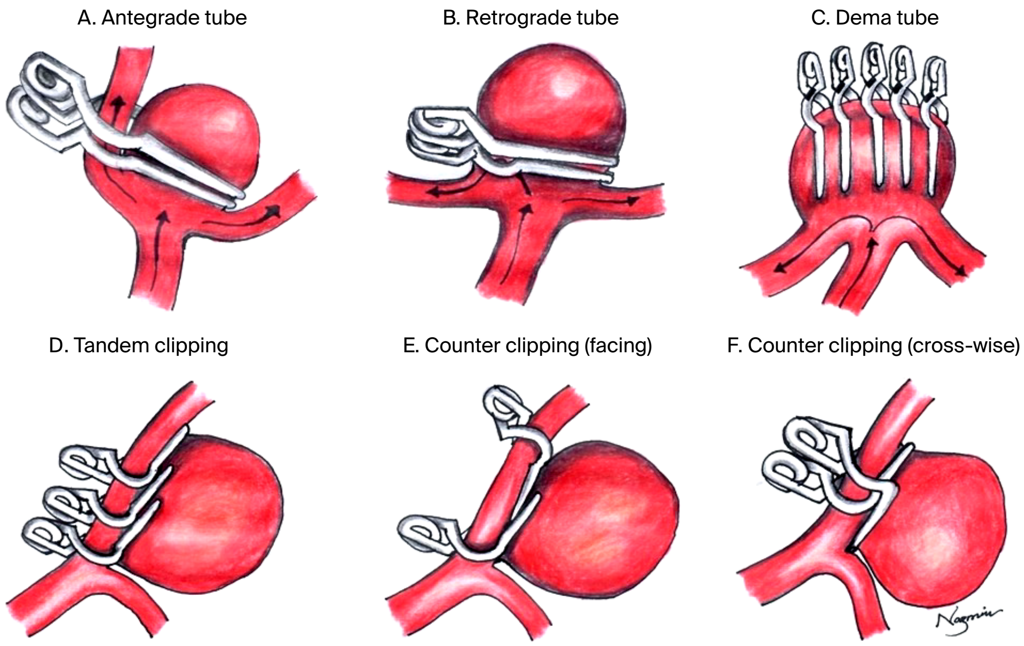



**Figure 5.** Diagram of various patterns of the clipping of different types of aneurysms (fenestration tubes, tandem angle-fenestrated clipping). Source: Figure by authors.

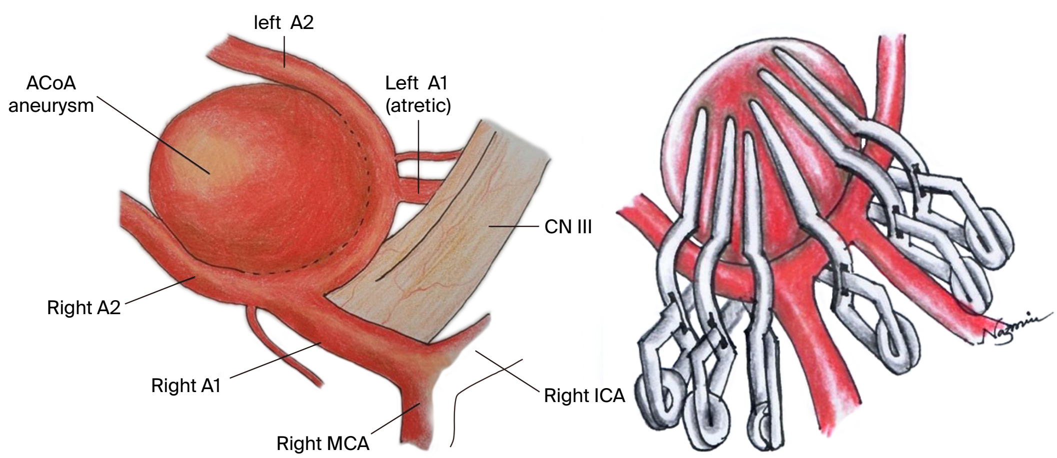



**Figure 6.** Reverse picket-fence-type clipping in the case of a giant ACOM or MCA aneurysm. Source: Figure by authors.

Comparison between coiling and clipping is shown in Table 5.

**Table 5.** Coiling vs. clipping with respect to the results.

| Coiling | Clipping |
|---|---|
| Equal risk | Equal risk |
| 22% obliteration/10 years | 93% obliteration/10 years |
| 19% retreatment/10 years | <1% retreatment/10 years |
| 2.5 to 6 times higher rebleed rate | 2.5 to 6 times lower rebleed rate |
| Can treat 64% of patients | Can teat >99% of patients |
| More expensive | Less expensive |

Source: Authors' compilation based on data from Spetzler (2018).

Giant Aneurysms

Giant aneurysms are >2.5 cm (about 1 inch) in diameter (Figure 7). Saccular (possibly an inflated "berry" aneurysm) and fusiform aneurysms are the two forms. Of all aneurysms, 3–5% are cerebral aneurysms, the common age of prevalence is 30 to 60 years, the female: male ratio = 3:1 and 35% present as a hemorrhage, with 10% displaying some signs of distant bleeding. About a third of them have a clippable neck (Greenberg 2010; Kalangu et al. 2009).

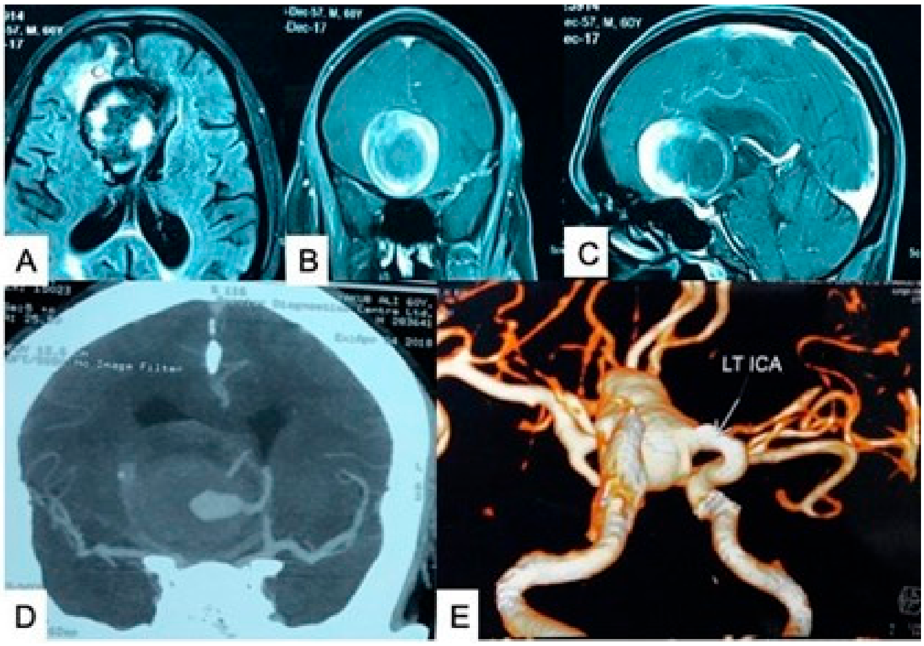



**Figure 7.** (**A**–**C**) MRI axial, coronal and sagital view showing a thrombosed ACOM aneurysm. (**D**) CT angiogram in coronal view showing a partially thrombosed ACOM aneurysm. (**E**) CT angiogram showing a giant ACOM aneurysm. Source: Figure by authors.

*Tips and tricks for aneurysm surgery*:

1. Adequate exposure under the microscope;
2. Meticulous sharp subarachnoid dissection;
3. Gentle brain retraction of brain support for proper vision;
4. Resection of some of the brain portion (gurus rictus);
5. Proximal control of patent artery by temporary clipping;
6. Occlusion of the neck or trapping of an aneurysm by permanent clipping;
7. Never panic during an intraoperative rupture, keep calm, get speedy help from an assistant, double and wide bore sucker, application of cottonoid, use of bipolar and proper clipping or in some cases cotton assistant clipping for a safe outcome;
8. Proper selection of clip length, breath and closing force, where length is commonly 1 $\frac{1}{2}$ of the aneurysm neck diameter. (Lawton 2011)

*Tenets of the aneurysm clipping*:

- Under the microscope;

- Meticulous sharp subarachnoid dissection;
- Gentle brain retraction;
- Vascular control: proximal control by temporary clipping;
- Temporary clipping;
- Proper selection of clip length (1 $\frac{1}{2}$ of aneurysm neck diameter), breath and closing force;
- Permanent clipping;
- Inspection;
- Brain transgression;
- Intraoperative rupture. (Lawton 2011)

## 8. Anterior Communicating Artery (ACOM) Aneurysm

ACOM aneurysms are the most common cranial aneurysms and the most complex aneurysms to clip in the anterior circulation (Kirollos et al. 2019; July and Wahjoepramono 2019; Yasargil 1987; Jiménez-Sosa et al. 2017).

### *8.1. Types of ACOM Arteries*

1. Adult-type ACOM arteries comprise 1/3 of A1 thickness; here, the aneurysm location is usually in the A1–A2 junction.
2. Fetal-type ACOM arteries are the same size as A1, and here, the aneurysm location is usually the ACOM itself.
3. There are about 3 to 13 perforators from the ACOM artery with a mean diameter of 250–300 µm (Greenberg 2010). The hypothalamic artery is a perforator, feeding the hypothalamus which is present in only in 10% of all cases. A1 perforators pass through the anterior perforated substance.

Important perforators:

- Recurrent artery of Heubner;
- Hypothalamic perforators.

There are variations in A1. Often, A1 runs over the optic nerve but it may be infraoptic (Figure 8).

