12 Principles and Techniques of Surgical Management of Ruptured Cerebral Aneurysms

Won-Sang Cho and Dae Hee Han

12.1 Introduction

Ruptured aneurysms, if left untreated, have been known to result in dismal clinical outcomes. The mortality rate in these cases is 30–60% within 6 months. Among the risk factors for poor clinical outcomes [1, 2], rebleeding is one of the most influencing factors. Rebleeding occurs most frequently during the first day of initial bleeding in approximately 10–20% of cases, and 50% of ruptured aneurysms rebleed within 6 months, although rebleeding decreases after the first day [3, 4, 5]. Rebleeding is a manageable factor, and management reduces mortality and improves prognoses, and it is therefore a major treatment target. However, there is currently no effective medical treatment for this condition, and surgical or endovascular interventions are the only methods available to prevent rebleeding [6]. In the past century, the chronicle of main events related to these surgical techniques include the following: Dr. Norman Dott performed the first wrapping of a ruptured aneurysm in 1933 [7]; Dr. Walter Dandy performed the first neck clipping of a ruptured posterior communicating artery (PCoA) aneurysm using a silver clip [8]; and the introduction of microscopy in the 1960s was a critical contributor to dramatic improvements in surgical techniques and outcomes [9].

Meanwhile, endovascular intervention became one of major treatment modalities soon after the invention of the detachable platinum coil by Dr. Guido Guglielmi in 1990 and the Food and Drug Administration's approval of the procedure in 1995 [10]. In its first randomized controlled study, the International Subarachnoid Aneurysm Trial in 2002 [11], coil embolization proved comparable to surgical clipping. The one-year morbidity and mortality rates were significantly lower in the coil embolization group than in the surgical clipping group (23.7% vs. 30.6%, $p = 0.0019$) [10], and the results of a midterm follow-up study were the same as the 1-year results (23.5% vs. 30.9%, $p = 0.0001$) [12]. Although there was some criticism regarding the results obtained during the early period, the superiority of coil embolization over surgical clipping in terms of clinical outcomes was acknowledged, even after the lower angiographic outcomes and higher rebleeding rates observed in the coil embolization group were considered. Coil embolization therefore is recommended by clinical guidelines around the world as the first treatment modality if both coil embolization and surgical clipping are available [6, 13–15].

W.-S. Cho
Department of Neurosurgery, Seoul National University Hospital, Seoul, South Korea

D. H. Han (✉)
Department of Neurosurgery, Cerebral and Cardiovascular Disease Center, National Medical Center, Seoul, South Korea
e-mail: daehan@snu.ac.kr

S.-H. Lee (ed.), *Stroke Revisited: Hemorrhagic Stroke*, Stroke Revisited,
https://doi.org/10.1007/978-981-10-1427-7_12

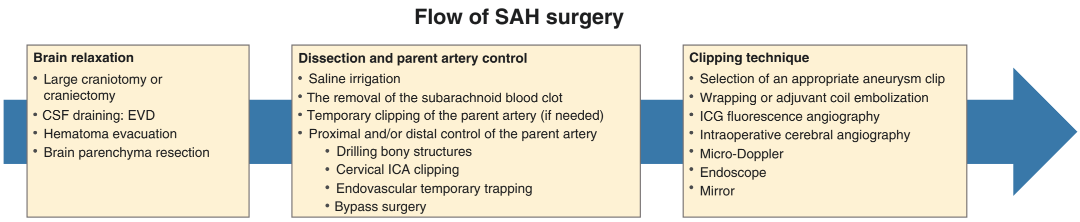

Fig. 12.1 A schematic diagram showing general surgical techniques of subarachnoid hemorrhage (SAH). *CSF* cerebrospinal fluid, *EVD* extraventricular drainage, *ICA* internal carotid artery, *ICG* indocyanine green

Nonetheless, surgical clipping is still recommended as the first line when surgical results are better than coil embolization in certain institutions; in patients younger than 40 years old; in aneurysms with a complex configuration, such as a wide neck or branches arising from the sac, those too small to perform a coil embolization, and those with a mass effect due to size; in hematomas accompanied by high intracranial pressure (ICP); and cases in which an endovascular approach is not feasible because of vessel tortuosity or atherosclerotic vessel wall changes [6, 13, 14]. In this chapter, we examine the surgical techniques used to treat ruptured cerebral aneurysms (Fig. 12.1).

12.2 General and Basic Surgical Techniques

12.2.1 Brain Relaxation

The most important goal during surgery for a ruptured cerebral aneurysm is brain relaxation, which allows enough room to be made for the microscope to view and for surgical instruments to access the affected area. Ruptured aneurysms are always accompanied by variable states of brain swelling, and specific procedures are needed to achieve adequate brain relaxation and space to perform the surgery. These procedures consist of a large craniotomy or craniectomy, draining the cerebrospinal fluid (CSF), evacuating any associated hematoma, and resecting the brain parenchyma. Among these, CSF drainage is the easiest and most effective method for reducing ICP and relaxing brain swelling. Performing a subarachnoid dissection toward the aneurysms can by itself achieve enough CSF drainage and brain relaxation to perform the surgery. However, this procedure usually takes time, and rapid CSF drainage can be more effectively performed using ventricular drainage. Inserting an external ventricular catheter or lumbar catheter to achieve CSF drainage can be performed via a small burr hole in some safety zones or via a lumbar puncture that is made before the craniotomy. In addition, CSF drainage can be achieved through a transcortical puncture, such as Paine's point, after the craniotomy and dural opening have been performed or through an opening in the lamina terminalis or cisterna magna during an approach to the aneurysm through the subarachnoid dissection.

