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The Roles of Endoscope in Aneurysmal Surgery

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Abstract

The neuroendoscope, with its higher magnification, better observation, and additional illumination, can provide us information that may not be available with the microscope in aneurysm surgery. Furthermore, recent advancement of the holding systems for the endoscope allows surgeons to perform microsurgical manipulation using both hands under the simultaneous endoscopic and microscopic monitoring. With this procedure, surgeons can inspect hidden structures, dissect perforators at the back of the aneurysm, identify important vessel segments without retraction of the aneurysm or arteries, and check for completion of clipping. In addition, we have recently applied endoscopic indocyanine green video angiography to aneurysm surgery. This newly developed technique can offer real-time assessment of the blood flow of vasculatures in the dead angles of the microscope, and will reduce operative morbidity related to vascular occlusion, improve the durability of aneurysm surgery by reducing incomplete clipping, and thus promote the outcome of aneurysm surgery.

Key words: clipping, endoscope, endoscopic fluorescence video angiography, intracranial aneurysm

Introduction

The principle of microsurgical clipping of the intracranial aneurysm is to achieve complete occlusion of the aneurysm while preserving blood flow in the involved parent artery, its branches, and perforators. For this purpose, it is indispensable to obtain an excellent view of the regional anatomic features including the relationship between the aneurysm and the surrounding arteries before, during, and after clipping. However, this is not always possible during surgery, since the straight line of the view imposed by the microscope results in inadequate observation of structures that lie behind other structures or around corners.

The neuroendoscope can provide us information that may not be available with the microscope. In 1977, Apuzzo et al. applied the side-angled rigid endoscope to neurosurgical procedures, and reported its great value for assessing confirmation of clip placement in a case of the basilar tip aneurysm.[1] Subsequent case series have reported its exceeding usefulness to compensate for the shortcomings of the microscope.[2–10] Perneczky and Fries elaborated on the general principles of endoscope-assisted microsurgery, and described three advantages of the endoscope as follows[11,12]: (1) increased light intensity while approaching an object, (2) clear depiction of details in close-up positions, and (3) extended viewing angles. In addition, recent advancement of the holding systems for the neuroendoscope allows surgeons to perform microsurgical manipulation using both hands under the endoscopic and microscopic control at all times. Therefore, the surgeon can inspect hidden structures, dissect perforators at the back of the aneurysm, identify important vessel segments without retraction of the aneurysm or arteries, and check for completion of clipping.[11,12]

On the other hand, intraoperative fluorescence video angiography using indocyanine green (ICG) or sodium fluorescein has been widely used in aneurysm surgery to confirm complete occlusion of the aneurysm and preservation of the blood flow in the arteries around the aneurysm.[13–19] However, the observation field of this procedure is limited to the microscopic view, and it is difficult to confirm the blood flow hidden behind the skull base anatomy such as the parent arteries and nerves. To overcome this weak point, we have adopted endoscopic fluorescence video angiography in aneurysm surgery, and firstly reported its efficacy for the observation of the blood flow in vasculatures in the dead angles of the microscope.[20]

In this article, we review the roles of the endoscope in aneurysm surgery, and introduce our simultaneous

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monitoring technique with the microscope and endoscope held by the air-lock system. In addition, we refer the newly developed endoscopic fluorescence video angiography.

Instrumentation for Endoscope-assisted Aneurysm Surgery

Two types of neuroendoscopes, flexible and rigid, are presently available, and the rigid endoscopes are commonly used for endoscope-assisted aneurysm surgery since they provide high quality images with a smaller diameter.

The viewing angles of the rigid endoscopes for the assistance of clipping procedures have a range from 0° to 110°.[4,5,8,21–24] The straight endoscope provides a central magnified view of the interested area; however, a straight view is readily achieved by the microscope, hence the value of information gained by the endoscope is limited. Consequently, more additional information is available by using a side-viewing endoscope. The 30° and 45° angled endoscopes offer a combination of views that “look around corners,” and many authors have recommended these medium-angled endoscopes in aneurysm surgery.[5,12,25] Some have affirmed that the most useful angulation is 70°,[4] since the view in certain places, such as the back wall of the aneurysm, is improved. However, with greater angulation, the distance between the tip and the lens becomes larger, and surgeons should pay attention not to damage neuronal structures by the tip of the endoscope while inserting. Therefore, angled endoscopes more than 70° should be used only if needed after exploration with a medium-angled endoscope such as 30°. Recently, Ebner et al. reported that the preliminary experience with a variable-angled rigid endoscope (EndoCAMeleon, Karl Storz, Tuttlingen, Germany) to visualize the anterior communicating complex in a cadaveric study.[26] With this tool, the viewing range is between −10° and +120°, alleviating the need to replace the endoscope. Thus, there may be less risk of injuring the brain, and its use could be time saving. However, future studies in the clinical experience are needed to conclude the safety and the effectiveness.