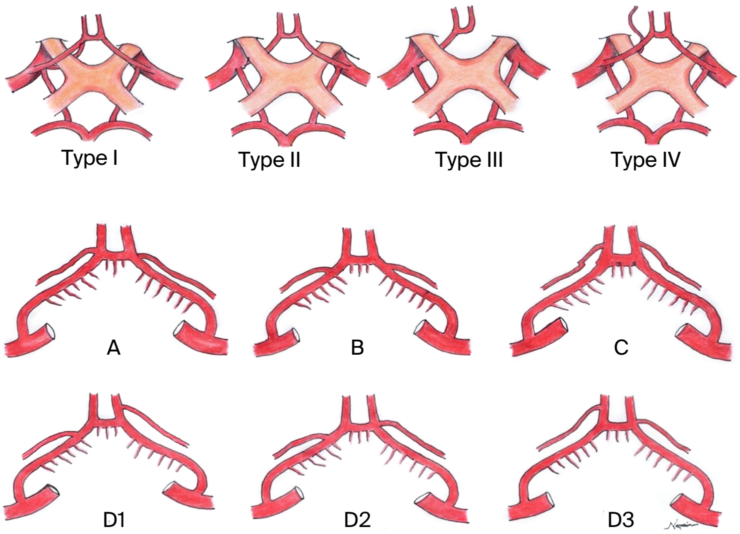



**Figure 8.** Four different types of an infraoptic A1**,** as modified after Wong et al. Type 1: infraoptic anastomotic branch between the ICA and ACA in the presence of normal anatomy around the ICA. Type 2: infraoptic A1 with the bifurcation at the level of the ophthalmic origin but no supraoptic A1. Type 3: similar to type 2, except for the absence of contralateral A1. Type 4: an accessory ACA variant. Variations in the origin of Heubner's artery are shown in (**A**–**D**). Recurrent artery of Heubner: The ACOM artery complex is located in the basal frontal lobes, near the hypothalamus, optic apparatus and cognitive/emotional centers, and its arteries supply the motor/sensory cortex, the basal ganglia and internal capsule. Source: Figure by authors.

A recurrent artery of Heubner is an important perforator originating from the initial portion of A2 (Figure 8).

- *Hypothalamic perforators:* originates from the ACOM and present in 10% of the cases.
- *Variation in A1 and A2* (Jiménez-Sosa et al. 2017) is shown in Table 6.

**Table 6.** Anatomic variants associated with an anterior communicating artery aneurysm.

| |
|---|
| Dominant A1: fills both A2s |
| Unilateral hypoplasia of one A1 (25%) |
| Exclusive filling of the anterior communicating artery by one A1 |

Source: Authors' compilation based on data from Jiménez-Sosa et al. (2017).

When an ACOM aneurysm ruptures, it presents with an impaired consciousness, and in the case of an unruptured and giant aneurysm, it may present with a bitemporal field defect.

A fenestrated ACOM is shown in Figure 9A. The types of ACOM aneurysms are shown (July and Wahjoepramono 2019) in Figure 9B and a fenestrated A1 is depicted in Figure 9C.

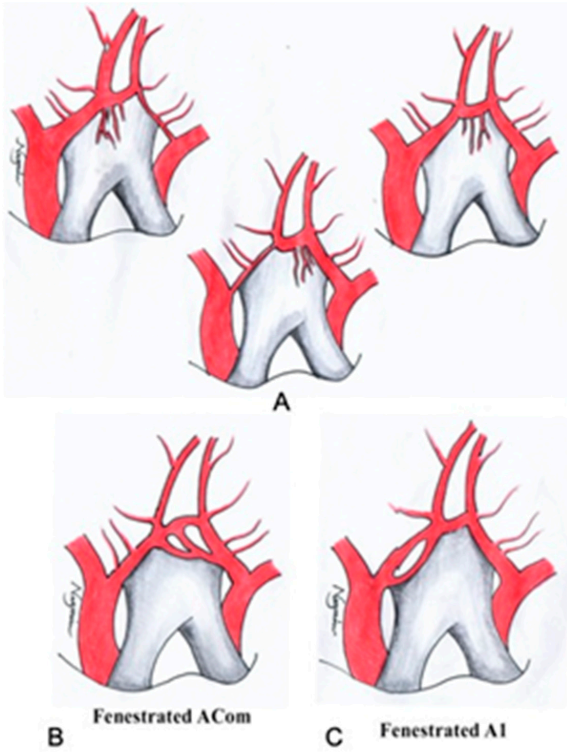
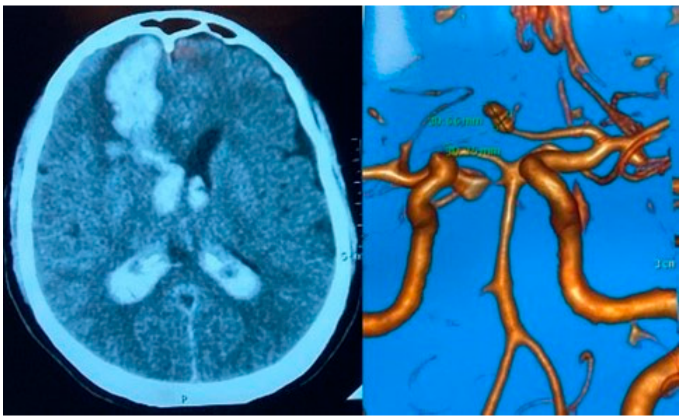



**Figure 9.** (**A**) Variation in the origin of the hypothalamic arteries; (**B**) Fenestrated ACOM; (**C**) Fenestrated A1. Source: Figure by authors.

In Figure 10, a CT scan of the head shows an SAH of a ruptured ACOM aneurysm and a CTA of the brain shows an ACOM aneurysm.



(**A**) (**B**)

**Figure 10.** (**A**) CT scan showing basal frontal blood along with intraventricular bleed and no SAH; (**B**) CT angiogram showing an ACOM aneurysm. Various origin-types of ACOM aneurysms are illustrated in Figure 11. Source: Figure by authors.

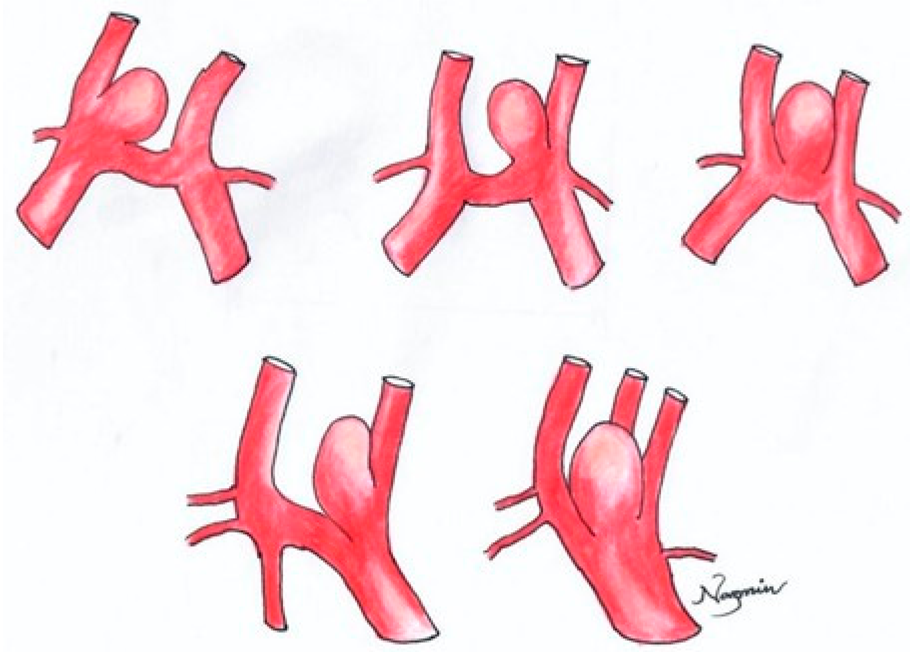


**Figure 11.** Various sites of origins of an ACOM aneurysm. Source: Figure by authors.

Schematic diagram of different dome directions of an ACOM aneurysm are seen in Figure 12.

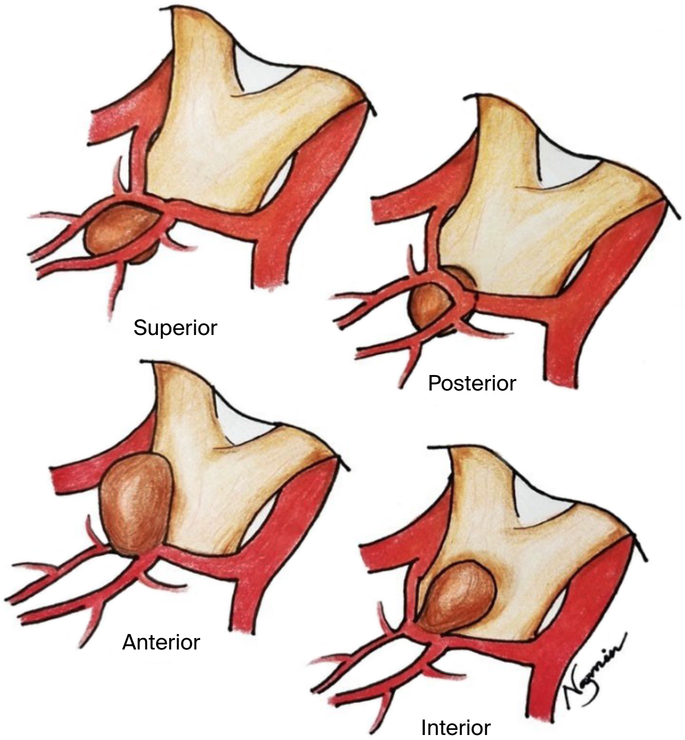



**Figure 12.** Schematic diagram showing an ACOM aneurysm with different directions, such as the anterior, superior, posterior and inferior directions (July and Wahjoepramono 2019). Source: Figure by authors.

*8.2. Surgical Technique*

- *Pterional craniotomy*—most ACOM aneurysms are carried out by pterional craniotomy;
- *Bifrontal basal approach* for superiorly directing ACOM aneurysms;
- *Supraorbital keyhole approach* for a small size, both for ruptured and unruptured aneurysms;
- *Orbitozygomatic approach* for giant ACOM aneurysms.

The types of clippings of an ACOM aneurysm are diagrammed in Figure 13.