12.2.2 Dissection and Parent Artery Control

Because subarachnoid hemorrhage (SAH) itself makes it difficult to identify vessels and cranial nerves, surgeons should be familiar with structures of intracranial vessels and should carefully dissect the subarachnoid space to avoid injuring them. Saline irrigation and the removal of the subarachnoid blood clot are helpful for identifying and dissecting neurovascular structures. Major vessels are not as difficult to identify and safely dissect. However, it is easy to damage small perforators during the dissection. Therefore, dissection should be performed through the bare side of the major vessels, from which perforators do not arise. For example, perforators from the anterior (ACA) and middle cerebral (MCA) arteries usually arise from the posterosuperior wall of the parent artery facing the brain parenchyma, and dissections performed through the anteroinferior wall should therefore be safe. As the ruptured aneurysm closes during the subarachnoid dissection, temporary clipping of the parent artery could be needed to achieve proximal or distal control. Marking the clipping point on the parent artery is sometimes helpful because it allows for prompt and appropriate temporary clipping without causing perforator damage in a situation such as rebleeding.

Proximal and/or distal control of the parent artery is essential in a surgery for ruptured aneurysms in order to prevent rebleeding or minimize the amount of bleeding. One of the important factors to consider when choosing a surgical approach is the convenience of controlling the parent artery. Proximal control of the parent artery is usually enough to perform permanent clipping of the ruptured aneurysm. However, temporarily trapping the parent artery is sometimes needed in cases in which a considerable amount of bleeding has occurred, such as aneurysms arising from the internal carotid artery (ICA) and those with retrograde flow via collaterals or in cases requiring the surgeon to precisely dissect large/giant aneurysms or complex structures under a clear microscopic view. Proximal control is not easy to achieve in paraclinoid ICA and posterior circulation aneurysms because of bony structures, such as the anterior and posterior clinoid process, jugular tubercle, and petrous bone. Hence, drilling in these bony structures is needed to achieve proximal control. When drilling bony structure is not enough for proximal control, other alternatives, such as temporary clipping at the cervical ICA and endovascular temporary trapping, can be considered. For large or giant paraclinoid ICA aneurysms, in which drilling the anterior clinoid process is not enough to expose the proximal ICA, exposing the cervical ICA is a good alternative. Recently, it has been shown that transient endovascular trapping of the parent artery can be performed using a balloon catheter in a hybrid operating room.

Clipping of complex aneurysms, such as dissecting, giant thrombosed and atherosclerotic aneurysms, is more time-consuming and difficult than clipping normal aneurysms. Therefore, bypass surgery could be required for flow restoration and to prevent ischemic insult during the temporary clipping of complex aneurysms. Preoperative balloon test occlusion and intraoperative methods, such as intraoperative physiologic monitoring, indocyanine green (ICG) angiography, cerebral angiography, and micro-Doppler, are helpful for evaluating perfusion status and determining whether bypass surgery is needed.

12.2.3 Clipping Techniques

A general practice during aneurysm clipping is to clip the neck through the closure line and parallel to the long axis of the neck along the parent artery using a clip blade that is 1.5 times longer than the aneurysm neck. Some considerations should be taken into account when selecting an appropriate aneurysm clip. These include the size and shape of the aneurysm itself in addition to the spatial relationships among the aneurysm, parent artery, and brain and the clip. Clipping perpendicular to the long axis of the neck can compromise the parent artery, the neck remnant or sac, and the neck tear. However, when clipping perpendicular to the long axis of the neck is unavoidable because of the surgical approach and the geometry of the aneurysm and parent artery, the clipping should be carefully performed using the following technical tips in order to prevent neck tearing and bleeding: lowering aneurysmal pressure by proximally or distally controlling the parent artery using temporary clips and intentionally retaining a small piece of the neck.

When rebleeding occurs before the adjacent neurovascular structures are identified and before complete clipping has been performed, hasty clipping without identifying the exact rupture point should be avoided because inaccurate clipping can make the rupture point larger and result in a more severe situation. In such a situation, the surgeons should calmly perform a temporary clipping combined with suction using multiple suction catheters or compression with cottonoid over the rupture point until the rupture point and essential adjacent anatomy are clarified.

Some aneurysms are difficult to completely clip because of their fusiform configuration and aneurysmal changes that occur in the parent artery itself. Retaining a small part of the aneurysm is better than symptomatically compromising the parent artery. Wrapping and adjuvant coil embolization are good alternatives. However, a wrapped remnant or a coil embolization should be routinely followed up because of the possibility of regrowth or recurrence and rebleeding [22].