With regard to the outer diameter of the endoscopes, the rigid endoscopes have two types of the diameter, 2.7 mm and 4.0 mm. The outer diameter of 4.0 mm is occasionally too large to allow for its easy insertion to the limited spaces and to leave enough space for operative procedures. A smaller endoscope should be more convenient though it has a disadvantage in the slight reduction in image quality.

Endoscopes can be either handheld or fixed to a holding device. Some neurosurgeons prefer the endoscope to be held in the left hand and perform neck clipping with the right hand. This technique does not need additional equipment but requires a skilled technique, and has a disadvantage of unsteady imaging. In contrast, the advantage of using a holding device is the availability of the bimanual manipulation under simultaneous endoscopic and microscopic control. With the fixed endoscope, the surgeon can inspect hidden structures, dissect perforators at the back of the aneurysm, identify important vessel segments without retraction or the aneurysm of arteries, and check for completion of clipping.[11,12] We usually fix the endoscope with an endoscope-integrating holding device (EndoArm, Olympus, Tokyo), and joint motion is controlled with high-pressure gas and low force. It can be fixed with 1-touch operation, providing superior safety and handling.

There are several ways in which microscopic and endoscopic images can be observed at the same time[5]: (1) observation of the microscopic image through the ocular system of the microscope and observation of the endoscopic image on a video screen placed in front of the surgeon, (2) observation of the microscopic image through the ocular system of the microscope and observation of the endoscopic image on a head-mounted liquid crystal display screen, (3) observation of both the microscopic and endoscopic images on one screen in a picture-in-picture mode, (4) observation of both the microscopic and endoscopic images through a specifically designed microscopic ocular system, or (5) observation of both the microscopic and endoscopic images on a head-mounted liquid crystal display screen.

We connect the scope to a three-chip camera, and the images are recorded and viewed on a 19-inch video monitor. The video monitor showing the endoscopic view is positioned in front of the surgeon.

Operative Procedure and Management

In endoscope-assisted aneurysm surgery, the craniotomy, subarachnoid dissection, and cranial base osteotomy are generally performed in the usual manner.

The use of the endoscope during clipping procedures includes three steps: initial inspection, clipping, and final inspection. During the first step, after microsurgical subarachnoid dissection and eventual washing of blood clots in cases of subarachnoid hemorrhage to expose the aneurysmal neck and sac, the rigid endoscope connected to the arm of the holding system is introduced by hand under the microscope. If the position of the endoscope is appropriate for the observation of the aneurysms and the surrounding structures, the endoscope with the holding system is locked. The clipping step is performed under simultaneous microscopic and endoscopic monitoring. This step includes dissection of the perforators behind the aneurysm sac and neck, temporary clipping and placement of permanent clips. The final inspection step includes the assessment of the complete exclusion of the aneurysm and the preserved patency of the parent arteries and the perforators.

Simultaneous microscopic and endoscopic monitoring increases the safety and durability of the aneurysm clipping: however, meticulous attention is required to prevent intraoperative morbidity. Mechanical injury of the nerves and blood vessels by the endoscope could be possible because the endoscope does not provide a view behind its tip. The surgeon should rather concentrate on the microscopic view, being careful not to touch the vulnerable structures with the endoscope while inserting. The operating room stuff must pay attention not to touch or move the surgical bed, bed controller, and endoscope-holding system to avoid injury while the endoscope is inserted into the operative field. Because subarachnoid clot is an obstacle for endoscopic observation in ruptured cases, suction of clot is inevitable. However, extensive clot removal should not be done in the dead angle of the microscope. We should recognize that the point we can see with the endoscope is different from that which we can manipulate with it.

Roles of Endoscope in Aneurysmal Surgery

I. General roles of endoscope

The endoscope provides better illumination and clear views of regional anatomic features at close range in aneurysm surgery. The extended viewing angles of the endoscope allow the observation of the blind area of the microscope. The use of the endoscope makes dissection in and around aneurysms easier and safer. Furthermore, the endoscope facilitates confirmation of optimal clip positions.