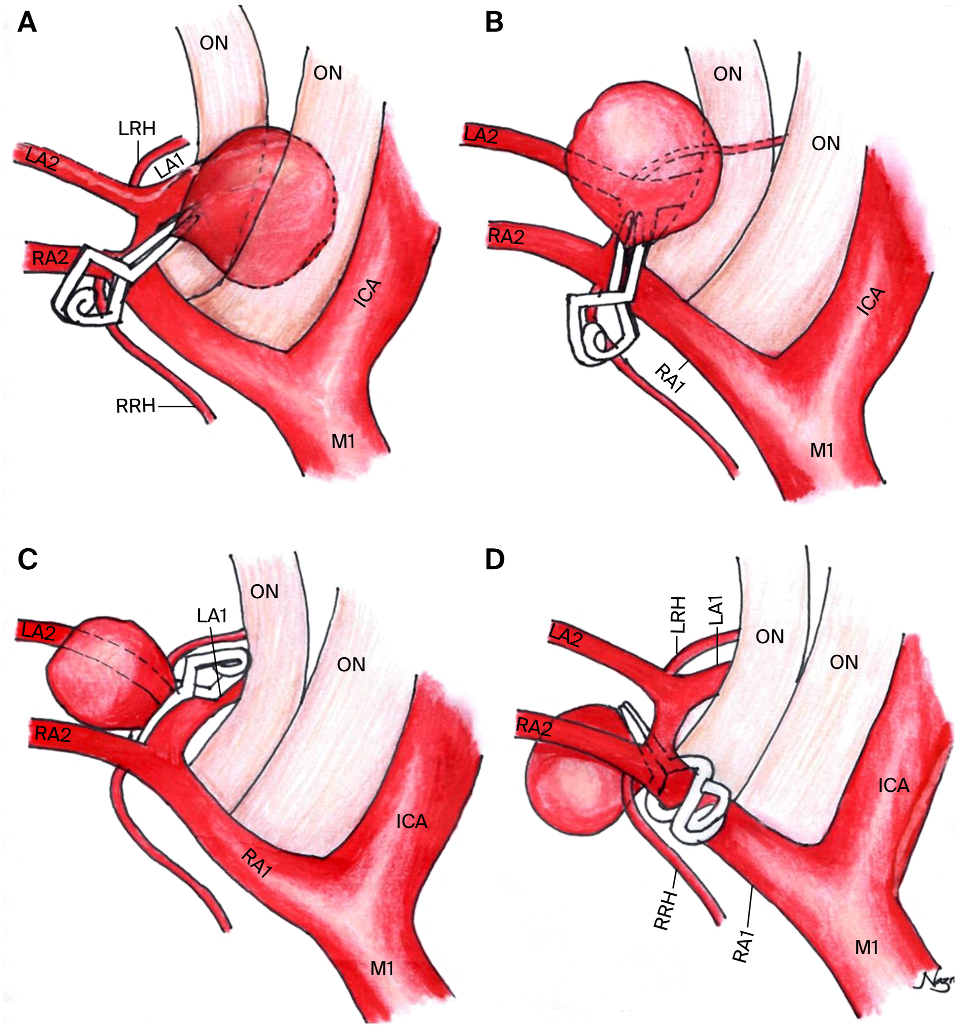



**Figure 13.** (**A**,**B**) Various types of clippings of an ACOM aneurysm (**C**,**D**). Anteriorly projecting aneurysm. Schematic demonstration of the clip placement. Source: Figure by authors.

### *8.3. Complications of ACOM Aneurysms*

(1) Vasospasm—leads to ischemia in anterior circulation areas and produces leg weakness with incontinence of the bowel and bladder;
(2) Rebleeding;
(3) Hydrocephalus—needs a VP shunt.

## 9. Posterior Communicating (PCOM) Artery Aneurysm

Posterior communicating artery (PCOM) aneurysms (Kirollos et al. 2019; Lawton 2011; Yasargil 1987) are one of the most common aneurysms following ACOM aneurysms, which constitute about 25% of all aneurysms. The PCOM artery runs parallel and above the 3rd nerve, so an aneurysm of the PCOM produces a pupil involving 3rd nerve palsy (Figure 14), along with headaches.

There are three types of PCOM artery patterns:

1. Adult pattern

   Flow from basilar to posterior cerebral artery (PCA).

2. Fetal pattern

   Flow from the internal carotid artery (ICA) to PCA;
   Hypoplastic P1.

3. Hypoplastic

   Flow from basilar to PCA;
   PCOM gives perforators which supply the internal capsule.

*Surgical technique for PCOM aneurysms:*

Pterional craniotomy and clipping of an intact PCOM, as well as an anterior choroidal artery are the aim of treatment.

The clipping patterns of a PCOM are illustrated in Figure 15.

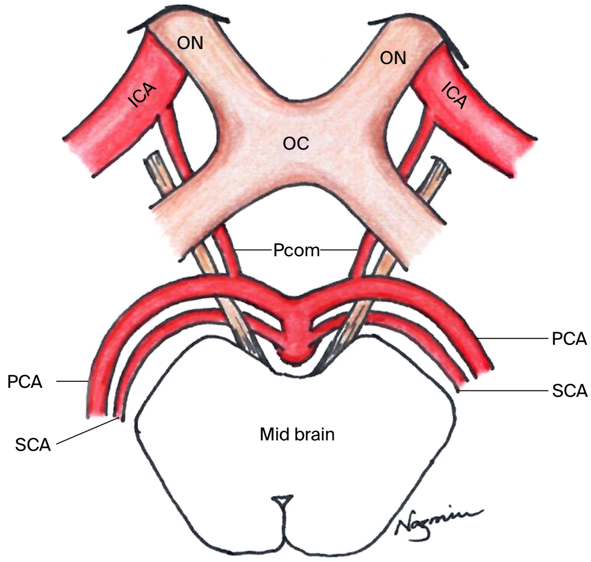



**Figure 14.** Anterior relationships between the 3rd cranial nerve and the posterior circulation. PCOMA; posterior communicating artery; roman numeral cranial nerves. Source: Figure by authors.

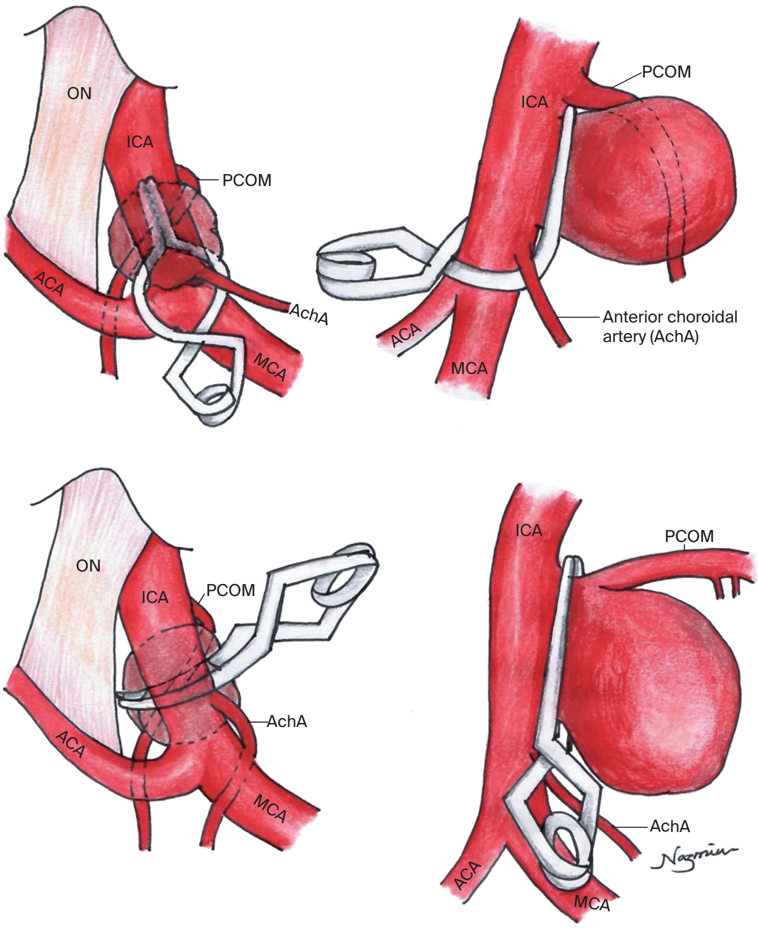
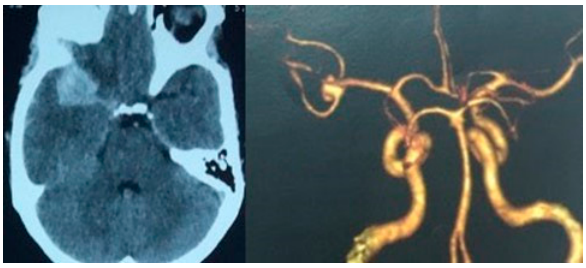



**Figure 15.** Drawing shows different clipping techniques for PCOM aneurysms. Source: Figure by authors.

## 10. Middle Cerebral Artery (MCA) Aneurysm

An MCA aneurysm (Lawton 2011; Paulo et al. 2010) constitutes about 20% of intracranial aneurysms, classically arising in the second division of a lateral sulcus (Sylvian fissure). When it ruptures, it commonly presents with aphasia, hemisensory loss, hemiparesis, visual field defects or anosognosia along with a headache and decreasing mentation.

A Sylvia fissure SAH, along with a temporal lobe hematoma, is the common radiological findings (Figure 16).

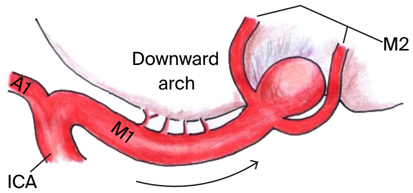


(**A**) (**B**)

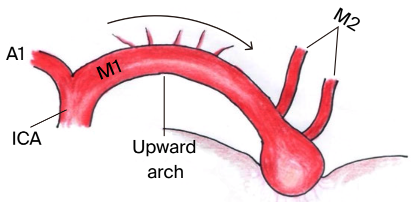
**Figure 16.** CT scan showing blood in the right Sylvian fissure (**A**) and CT angiogram showing a right MCA aneurysm (**B**). Source: Figure by authors.

### *10.1. MCA Aneurysm Dome Projection*

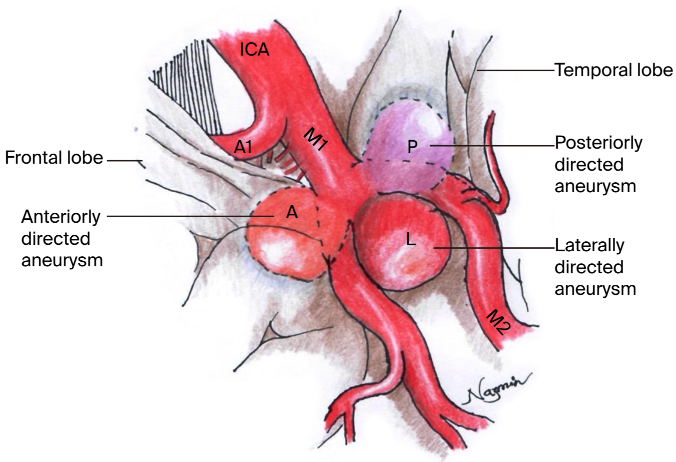
Dome projection of MCA aneurysm is shown in Figure 17.