Although aneurysms with atherosclerotic walls appear complete after clipping, some such situations are problematic. These include persistent inflow into the sac and a compromised parent artery. When the atherosclerosis is not even, the aneurysm walls are completely occluded in some sections and incompletely occluded in the others, through which intra-aneurysmal flow continues. Therefore, ICG fluorescence angiography and intraoperative cerebral angiography are helpful, and additional clips can be considered selectively or routinely based on the findings. Complete clipping of the atherosclerotic aneurysm on the microscopic view is sometimes accompanied by stenosis or occlusion of the parent artery because of intraluminal atheroma. Hence, performing redundant clipping while leaving a little space at the neck is advisable, and some tools, such as micro-Doppler and intraoperative angiography, are helpful for detecting changes in flow and identifying intraluminal stenosis.

Clip slippage sometimes occurs in large aneurysms or those with atherosclerotic walls. For example, high intra-aneurysmal pressure within the sac can push out the clip. Therefore, using a reinforcing clip, using clips with a higher closing force, or using multiple clips can be useful. When a thick atheroma involves a part of the aneurysm, clipping the softer wall without parent artery compromise can be considered because the thick and hard atherosclerotic wall has a very low risk of rupturing.

Even when completely clipping the ruptured aneurysm is considered, a close inspection of the region around the clipped aneurysm using ICG fluorescence angiography, intraoperative angiography, micro-Doppler, an endoscope, and a mirror is recommended because incomplete structures, such as a remnant aneurysm or a compromised perforator or parent artery, are commonly observed when treating ruptured aneurysms.

As the role of endovascular intervention has become larger and surgical roles have become smaller, difficult cases that cannot be treated using endovascular interventions have tended to be increasingly referred to surgical teams. In addition to the previously mentioned routine clipping techniques, other surgical techniques that require a great deal of skill, such as bypass and trapping, aneurysmorrhaphy, and direct puncture/suction decompression and reconstructive clipping, are needed to treat rare but complex aneurysms, including dissecting, blood blister-like, large or giant, thrombosed and atherosclerotic aneurysms. Hence, while the roles of surgeons are decreasing, the training of key surgeons should continue.

12.3 Specific Considerations [16–21]

12.3.1 Aneurysms Arising from the ICA

Among ICA aneurysms, in extradural aneurysms, conservative observation is recommended unless the aneurysm causes a mass effect or ruptures because the extradural origin is associated with too low a risk of bleeding [23]. The treatment indications in ICA aneurysms include intradural paraclinoid ICA aneurysms with ophthalmic involvement, superior hypophyseal artery aneurysms, PCoA aneurysms, anterior choroidal artery (AChA) aneurysms, and blood blister-like aneurysms. Most paraclinoid ICA aneurysms can be treated using endovascular interventions. However, surgical treatment is considered in cases with a high probability of ophthalmic artery compromise and no collaterals and those with aggravation of cranial neuropathy caused by a mass effect on adjacent cranial nerves. Precautions, such as temporary clipping or trapping, multiple suction, and temporary cardiac arrest, should be always taken in consideration to combat intraprocedural rebleeding because bleeding from the ICA is quite substantial. When there is little room to place a clip to achieve proximal control, drilling into the anterior clinoid process or exposing the cervical ICA are needed. When a long temporary clipping time is expected, whether collateral flow via the anterior communicating artery (ACoA) and PCoA is possible should be checked, and a donor artery for bypass surgery should be prepared in case it is needed to prevent ischemic injury during temporary flow interruption. When clipping an aneurysm arising from the superior hypophyseal artery, preserving the artery is important because it supplies the inferior part of the optic nerve, and an injury in this location can cause partial visual defects on the superior part of the affected side. The direction of the aneurysm is one of the determinants that should be considered when selecting the surgical approach and clip design because the proximal ICA is trapped within the anterior clinoid process, and there is little opportunity to deviate and manipulate the ICA (Fig. 12.2). Wide-necked paraclinoid ICA aneurysms that grow toward the true medial side are very difficult to clip via a routine pterional approach because of the way conventional clips are designed. In these cases, fenestrated clips with a blade rotated toward the aneurysm neck or a craniotomy that exposes the more inferior part of the middle cranial fossa should be considered to make clipping more convenient and to reduce the risk of neck tear and neck remnant.

When clipping aneurysms arising from the PCoA and AChA, preserving these arteries is the most important goal. Some tactics should be taken into consideration, such as clip direction and the distance between the clip and aneurysm neck or branching arteries because clip torsion or slippage caused by brain expansion/swelling and high blood pressure in the ICA can cause delayed compromise of the parent artery and neck remnant. Sometimes, a few branches of the PCoA and AChA arise from the ICA, and these should be closely inspected and preserved without injury. When an aneurysm adheres to the oculomotor nerve, meticulous dissection and detachment is important to prevent additional oculomotor injury. Certain aneurysms that arise from the PCoA and AChA are hard to identify because they are located on the side opposite to the microscopic

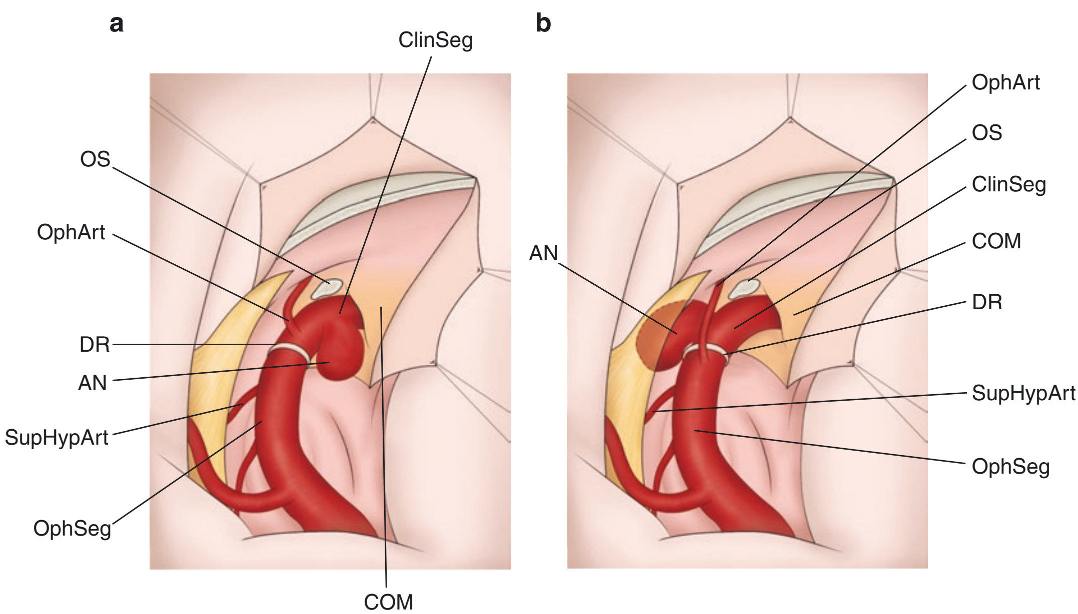

Fig. 12.2 Operative views of clinoidal segment aneurysms. (**a**) Anterolateral variant. (**b**) Medial variant. *OS* optic strut, *OphArt* ophthalmic artery, *DR* dural ring, *AN* aneurysm, *SupHypArt* superior hypophyseal artery, *OphSeg* ophthalmic segment, *ClinSeg* clinoidal segment, *COM* carotid-oculomotor membrane

view. In addition, branches, such as the PCoA and AChA, and perforators, such as the medial lenticulostriate artery and superior hypophyseal artery that arise from the medio-inferior wall of the ICA, are also difficult to identify. In such cases, a mirror or endoscope is useful and sometimes essential for preventing compromise of the branching arteries and rebleeding during blind clipping.

In cases of ICA bifurcation aneurysms, posteriorly directed cases are difficult to clip because they are in the space opposite to the microscopic view and the medial lenticulostriate arteries arising from the posterosuperior wall of ICA. It is not easy to detach the perforators from the sac to make a room for a clip blade. In addition, incomplete clipping and clipping in compromised perforators are frequent. Therefore, closely inspecting the region using a mirror, endoscope, ICG fluorescence angiography, and intraoperative angiography is essential for complete and safe clipping.

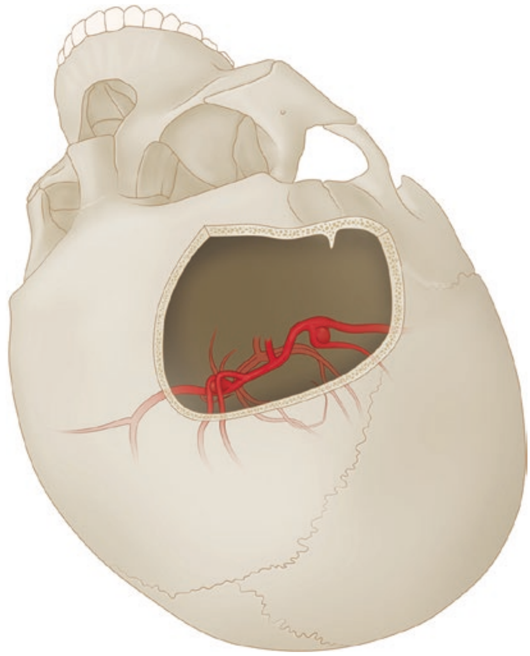

Fig. 12.3 Pterional craniotomy for approach to middle cerebral artery and anterior communicating artery aneurysms

12.3.2 Aneurysms Arising from the MCA

MCA aneurysms consist primarily of M1, MCA bifurcation, and M2 aneurysms (Fig. 12.3). MCA aneurysms have the following characteristics: this is the most common site of ruptured aneurysms, they are complex vascular structures, they develop draining veins, the lateral lenticulostriate artery is a major perforator, and it is clinically important to supplying the major functional cortex. Surgical clipping is relatively more frequently recommended than endovascular intervention in these cases because of their complex vascularity, their tendency to have a wide-necked configuration, and the lack of difficulty in finding a surgical approach [6]. However, during surgical clipping of MCA aneurysms, it is easy to compromise or distort the parent arteries with the clip. Therefore, the state of blood flow and neurological function should always be checked using micro-Doppler, ICG angiography, intraoperative physiological monitoring, and angiography.