A. Superior directed aneurysm




B. Inferiorly directed aneurysm




C. Anterior, Posterior & Lateral Tilt

**Figure 17.** Image shows different directions of an MCA aneurysm; (**A**) superior projection, (**B**) inferior projection, (**C**) L—lateral projection, P—Posterior projection and A—anterior projection. Source: Figure by authors.

*10.2. Surgical Technique*

Pterional craniotomy with a trans- Sylvian approach is the choice of surgery.

A hematoma needs to be evacuated through the wash of the Sylvian fissure with urokinase-mixed normal saline.

The Sylvian fissure can be exposed either distally to proximally, or proximally to distally.

Proximal control in the M1 artery is needed to make the aneurysm soft, and dissecting the neck is needed for proper clipping and keeping the superior and inferior trunks intact (Figure 18).

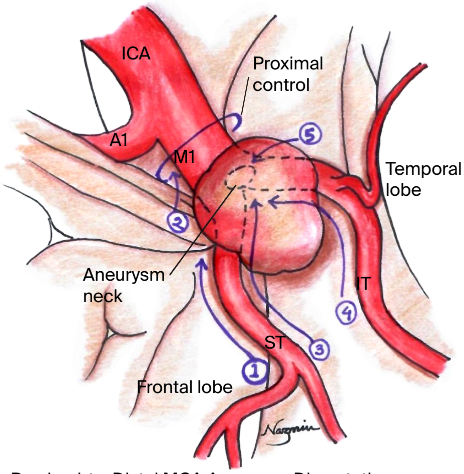



**Figure 18.** MCA aneurysm dissection strategy: distal-to-proximal dissection. Step 1: following the superior trunk (outer surface); step 2: preparing the M1 segment for proximal control; step 3: following the superior trunk (inner surface); step 4: following the inferior trunk (inner surface); step 5: dissecting the distal neck (blind spot). Source: Figure by authors.

Pterional craniotomy is the approach for an MCA aneurysm. In the case of an acutely ruptured MCA aneurysm with a significant hematoma, we need wide exposure with the aim to evacuate and decompress the hematoma if needed. Those having a hematoma with evidence of a vasospasm need to undergo wide temporal decompression to avoid tentorial herniation.

A trans-Sylvian trajectory is chosen in most of the cases; however, a transcortical trajectory is sometimes chosen when the temporal lobe is swollen and has an underlying hematoma.

The Sylvian vein is commonly dissected from the frontal side and kept to the temporal lobe, but it can also be dissected from the temporal side and kept with the frontal lobe when necessary. Figure 19 shows different types of clip occlusions of an MCA aneurysm.

A keyhole or mini pterional craniotomy is commonly chosen for chronic or unruptured cases of MCA aneurysms.

*10.3. Complications*

1. Vasospasm of the MCA leading to a massive MCA territory infarction, which may lead to uncal herniation and death of the patient if unnoticed;
2. Rebleed;
3. Hydrocephalus.

*10.4. Giant MCA Aneurysm*

The MCA is the most common site for the development of a giant aneurysm. About 6% of all MCAs are giant (>25 mm).

A combination of 3D DSA, 3D CTA and MRI data is needed for a complete idea of the vascular anatomy, intraluminal thrombus, calcification and thickness of the wall.

10.4.1. Surgical Technique

The EC–IC and IC–IC bypass are now popular to manage a giant MCA aneurysm.

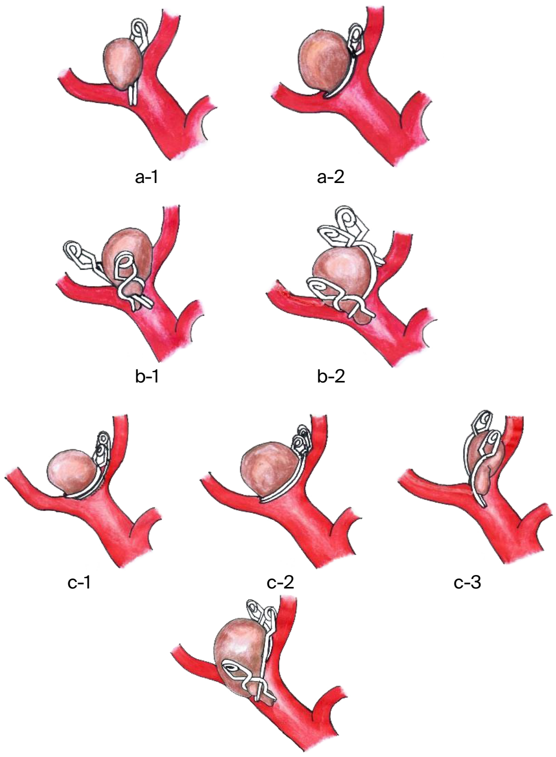



**Figure 19.** Images showing different clipping techniques for MCA aneurysms. Source: Figure by authors.

## 11. Basilar Top Aneurysm

Basilar top aneurysms (Kirollos et al. 2019; Lawton 2011; July and Wahjoepramono 2019) are the most common in posterior circulation and constitute about 5–10% of all intracranial aneurysms.

- Basilar artery aneurysms may be either fusiform or saccular;
- Rupture of a basilar artery aneurysm is classically localized to the interpeduncular cistern, though it may extend into the suprasellar cistern.

### *11.1. Types of Basilar Top Aneurysms*

Three types of aneurysms according to the level of aneurysm and dorsum sellae (Figure 20): 1. High riding; 2. normal; 3. low riding.

The carotid is normally fixed at two points: distal dural ring and by the PCOM artery. Thus, for better exposure, we need to mobilize the ICA by cutting the distal dural ring following anterior clinoidectomy and coagulation, and scarify the posterior communicating artery close to the PCA junction. The corridor is often used to reach is carotid oculomotor corridor which can be expanded by mobilizing the 3rd and or 4th nerve (Figure 21), as well as retraction of the tentorium cerebelli by a stitch. Unroofing of the cavernous sinus is carried out by clipping of the aneurysm (Figure 22). Often, long clips are applied, preserving the contralateral posterior cerebral artery and thalamo-perforators.

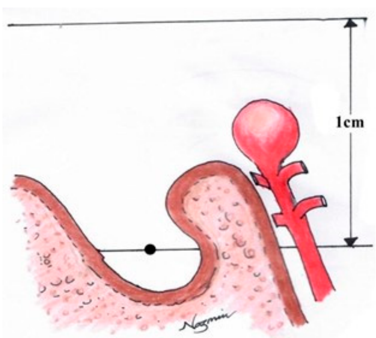



**Figure 20.** Schematic image showing relation of the basilar top aneurysm and dorsum sella. Source: Figure by authors.

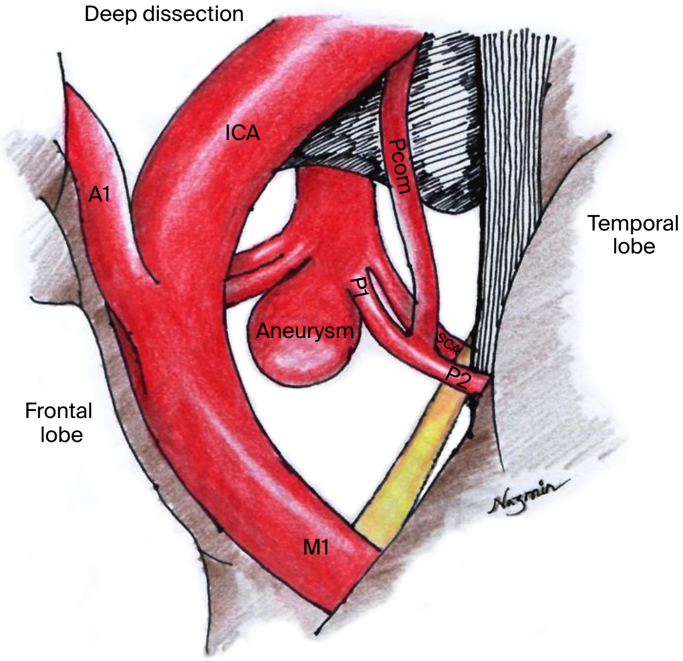



**Figure 21.** Image showing the PCOM and 3rd nerve reaching the basilar top location. Source: Figure by authors.

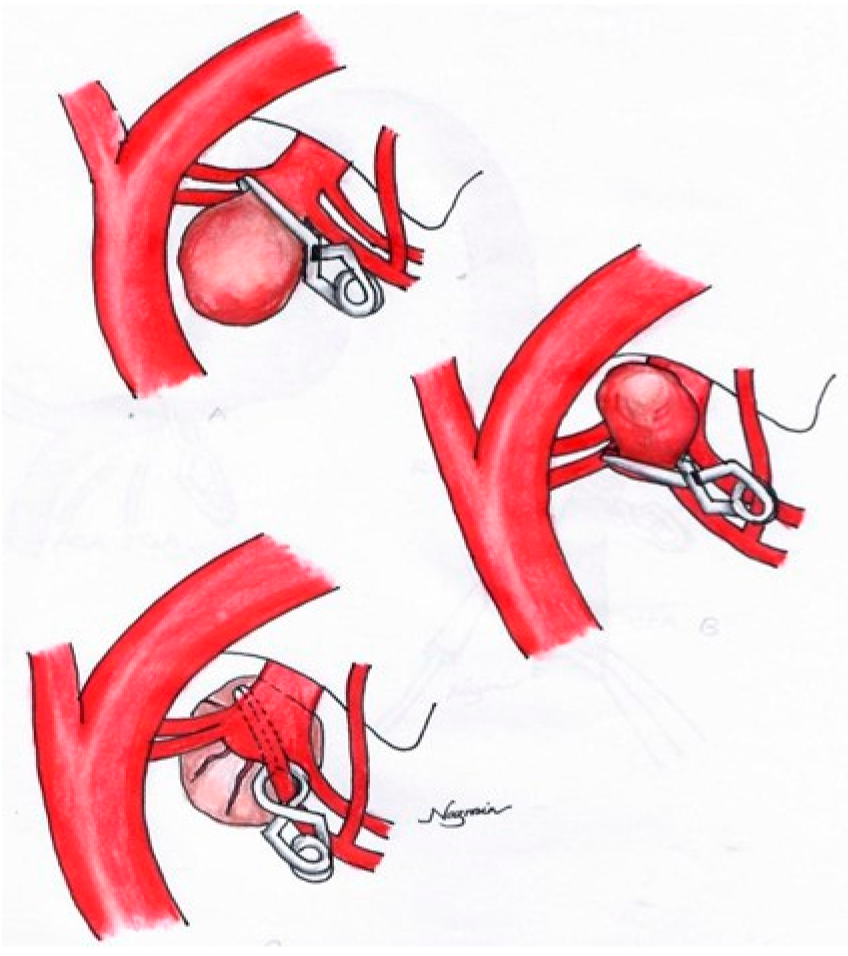


**Figure 22.** Types of clippings of a basilar top aneurysm. Source: Figure by authors.

In Figure 23, a cerebral DSA shows a basilar top aneurysm.