Because brain swelling generally accompanies an SAH, CSF drainage is very important to make room for the dissection and to control the ICP. A sylvian dissection is not sufficient for achieving effective CSF drainage and brain relaxation. Instead, ventricular catheter insertion can be rapidly and effectively performed through Paine's point or the lamina terminalis. A preoperative evaluation of the structures of the sylvian fissure using cerebral angiography and T2-weighed magnetic resonance imaging is informative. The final location of the sylvian dissection is determined based on the subarachnoid space, the relationship between the frontal and temporal lobes, the amount of SAH, and the development of sylvian veins. Preserving the draining veins during dissection is very important but is not easy to achieve because of the SAH itself. Especially in cases with thick sylvian SAH, too meticulously removing the hematoma can result in damage to the draining veins and consequentially exaggerated brain swelling. Compression is better than coagulation for controlling venous bleeding. Intermittent releasing the retractor is important because long-term retraction can cause brain swelling as a result of retraction injury and venous compromise.

Retracting the temporal lobe is usually better than retracting the frontal lobe because of probable parenchymal injury and neurological sequelae.

When clipping M1 aneurysms, preserving the lenticulostriate artery is the most important goal. Aneurysms embedded in the frontal lobe and those positioned high or posteriorly directed should be carefully dissected, and the surrounding structures should be checked to avoid, as much as possible, injuring the brain parenchyma and perforators.

Except for proximal M2 aneurysms, sylvian dissection is difficult because the subarachnoid space is very narrow and the frontal and temporal lobes are usually tightly adhered at this location. In addition, locating these aneurysms is not easy because MCA branches are complex and the aneurysms are embedded within the deep insular cortex. Hence, preoperative angiographic findings should be carefully reviewed, and intraoperative navigation systems are recommended because they are very useful for locating these aneurysms.

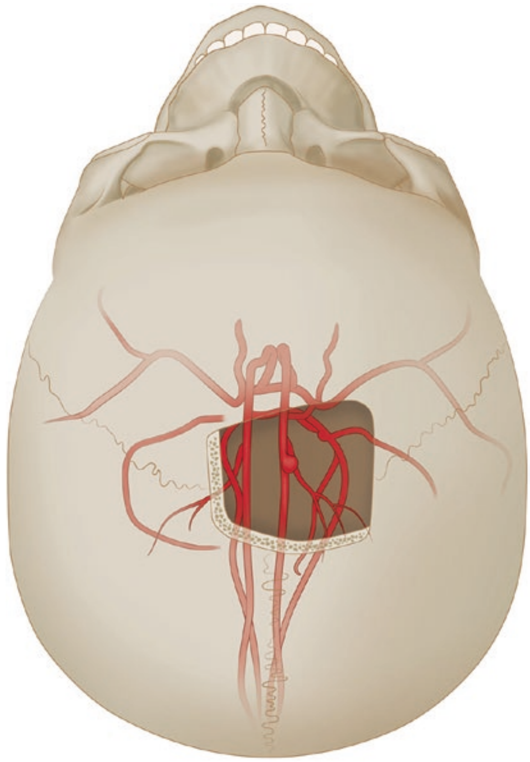

Fig. 12.4 Interhemispheric approach for aneurysms in the distal anterior cerebral artery

12.3.3 Aneurysms Arising from the ACA

Aneurysms arising from the ACA include those most frequently located at the ACoA and distal ACA. ACoA aneurysms are usually clipped via the lateral approach, such as conventional pterional (Fig. 12.3) and supraorbital keyhole craniotomy, or an anterior interhemispheric approach (Fig. 12.4). The approach side is determined based on the laterality of the dominant proximal ACA, the aneurysmal geometry (e.g., its size, direction, and associated perforators), hemispheric non-dominance, and the location of associated hematoma. Most affected cases can be treated via the lateral approach. However, an anterior interhemispheric approach would be advantageous for high-positioned and posteriorly directed cases in order to preserve perforators and secure a clear surgical view (Fig. 12.4). An anterior interhemispheric approach has an advantage in that it can be used to identify the H-complex and posteriorly hidden perforators. However, it also has a disadvantage in that it can result in frontal lobe injury during dissection, bilateral olfactory nerve injury, and a deep surgical field. When using a pterional approach, CSF can be effectively drained after the lamina terminalis is opened, and focal aspiration of the nonfunctioning rectus gyrus is helpful for exposing deep or high-positioned large aneurysms. Minimizing frontal lobe retraction with bone exposure as close to the skull base as possible is important, and dissecting the olfactory nerve is sometimes needed to prevent nerve injury. Preserving the perforators from the ACA and ACoA, including the recurrent artery of Heubner and the medial lenticulostriate artery, is very important because these vessels supply the hypothalamus, fornix, caudate nucleus, and anterior limb of the internal capsule. Because ischemic changes in such areas cannot be detected using intraoperative physiological monitoring, it is important to use direct visual inspection with the assistance of ICG or intraoperative angiography and micro-Doppler. Because the vessels surrounding the ACoA are complex and their perforators well developed, it is necessary to use a variety of shapes of clips.

Distal ACA aneurysms are usually clipped via a bicoronal incision, a parasagittal craniotomy, and an interhemispheric approach. The side from which the interhemispheric approach is made is determined based on the bridging veins that traverse the brain and superior sagittal sinus. Preoperative magnetic resonance imaging or cerebral angiography and intraoperative navigation systems are useful for choosing the approach side. The superior part of the medial frontal lobe is loosely adhered to the falx and the contralateral medial frontal lobe, making this a less difficult dissection. However, the anterior and inferior parts of the bilateral medial frontal lobe are tightly adhered, and the medial frontal lobes are prone to damage. Hence, anterior and inferior interhemispheric dissections should be carefully performed because the medial frontal lobe is associated with memory functions. Unlike ruptured aneurysms located in other parent arteries, it is very possible to reach the ruptured sac before exposing the proximal parent artery because of the anatomical characteristics of the interhemispheric approach. Therefore, when the aneurysm is nearly exposed, a careful dissection should be performed, and the surgeons should try to identify the proximal part of the parent artery in order to exert proximal control. The distal ACA is frequently smaller in size than the aneurysm, and the ACA is therefore easily compromised after clipping. The use of a mini-clip is advantageous in such situations. During the dissection, it is advisable to preserve and avoid compromising the perforators from the distal ACA to the corpus callosum or medial frontal lobe and the callosomarginal artery that supplies the motor cortex.

12.3.4 Aneurysms Arising from the Posterior Circulation

Posterior circulation aneurysms account for approximately 10% of cerebral aneurysms, relatively frequently have a fusiform shape and are dissecting type. Endovascular intervention is usually recommended as the first-line treatment option because of the difficulty of accessing the deep skull base, close proximity to the brainstem and lower cranial nerves, variable vascular anatomy, high rebleeding risk, and surgical complication rate. However, a surgical approach would be appropriate for giant and thrombosed aneurysms with a mass effect and those with major branches or perforators arising from the sac.

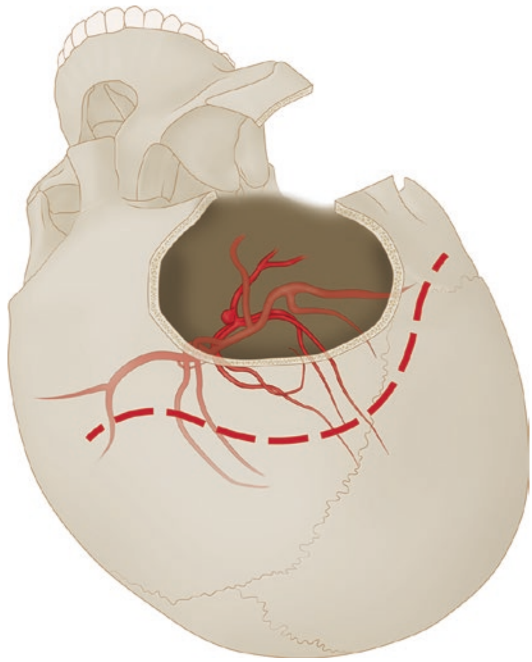

Fig. 12.5 Orbitozygomatic approach for aneurysms in the basilar bifurcation, superior cerebellar and posterior cerebral arteries. *Red line*: skin incision

Aneurysms at the basilar bifurcation (BB), posterior cerebral artery (PCA), and superior cerebellar artery (SCA) can be surgically managed using routine pterional trans-sylvian, orbitozygomatic trans-sylvian, and subtemporal transtentorial approaches. An orbitozygomatic approach is suitable for highly positioned BB aneurysms (Fig. 12.5), and a subtemporal approach is recommended for BB aneurysms located below the posterior clinoid process. The trans-sylvian approach has some advantages in that it reveals both proximal PCAs and makes a relatively lager amount of space for the procedure. However, it also has a disadvantage in that it is difficult to inspect posteriorly directed perforators and clip blades, and clipping an anteriorly or posteriorly directed cerebral aneurysm is therefore not easy. On the other hand, when using a subtemporal approach, perforators are easy to identify, and clipping anteriorly or posteriorly directed aneurysms is more feasible than when using another approach. However, the contralateral proximal PCA is difficult to see, and the exposed space is narrow, especially in ruptured aneurysms, and the basal temporal lobe and adjacent nerves, such as the oculomotor and trochlear nerves, are therefore vulnerable to damage.