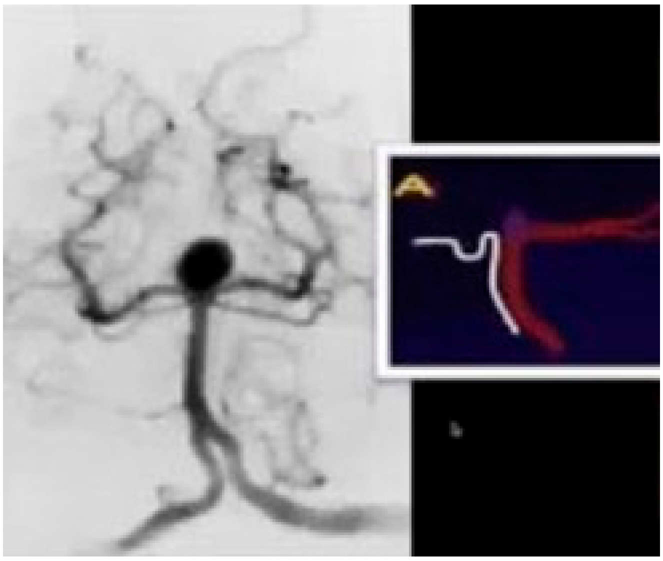


**Figure 23.** DSA showing a basilar top aneurysm. Source: Figure by authors.

*11.2. Microsurgical Approaches*

Different surgical approaches to reach the basilar top area are employed as follows:

1. **Extradural temporal approach/trans-cavernous approach/temporopolar extradural approach/trans-Sylvian trans-clinoidal trans-cavernous approach:** for normal or low-riding basilar top aneurysms;
2. **Orbito-zygomatic craniotomy:** for high-riding basilar top aneyrysms; this approach is a versatile approach in neurosurgery and can be carried out in one piece, two pieces or even three pieces;
3. **Pretemporal craniotomy/half-and-half approach:** for normal or low-riding basilar top aneurysms;
4. **Sub-temporal approach for normal-position basilar top aneurysms.**

Details of a craniotomy of frequently used approaches for posterior circulation aneurysm are shown in Table 7.

**Table 7.** Positioning, skin incision and details of a craniotomy of frequently used approaches for posterior circulation aneurysms at or about the basilar apex level.

| Approach | Pterional | Lateral Supraorbital | Orbito-Zygomatic | Anterior Temporal or Temporopolar |
|---|---|---|---|---|
| Position | Supine position, head rotated 15–20° toward the opposite side, head extension 20° | Supine position, head rotated 15–30° toward the opposite side, head flexion or extension according to the lesion | Supine position, head rotated 30–90° toward the opposite side, neck extension (top point is at the ipsilateral malar eminence) | Supine position, head rotated 30° to the opposite side and slightly elevated above the heart level |
| Skin incision | Posterior the hairline, beginning at the root of the zygoma and crossing the midline | Posterior the hairline, starting 3 cm cranial to the zygoma to the same-sided midpapillary line | Posterior the hairline, beginning at the root of the zygoma and crossing the midline toward the opposite midpapillary line | Posterior the hairline, beginning at the root of the zygoma, extending backward to the retro-ocular area and crossing the midline |
| Temporalis muscle (TM) dissection | Interfascial dissection, TM is totally dissected | Myocutaneous flap (only the upper and anterior aspect of the TM is dissected) | Subfascial or interfascial dissection, the TM is totally dissected | Subfascial or interfascial dissection, the TM totally dissected and retracted downward |

**Table 7.** *Cont.*

| Approach | Pterional | Lateral Supraorbital | Orbito-Zygomatic | Anterior Temporal or Temporopolar |
|---|---|---|---|---|
| Site of craniotomy | Frontal bone, squamous temporal bone, pterion | Frontal bone, between zygomatic process of the frontal bone, greater sphenoid wing, as well as superior temporal line | Frontal bone, pterion, squamous temporal bone and orbito-zygomatic osteotomy (orbital roof, orbital rim, lateral orbital wall, as well as zygomatic arch) | Frontal bine, squamous temporal bone pterion and orbito-zygomatic osteotomy can be performed |
| Size of craniotomy | 6 × 6 cm | 4 × 4 cm | Nearly 8 × 8 cm (varies based on the necessary temporal or frontal exposure) | Nearly 6–8 cm in diameter |
| Sphenoid ridge drilling | Up to the superior orbital fissure (SOF) | Not essential | To SOF | To SOF |

Source: Authors' compilation based on data from July and Wahjoepramono (2019).

## 12. ICA Bifurcation Aneurysm

The incidence of ICA bifurcation aneurysms (July and Wahjoepramono 2019; Lawton 2011; van Rooij et al. 2008) is about 2.4% to 4% among all intracranial aneurysms.

An aneurysm fundus projection may be superior (56%), posterior (18%), anterior (20%) or lateral (6%).

### *12.1. Surgical Technique*

- Pterional craniotomy is the approach of choice for this aneurysm, with or without anterior clinoidectomy.
- A single clip or multiple clips are commonly required to secure the neck of the aneurysm.

Figure 24 shows a DSA and CTA with different types of ICA aneurysms.

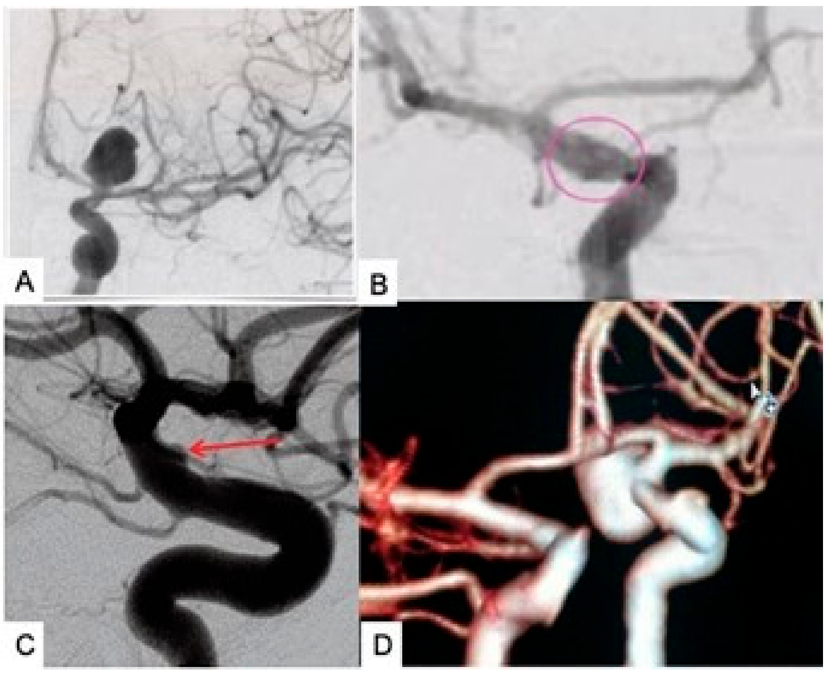



**Figure 24.** (**A**) DSA showing an ICA bifurcation aneurysm. (**B**) DSA showing the focal dilatation of an ICA. (**C**) DSA showing the focal bulging of an ICA, suggestive of a blood blister aneurysm. (**D**) Huge ICA of a dorsal wall aneurysm. Source: Figure by authors.

## 13. Blood Blister Aneurysm

A blood-blister-like aneurysm (Gopaul et al. 2015) is a wide-based bulge at the non-branching point of an artery that is unsimilar to saccular (or 'berry') aneurysms that generally occur at the branching points.

It accounts for 0.5–2.0% of ruptured intracranial aneurysms that cause unexpectedly higher mortality, as well as morbidity.

It is small dilatation or focal bulging in the non-branch portion of the supraclinoid ICA opposite to the origin of the PCOM or anterior choroidal artery.

It is frequently tiny (<6 mm), with an average of 3 mm.

- CTA: often negative
- DSA: is the most effective diagnostic imaging

### *13.1. Surgical Technique*

Microsurgical clipping carries a higher danger of tearing the aneurysm or ICA laceration during surgery:

A. Clipping with wrapping;
B. EC-IC arterial bypass plus surgical or endovascular trapping (can be used as the last resort);
C. Endovascular management by a stent assistant coiling or flow-diverting device may be used, but the value is yet to be proven.

## 14. IC Dorsal Wall Aneurysm

Aneurysms originating from the anterior (dorsal) wall of the ICA (Figure 24D) comprise 0.3 to 1% of all intracranial aneurysms (Gopaul et al. 2015). It is assumed that a blood blister aneurysm may turn to a dorsal wall aneurysm rapidly.

### *14.1. Surgical Technique*

A. Trapping surgery, both with and without an EC–IC bypass has been described; however, due to the delicate nature of the ICA, re-rupture may happen during operation (Figures 25 and 26).
B. Coiling, stent-assisted coiling, flow-diverter and coated stents in endovascular surgery.

Application of a distal ICA temporary clip and suction decompression technique from the neck allows for the collapse of the aneurysm and helps in clipping. In Figure 24B, the fenestrated clipping technique in an ICA dorsal wall aneurysm is shown.