When using a trans-sylvian approach to reach BB aneurysms, the following structures are sequentially passed through: windows made by the optic nerve, ACA, ICA, and PCoA; the Liliequist membrane; and the interpeduncular cistern harboring the BB aneurysms. The accessible windows consist of the optico-carotid triangle (made by the lateral margin of the optic nerve, the medial margin of the ICA, and the inferior margin of the ACA), the supra-carotid triangle (made by the superior margin of the ACA, the lateral margin of the optic nerve, and the medial margin of the MCA), and the carotico-oculomotor triangle (made by the lateral margin of the ICA, the anterior clinoid process, and the medial margin of the oculomotor nerve with a traversing PCoA). Among these, the carotico-oculomotor triangle is frequently used because it is a wider space than the others and has a lower risk of injuring the optic nerve, ICA and ICA perforators than an approach via the optico-carotid triangle and a lower risk of injuring the medial lenticulostriate perforators than an approach via the supra-carotid triangle.

SCA aneurysms can be approached via the trans-sylvian and subtemporal routes, and the latter is usually advantageous because SCA aneurysms are located below the posterior clinoid process. Making a tentorial incision and opening the crural and ambient cisterns exposes the SCA aneurysm. The trochlear nerve is prone to injury during a tentorial incision. Because it is located within the subarachnoid space under the arachnoid membrane, preserving the arachnoid membrane while making a tentorial incision can protect the nerve. Aneurysms that occur in the P1, P2, and P3 segments of the PCA can be accessed by opening the crural and ambient cisterns using a subtemporal approach, and those that occur in the P3 and P4 segments can be approached by opening the quadrigeminal cistern using a posterior interhemispheric approach.

Aneurysms arising from the basilar trunk, anterior inferior cerebellar artery, and vertebra-basilar junction are the rarest. However, this space is very narrow and deep, and the perforators originating from the parent arteries and lower cranial nerves are very complex. Hence, more than 90% of them are treated using an endovascular intervention rather than surgery. According to the location, which can range from the BB via the mid-basilar artery to the vertebra-basilar junction, the type of approach is selected in the following order: trans-sylvian, extradural temporo-polar, subtemporal, anterior petrosal, trans-facial trans-clival, combined supratentorial and infratentorial, retro-labyrinthine trans-sigmoid, and far lateral. Recently, advancements in the endonasal endoscopic approach have gradually made it possible to access deep-seated aneurysms located at the basilar trunk, SCA, anterior inferior cerebellar artery, vertebra-basilar junction, proximal posterior inferior cerebellar artery (PICA), and proximal PCA, ACoA, and paraclinoid ICA in a less invasive manner [24].

Aneurysms located in the PICA and vertebral arteries are generally accessible via the far lateral approach (Fig. 12.6), and distal PICA aneurysms can be accessed via the midline sub-

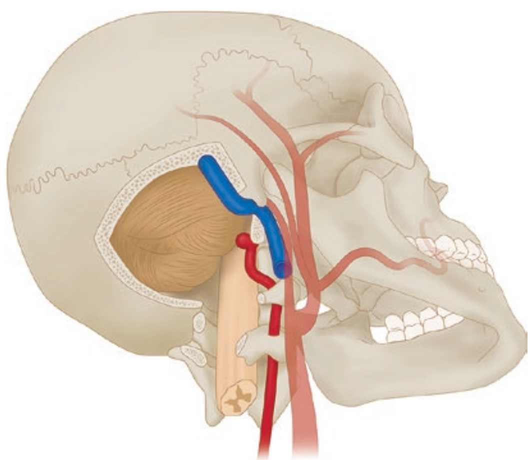

Fig. 12.6 Far lateral transcondylar approach for vertebral artery aneurysm

occipital or retromastoid suboccipital approaches. When performing the far lateral approach, the lower cranial nerves are prone to damage because the aneurysms can be manipulated by passing the cranial nerves. During the procedure used to approach proximal PICA aneurysms, surgeons should be careful not to injure the perforators when approaching from the distal vertebral artery and proximal PICA because there could be lateral medullary syndrome. When the jugular tubercle disturbs the surgical view, drilling the jugular tubercle and the medial one-third of the occipital condyle should be considered. In cases in which the aneurysm involves the PICA itself, sacrificing the involved portion of the PICA is sometimes considered. In such a situation, preserving the perforators originating from the PICA and restoring flow with bypass surgery, such as occipital artery-PICA or PICA-PICA microanastomoses, should be considered. When the preservation of the perforators cannot be guaranteed, performing a PICA segment occlusion without bypass surgery may be a good less invasive option because the territory of the distal PICA is usually supplied by the leptomeningeal collaterals, and the clinical symptoms caused by the infarction of the unilateral PICA territory can be recovered.