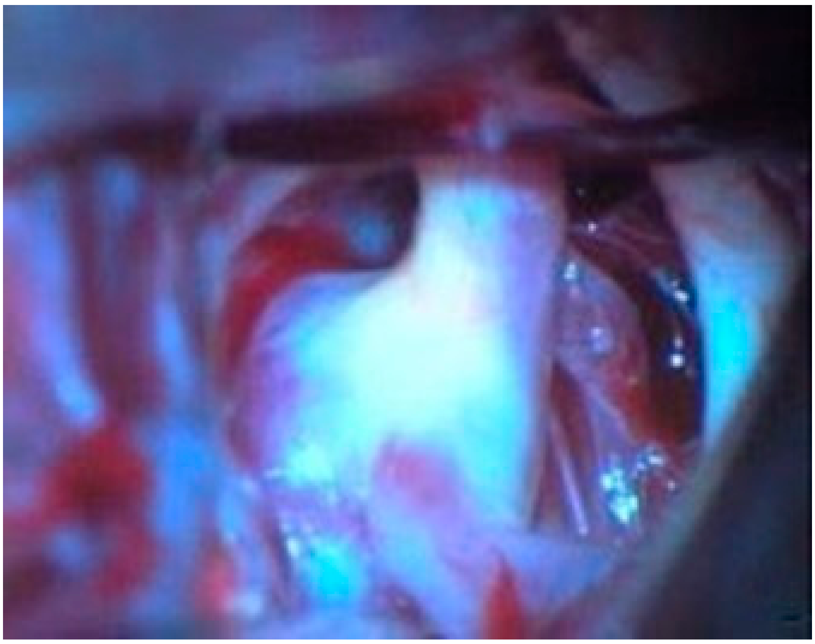


**Figure 25.** Preoperative picture of an ICA dorsal wall aneurysm. Source: Figure by authors.

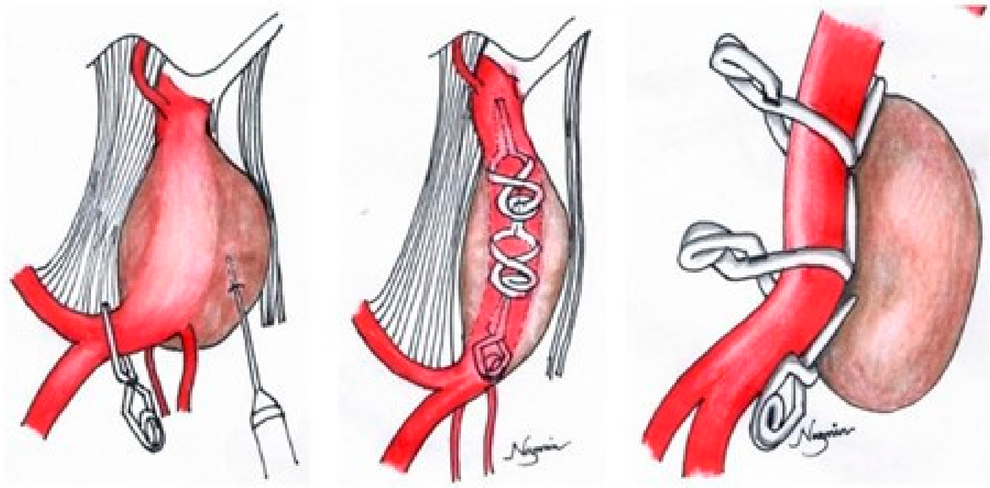


**Figure 26.** Schematic showing the fenestrated clipping technique for an ICA dorsal wall aneurysm. Source: Figure by authors.

**15. Ophthalmic Segment Aneurysm**

A supraclinoid ICA, particularly the ophthalmic part of the supraclinoid ICA, is the site of origin of ophthalmic artery aneurysms (Day 1990). An ICA from the distal dural ring to the PCOM artery is included in this segment.

Ophthalmic aneurysms are intradural. Ophthalmic artery aneurysms, superior hypophyseal aneurysms and unusual varieties such as those on the ventral and dorsal surfaces of this ICA segment are among them.

Ophthalmic segment aneurysms, as well as transitional or distal cavernous ICA aneurysms, are all classified as paraclinoid aneurysms (Figure 27).

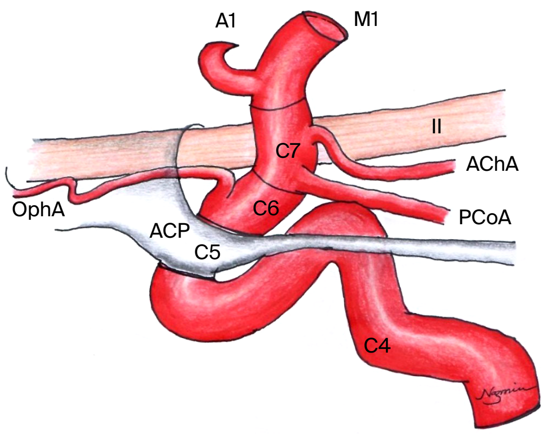



**Figure 27.** Anterior clinoid process and optic strut, along with an optic foramen and superior orbital fissure. Source: Figure by authors.

*15.1. Surgical Technique*

- An ophthalmic segment aneurysm, when small, can be managed by pterional craniotomy with anterior clinoidectomy and clipping of the aneurysm neck.
- Clinoidectomy can be performed either by an intradural or extradural route, depending on surgeons' choice and patient status.
- Release of the distal dural ring and getting proximal control, but when the aneurysm is big, it needs exposure of the neck to get vascular proximal control and for suction decompression technique.
- Contralateral pterional approach for an ophthalmic segment aneurysm—when the neck and dome of an aneurysm are redirected toward the contralateral site, then a contralateral pterional craniotomy can be carried out to secure the aneurysm.

## 16. Paraclinoid Aneurysm

Aneurysms that start at the ICA distal to the proximal dural ring (PDR) and proximal to the PCOM artery, which includes both the ophthalmic and clinoidal segments of the ICA, are known as paraclinoid aneurysms (Otani et al. 2018).

Ocular indications could be the first signs of a gradually expanding paraclinoid ICA aneurysm, which can cause blindness and death if left untreated. A patient with a rapidly increasing paraclinoid aneurysm, on the other hand, may exhibit acute symptoms such as episodic visual loss and headache. The different sites of origin of a paraclinoid aneurysm are shown Figure 28.

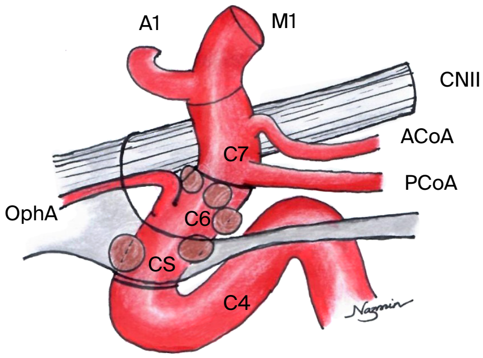



**Figure 28.** Different sites of the origin of a paraclinoid aneurysm. Source: Figure by authors.

### *16.1. Surgical Treatment*

Obtaining proximal control of the artery, proper dissection of the aneurysm neck and effective clipping of the aneurysm with less handling of the optic nerve are all critical characteristics of the successful surgical therapy of these diseases.

The extracranial cervical carotid and intracranial carotid arteries distal to the aneurysm are temporarily clipped and the aneurysm is aspirated through a catheter insertion into the extracranial carotid (a needle decompression technique similar to suction decompression can be achieved by first trapping the intracranial arterial segment and then puncturing the aneurysm dome with a "butterfly" needle connected to the suction).

Pterional craniotomy:

- Intradural or extradural clinoidectomy;
- Release of the distal dural ring and falciform ligament and mobilization of the optic nerve;
- It needs exposure of the neck for proximal vascular control and the suction decompression technique (Figure 29) of clipping;
- In some case, it needs a high-flow STA–MCA brain bypass and entrapment of the aneurysm.

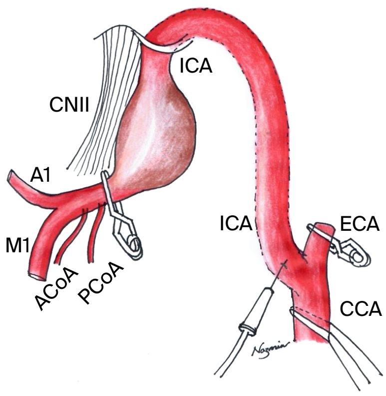



**Figure 29.** Suction decompression technique. "Dallas" technique for proximal internal carotid aneurysms. Source: Figure by authors.

## 17. Cavernous Carotid Aneurysm

Cavernous ICA aneurysms (Eddleman et al. 2009) comprise 2–9% of all intracranial aneurysms. The risk assessment of a cavernous ICA aneurysm rupture is limited (Figure 30).

Figure 30. CT scan showing a giant cavernous carotid aneurysm on the left. CT angiogram showing a giant cavernous carotid aneurysm on the right side. Source: Figure by authors.

*17.1. Surgical Technique*

A carotid cavernous aneurysm seldom needs treatment in the form of carotid ligation at the neck, plus/minus an STA–MCA/high-flow bypass (Figure 31).

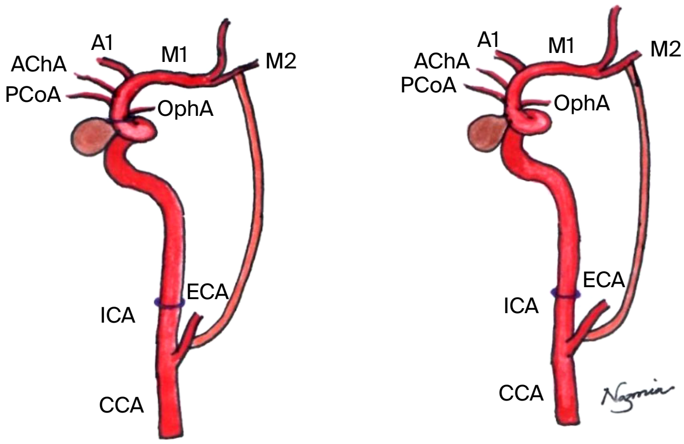



**Figure 31.** Pictures showing an EC–IC bypass with trapping and without trapping but only neck ligation of an ICA. Source: Figure by authors.

## 18. DACA (Distal Anterior Cerebral Artery) Aneurysm

Aneurysms of the distal anterior cerebral artery (DACA) (also called pericallosal artery aneurysms) account for around 6% of all intracranial aneurysms (Figure 32). They are found on the anterior cerebral artery's A2–A5 segments, as well as its distant branches (Lehecka et al. 2010).

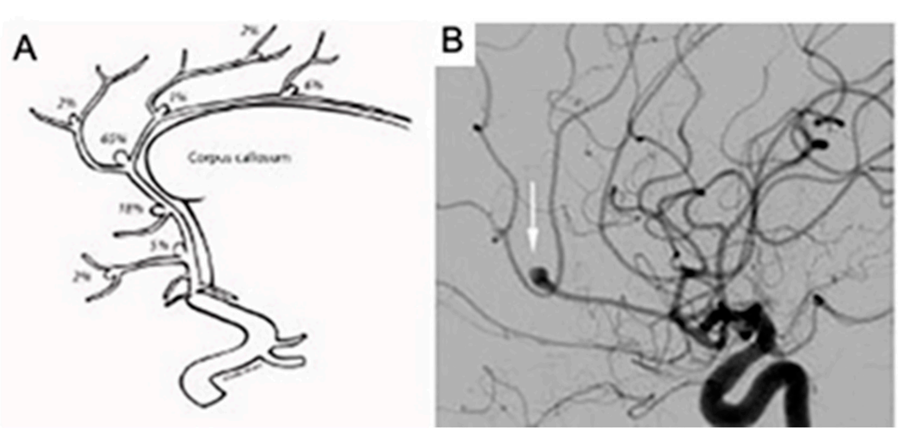



**Figure 32.** (**A**) Distribution of a DACA aneurysm based on the microneurosurgical division. (**B**) DSA showing a DACA aneurysm. Source: Figure by authors.

*18.1. Surgical Technique*

The surgical clipping of these aneurysms also presents a unique challenge due to a narrow operative field, dense interhemispheric adhesions, difficulty in locating the aneurysm, associated vascular anomalies, a small pericallosal cistern and occasional problems in attaining proximal control.

The surgical approaches used are a unilateral parasagittal craniotomy or bifrontal craniotomy.

## 19. PICA Aneurysm

Aneurysms of the vertebral artery–posterior inferior cerebellar artery (VA–PICA) constitute 0.5–3% of all intracranial aneurysms (Figures 33 and 34). Subarachnoid hemorrhage, neck pain, disorientation and coma are the common symptoms and indicators (Singh et al. 2012).

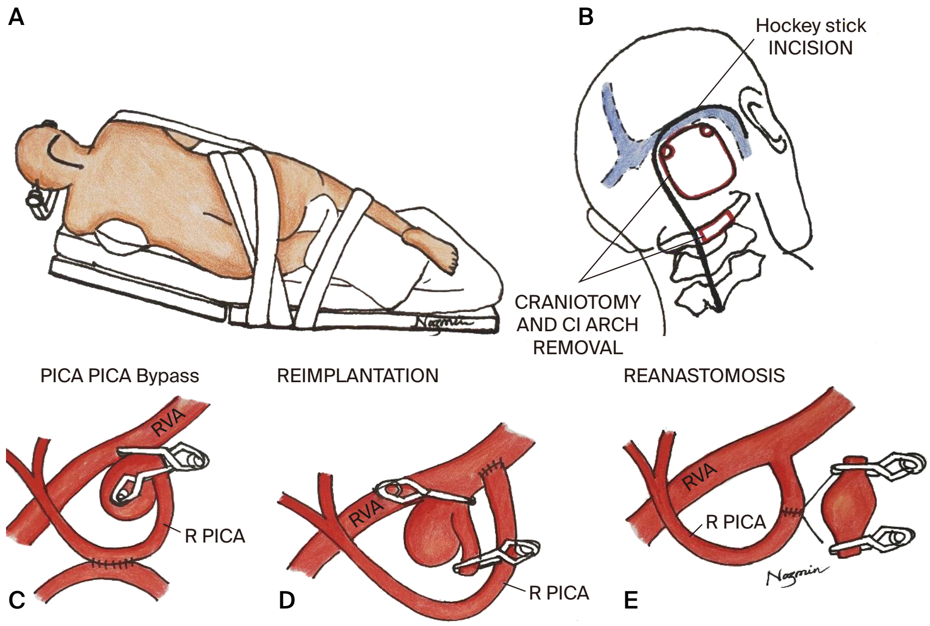



**Figure 33.** (**A**,**B**) Picture showing the far lateral transcondylar approach for a PICA aneurysm; (**C**) drawing of a PICA–PICA bypass; (**D**) reimplantation of the PICA to VA; (**E**) reanastomosis of the PICA. Figure by authors.

The PICA is divided into five parts along its course; these are anterior medullary (p1), lateral medullary (p2), tonsillomedullary (p3), telovelotonsillar (p4) and cortical (p5) segments.

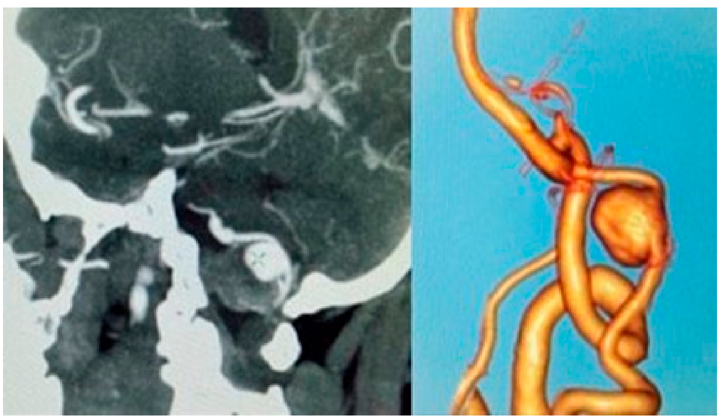


**Figure 34.** On the left-CT angiogram of a partially thrombosed aneurysm. On the right- CT angiogram of a PICA aneurysm. Source: Figure by authors.

### 19.1. Surgical Technique

The far-lateral transcondylar approach is the preferred surgical route in the park bench or lateral position (Figure 33).

When direct surgical clipping is not feasible, then a bypass is an alternative way of treatment of PICA aneurysms (Figure 33). A bypass can be:

1. Bypass from a PICA to a PICA;
2. Reimplantation of a PICA in the VA;
3. Reanastomosis after excision of a PICA aneurysm;
4. Using radial an artery graft high-flow bypass from the VA to the PICA;
5. Occipital artery (OA) to a PICA bypass.

## 20. Dissecting Aneurysm

Dissecting aneurysm (Keedy 2006): The wall of an artery tears (dissects) longitudinally in an aneurysm. This happens because hemorrhage into a vulnerable wall causes the wall to split. This is common in the aorta. Intracranially, it is common in posterior circulation. Often, it is connected to a genetic disorder (Table 8) such as Down's syndrome or Ehlers–Danlos syndrome.

**Table 8.** Vascular diseases associated with cerebral arterial dissection.

| |
|---|
| 1. Fibromuscular dysplasia |
| 2. Syphilitic arteritis |
| 3. Polyarteritis nodosa |
| 4. Mucoid degeneration of the media |
| 5. Marfan's disease/cystic medial necrosis |
| 6. Atherosclerosis |
| 7. Takayasu's disease |
| 8. Allergic arteritis |

Source: Authors' compilation based on data from Yasargil (1987).

### 20.1. Surgical Technique

It is commonly managed by a high-flow bypass.

## 21. Mycotic Aneurysm

Mycotic aneurysms (Kirollos et al. 2019) are aneurysms that develop due to a bacterial infection of the artery wall. They are a typical consequence of a bacterial or fungal infection that spreads through the bloodstream. Intracranial mycotic aneurysms (ICMAs) complicate roughly 2 to 3% of infective endocarditis (IE) cases, despite the fact that up to 15 to 29% of IE patients experience neurologic symptoms:

- ICMAs are thought to account for 0.7% to 6.5% of all intracranial aneurysms and complicate 2% to 10% of infective endocarditis cases.
- Endocarditis caused by native or prosthetic valves is frequently associated with an ICMA.
    - Most cases occur with left-sided bacterial endocarditis.
    - Locations of an endocarditis-associated ICMA:
      55%–77% reported in the middle cerebral artery;
      18% reported in the posterior cerebral artery.
- Indirect spread of intracranial bacterial infections, such as meningitis, septic cavernous sinus thrombophlebitis and orbital cellulitis, is a less common cause of an ICMA.

### 21.1. Surgical Management

Perioperative rupture and clip erosion of the parent artery are the most serious consequences of surgery. In an unruptured aneurysm, the alternative is to postpone surgery and allow for enough time for the aneurysm to turn fibrotic, reducing the risk of perioperative rupture and allowing for direct cutting. It needs systemic antibiotic therapy for 4–6 weeks according to the culture and sensitivity.

## 22. Anterior Choroidal Artery (AChA) Aneurysm

Aneurysms at the intersection of the AChA and the ICA (Yu et al. 2018) constitute from 2% to 4% of all intracranial aneurysms.

The AChA is a tiny, thin artery that branches off from the posterior communicating artery, 2–5 mm away. The posterior limb of the internal capsule, the optical tract, the lateral geniculate body, the medial temporal lobe and the medial part of the pallidum are all supplied by the AChA.

### *22.1. Surgical Technique*

Pterional craniotomy and clipping of the aneurysm to secure its neck are a feasible approach for this type of aneurysm.

## 23. Multiple Aneurysms

Approximately 20% of patients who have had an SAH have multiple aneurysms (Diringer 2009). These are common in women and hypertensive patients. They may be in the following combinations:

- Bilateral PCOM aneurysm (Figure 35);
- PCOM and ICA bifurcation aneurysm;
- Bilateral ophthalmic segment aneurysm;
- DACA plus MCA aneurysm;
- ACOM plus MCA aneurysm;
- ACOM plus PCOM aneurysm.

**Figure 35.** CT angiogram showing a bilateral PCCOM aneurysm. Source: Figure by authors.

## 24. Management of Giant Aneurysms

### *24.1. BTO (Balloon Test Occlusion) of the Carotid and Vertebral Artery*

Sacrifice of the carotid or vertebral artery, or entrapment of the carotid may be required when treating giant carotid aneurysms or an advanced CCF (carotico- cavernous fistula). A sudden occlusion of the ICA can result in 50% cases of neurological deficits. Therefore, the safety of the carotid artery sacrificed should be assessed by BTO by local anesthesia and keeping the patient awake. The vertebral artery balloon test occlusion is also carried out to evaluate the feasibility of the vertebral artery occlusion in the case of fusiform or dissection posterior circulation aneurysms (Linskey et al. 1994).