Conclusion

As the devices and techniques of endovascular intervention rapidly develop, endovascular approach has become the first choice of treatment for the ruptured aneurysms. However, surgical clipping is still useful for those which cannot be treated with endovascular intervention or those for which surgery is more advantageous, and complex cases that needed highly skilled surgical techniques are relatively increasing. Advanced support systems are used in order to reduce surgical complications, and less invasive surgical approaches such as keyhole or endoscopic approaches are increasing in order to shorten the operation time and achieve the satisfactory cosmetic results. As the surgical cases are decreasing, experienced neurovascular surgeons are also decreasing. So, it is considered to organize the international training system and share the surgical experience in order to maintain rare but experienced surgeons.

References

1. Winn HR, Richardson AE, Jane J. The assessment of the natural history of single aneurysms that have ruptured. In: Hopkins LN, Long DM, editors. Clinical management of intracranial aneurysms. New York: Raven Press; 1982. p. 1–10.
2. Locksley HB. Natural history of subarachnoid hemorrhage, intracranial aneurysms and arteriovenous malformations. J Neurosurg. 1966;25:321–68.
3. Jane JA, Kassel NF, Torner JC, et al. The natural history of aneurysms and arteriovenous malformations. J Neurosurg. 1985;62:321–3.
4. Hijdra A, Vermeulen M, van Gijn J, et al. Rerupture of intracranial aneurysms: a clinicoanatomic study. J Neurosurg. 1987;67:29–33.
5. Ohkuma H, Tsurutani H, Suzuki S. Incidence and significance of early aneurysmal rebleeding before neurosurgical or neurological management. Stroke. 2001;32:1176–80.
6. Cho WS, Kim JE, Park SQ, et al. Korean clinical practice guidelines for aneurysmal subarachnoid hemorrhage. J Kor Neurosurg Soc. 2018;61:127–66.
7. Dott NM. Intracranial aneurysms cerebral arterio-radiography and surgical treatment. Edinb Med J. 1933;40:219–34.
8. Dandy WE. Intracranial aneurysm of the internal carotid artery cured by operation. Ann Surg. 1938;107:654–9.
9. Krayenbuhl HA, Yasargil MG, Flamm ES, et al. Microsurgical treatment of intracranial saccular aneurysms. J Neurosurg. 1972;37:678–86.
10. Guglielmi G, Viñuela F, Dion J, Duckwiler G. Electrothrombosis of saccular aneurysms via endovascular approach. Part 2: preliminary clinical experience. J Neurosurg. 1991;75:8–14.
11. Molyneux A, Kerr R, Stratton I, et al. International subarachnoid aneurysm trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms: a randomised trial. Lancet. 2002;360:1267–74.
12. Molyneux AJ, Kerr RS, Yu LM, et al. International subarachnoid aneurysm trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms: a randomised comparison of effects on survival, dependency, seizures, rebleeding, subgroups, and aneurysm occlusion. Lancet. 2005;366:809–17.
13. Connolly ES Jr, Rabinstein AA, Carhuapoma JR, et al. Guidelines for the management of aneurysmal subarachnoid hemorrhage: a guideline for

healthcare professionals from the American heart association/American stroke association. Stroke. 2012;43:1711–37.
14. Steiner T, Juvela S, Unterberg A, et al. European stroke organization guidelines for the management of intracranial aneurysms and subarachnoid haemorrhage. Cerebrovasc Dis. 2013;35:93–112.
15. Committee for guidelines for management of aneurysmal subarachnoid hemorrhage. Japanese society on surgery for cerebral stroke. Evidence-based guidelines for the management of aneurysmal subarachnoid hemorrhage. English edition. Neurol Med Chir (Tokyo). 2012;52:355–429.
16. Cho WS, Kim JE, Kang HS, et al. Keyhole approach and neuroendoscopy for cerebral aneurysms. J Korean Neurosurg Soc. 2017;60:275–81.
17. Cho WS, Kim JE, Kang HS, et al. Dual-channel endoscopic indocyanine green fluorescence angiography for clipping of cerebral aneurysms. World Neurosurg. 2017;100:316–24.
18. Cho WS, Kim JE, Kim SH, et al. Endoscopic fluorescence angiography with indocyanine green: a preclinical study in the swine. J Korean Neurosurg Soc. 2015;58:513–7.
19. Macdonald RL, editor. Neurosurgical operative atlas. Vascular neurosurgery, 2nd edn. New York: Thieme; 2009.
20. Britz GW, et al. Surgical approaches to intracranial aneurysms. In: Winn HR, editor. Youmans and Winn neurological surgery, 7th edn. Philadelphia: Elsevier; 2017. p. 3289–97.
21. Lawton MT. Seven aneurysms: tenets and techniques for clipping. New York: Thieme; 2011.
22. Jabbarli R, Pierscianek D, Wrede K, et al. Aneurysm remnant after clipping: the risks and consequences. J Neurosurg. 2016;125:1249–55.
23. Thompson BG, Brown RD Jr, Amin-Hanjani S, et al. Guidelines for the management of patients with unruptured intracranial aneurysms: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. Stroke. 2015;46:2368–400.
24. Szentirmai O, Hong Y, Mascarenhas L, et al. Endoscopic endonasal clip ligation of cerebral aneurysms: an anatomical feasibility study and future directions. J Neurosurg. 2016;124:463–8.