### *24.2. Bypasses for Giant Aneurysms*

An STA–MCA bypass is employed for complex aneurysms.

It may be as follows (Figure 36):

- High flow;
- Low flow;
- Protective/insurance bypass;
- Double-barrel bypass (both frontal and parietal branch of STA);

- Bonnet bypass (graft harbor beneath the bone);
- Fourth-generation bypass (endoluminal stitch and exoluminal stitch).

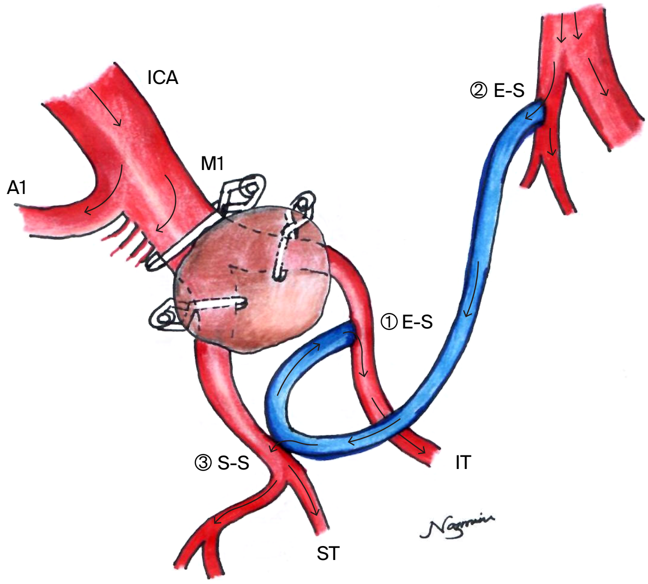



**Figure 36.** Picture showing the long saphenous graft EC–MCA bypass. End-to-side bypass with an inferior trunk of the MCA and side-to-side bypass with a superior trunk of the MCA. Source: Figure by authors.

Geometry of bypasses:

- End-to-side;
- Side-to-side;
- In situ bypass.

Types of bypasses:

1. End-to-side
    - STA–MCA;
    - STA–PCA;
    - OA–SCA.
2. Side-to-side
    - A3–A3;
    - PICA–PICA;
    - AICA–PICA;
    - M2–M2.

Donor vessels:

1. STA;
2. OA;
3. Radial Artery

*[Modified Allen test:*

- *Tell the patient to clench his or her fist; if the patient is unable to do so, tighten the person's hand.*
- *Apply occlusive pressure to both the ulnar and radial arteries with your fingers to stop blood flow to the hand.*
- *Relax the patient's hand while continuing occlusive pressure to both arteries, and check to see if the palm and fingers have blanched. If this is not the case, your fingers have not totally obstructed the arteries.*
- *Only assess whether the modified Allen test is positive or negative by releasing the occlusive pressure on the ulnar artery.*
    - *A positive modified Allen test reveals that the ulnar artery has good blood flow if the hand flushes within 5 to 15 s; this normal flushing of the hand is regarded as a positive test.*

- *A negative modified Allen test occurs if the hand does not flush within 5 to 15 s, ulnar circulation is either inadequate or absent; in this case, the radial artery is providing arterial blood to that hand (Benit et al. 1996).]*

4. Saphenous vein
5. IMAX (Nossek et al. 2014)

*[In an EC–IC bypass surgery, the internal maxillary artery (IMAX) is a relatively novel donor artery.*
*There is a necessity for a large skull base drilling while still allowing for appropriate proximal anastomosis space.*
*The temporalis muscle is separated from the zygomatic process of the frontal bone and the frontal process of the zygomatic bone, and is reflected caudally into the bony gap produced by the zygomatic osteotomy. A palpation of the posterior wall of the maxilla (PWoM) is performed. Following PWoM caudally, the IMAX passes* via *the pterygo-maxillary fissure (PMF), which is a constant point.*
*The calibers of the IMAX, RAG and MCA are closely matched, making anastomosis assembly easier.*
*When a long graft is under it, there is a need for a submandibular submuscular tunnel to transfer from the neck to the brain by using chest drain no. 24 or long artery forceps.]*

### *24.3. How to Manage Giant MCA Aneurysms*

The most prevalent location for large aneurysms of the anterior circulation is the middle cerebral artery (MCA). The treatment approaches are as follows:

- Aneurysm clipping;
- Clipping or trapping with an EC–IC bypass surgery;
- Endovascular treatment.

However, an acute cerebral infarction is the most common consequence (16%). When M1 is sacrificed or M2 is obstructed, we choose a high-flow bypass (Figure 36) using the saphenous vein or radial artery graft. A low-flow superficial temporal artery distal bypass is usually sufficient for an M3 or M4 blockage (Lee et al. 2018).

### *24.4. How to Manage Giant ACOM Aneurysms*

The treatment of massive intracranial aneurysms, including giant ACOM aneurysms, is debatable, and the final decision should be made by a multidisciplinary team that considers a variety of criteria.

#### 24.4.1. Surgical Technique

The surgical techniques include the cranio-orbito-zygomatic approach and multi-clip reconstruction of an ACOM aneurysm, OZ plus additional interhemispheric craniotomy and side-to-side bypass of A2–A2 or A3–A3 and ligation of preserving one A2, and sacrifice of feeding A1 of the contralateral side (Nakase et al. 2006).

### *24.5. How to Manage Giant Basilar Top Aneurysms*

Ruptured basilar top aneurysms (Ge et al. 2016) can cause a fatal SAH, with a fatality rate of up to 23%. Surgical clipping for basilar tip giant aneurysms remains difficult due to the brainstem's closeness and difficulties providing appropriate exposure, as well as crowding of the arteries in this location. The procedure-related mortality and morbidity can be as high as 9% and 19.4%, respectively.

Endovascular treatment can be feasible but may produce a mass effect and brainstem compression. Hence, a PCA bypass and micro-surgical excisions of the giant aneurysm are the choice by an OZ approach or trans-cavernous approach, or half-and-half approach.

## 25. Angio Negative SAH

A perimesencephalic SAH is commonly associated with a venous bleed, and angiograms reveal no evidence of aneurysms or other forms of vascular abnormality (Greenberg 2010). A hydrocephalus in the PMH is related to blockage of the tentorial hiatus due to the presence of blood in the perimesencephalic cistern. Angiography is the next line of investigation. If the first angiogram is negative, then a repeat angiogram is obtained after 2 weeks in the form of a 3D DSA.

Genetic disorders linked to the higher risk of aneurysm development are listed in Table 9. Factors influencing the treatment of incidental (unruptured) intracranial aneurysms are listed in Table 10.

**Table 9.** Genetic disorders linked to the higher risk of aneurysm development.

| Disorders |
| --- |
| Type IV Ehlers–Danlos syndrome |
| Klinefelter's syndrome |
| Autosomal dominant polycystic kidney disease |
| Tuberous sclerosis |
| Hereditary hemorrhagic telangiectasia |
| Alpha1-antitrypsis deficiency |
| Neurofibromatosis type 1 |
| Alpha-1,4-glucosidase deficiency |
| Noonan's syndrome |

Source: Authors' compilation based on data from Yasargil (1987).

**Table 10.** Factors influencing the treatment of incidental (unruptured) intracranial aneurysms.

| Favoring Surgical/Endovascular Treatment | Favoring Follow-Up |
| --- | --- |
| **Patient factors** | |
| Age less than 70 years<br>Previous SAH form another-site aneurysm | Age > 70 years<br>Significant medical comorbidities |
| Family incidence of intracranial aneurysms Symptoms due to aneurysm | Patient preference |
| **Size** | |
| Size approaching $\geq$ mm | Size <7 mm |
| **Location** | |
| Within the CSF space, posterior circulation aneurysm | Clinoidal or intracavernous ICA segment aneurysm<br>Tiny superior hypophyseal artery aneurysm |
| **Shape** | |
| Irregular shape with bleb multilobular (with daughter dome), aspect ratio is high | Regular unilobed<br>Aspect ratio is low |

Source: Authors' compilation based on data from Yasargil (1987).

**26. SCA Aneurysm**

The superior cerebellar artery (SCA) is responsible for roughly 1.7% of all aneurysms. The surgical management of these aneurysms, on the other hand, has its own set of complexities and necessitates meticulous planning, particularly in determining the approach trajectory. Endovascular treatment for all aneurysms has become more common in the last decade, particularly for aneurysms of the posterior circulation, where it has surpassed microsurgical clipping. But, in the Indian subcontinent, endovascular experience is either unavailable or too expensive. For these patients, microsurgical clipping is the primary therapy option (Nair et al. 2015). An SCA aneurysm tends to rupture despite the small aneurysm size (<7 mm). They usually present with an SAH.

An OFZ with a trans-Sylvian approach and temporal craniotomy with a subtemporal approach are commonly used (Nair et al. 2015).

**27. Posterior Cerebral Artery (PCA) Aneurysm**

Aneurysms of the PCA (van Rooij et al. 2006) are less common, accounting for only 1.2% of all aneurysms. An SAH, oculomotor palsy, visual field deficiency or a combination of these symptoms can be seen clinically. Aneurysms in the PCA can be saccular, fusiform or dissecting, and they can occur in any region of the PCA. If collateral circulation is insufficient, dissecting aneurysms might obstruct the PCA, resulting in homonymous hemianopsia. The aneurysm is selectively occluded or the parent artery is occluded in endovascular or surgical treatment. PCA aneurysm surgery is technically difficult, and the commonly used approach is temporal craniotomy with a subtemporal approach.

**28. Vertebral Artery (VA) Aneurysm**

Intracranial spontaneous VA dissecting aneurysms are common in people in their third to fifth decades of life, and they are usually linked to high blood pressure. They are present in patients with bleeding or ischemia events.

Patients who have had an intracranial hemorrhage have a 70% chance of having another one. Patients with basilar artery involvement have had poorer clinical outcomes. Surgical and endovascular therapy options are available for a ruptured dissecting VA aneurysm. Surgical or endovascular trapping is a straightforward procedure with positive results. Where the parent artery cannot be sacrificed (in patients with a posterior–inferior cerebellar artery (PICA) or ipsilateral dominant vertebral artery), revascularization may be the best technique to eradicate aneurysms by trapping the dissecting vessel. Flow-diverting and coiling embolization is treated with the help of a stent. The surgical approach used for a VA aneurysm is a far-lateral approach in combination with retromastoid lateral suboccipital craniotomy (Urasyanandana et al. 2017).

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