In a series of 54 cases reported by Taniguchi et al., the endoscope clarified the detailed additional regional anatomy in 9 cases (16.7%), and the surgeons reapplied the clip on the basis of endoscopic information obtained after the initial clipping in 5 cases (9.3%).[4] In a series of studies by Kalavakonda et al., the endoscope was used to observe clip position in 75 of 79 cases (95%) and anatomical features in 26 (33%). In 15 (19%) aneurysms, key information such as parent artery, branches, perforators, the neck and back wall of the aneurysm, and the completeness of clipping of the neck and inclusion of the parent artery in the clip could be visualized via the endoscope. The clip was repositioned because of a residual neck or inclusion of the parent artery in six cases, and the clip position was readjusted because of compression of the optic nerve in one case.[5] In a recent report by Fischer et al., the endoscope was used to gain additional topographic information before clipping in 150 of 180 cases (83%). Clipping under endoscopic view was achieved in four cases. After clipping, endoscopic inspection was performed in 130 of 180 procedures. Depending on the endoscopic findings, rearrangement of the applied clip or additional clipping was found to be necessary in 26 of 130 cases (20%).[9] In the other recent report by Galzio et al., the endoscope provided additional information in 147 cases (71.4%), and clipping under endoscopic view was done in 42 cases (20.4%). Reapplication of the clip was required in 42 cases (20.4%).[10]

The most important factors contributing to the efficacy of endoscope-assisted clipping are the size and the location of aneurysms.[10] In general, very large and giant aneurysms gain fewer benefits from the endoscope than smaller ones in the same location, because the mass of the lesion compromises insertion and fixation of the endoscope in the operative field. The aneurysmal location is the other important factor, namely the endoscope is especially useful in the treatment of deeply located cerebral aneurysm. Because middle cerebral artery aneurysms and distal aneurysms such as pericallosal aneurysms are superficially located in the operative field, the effectiveness of the endoscope for these aneurysms is limited. In the next section, we refer the roles of the endoscope in the surgery of internal carotid artery (ICA), anterior communicating artery (AcomA), basilar tip, and vertebral artery (VA) aneurysms.

On the other hand, some disadvantages of the endoscope have been reported as follows[5]: (1) The endoscope can cause rupture of the aneurysm during initial inspection, (2) Three-dimensional views are not possible, (3) When there is blood in the operative field, the endoscope is useless and clot must be removed as described above, and (4) There is still a lack of instrumentation specifically designed for endoscopic surgery.

II. ICA aneurysms

1. Paraclinoid aneurysms

Aneurysms encountered in the paraclinoid segment of the ICA include anterior paraclinoid,[27] ophthalmic artery, posterior paraclinoid, carotid cave, and subclinoid aneurysms. These aneurysms except anterior paraclinoid aneurysms usually arise from the medial/posterior aspect of the ICA.[28,29] The microscopic view of such aneurysms is obstructed by the ICA, optic nerve, and bony structures including the anterior clinoid process. Because of their location such aneurysms are more difficult to visualize completely,[28,29] and various innovations have been adopted to treat these aneurysms, including the contralateral approach[30] and skull base surgery techniques such as anterior clinoidectomy.

The endoscope is exceedingly useful for clipping of paraclinoid aneurysms. As we have reported, an aneurysm of this segment projecting to the medioposterior, completely invisible through the microscope, could be obliterated with a fenestrated clip without removal of the anterior clinoid process under the simultaneous endoscopic and microscopic monitoring.[8,31] To observe the medial aspect of the ICA, the endoscope is introduced to the prechiasmatic cistern or the space between the optic nerve and the ICA. This portion provides a view similar to that of the contralateral approach. Once the surgeon has confirmed the anatomical relationship among the dural ring of the ICA, proximal neck of the aneurysm, ophthalmic artery, and superior hypophyseal artery, and has determined that sufficient space exists for the clip blade, neck clipping can be performed under both microscopic and endoscopic monitoring.

2. Supraclinoid aneurysms

Internal carotid-posterior communicating artery (IC-PComA) aneurysm and internal carotid-anterior choroidal artery (IC-AChorA) aneurysm are the two representative supraclinoid ICA aneurysms. In many cases of these aneurysms, the PComA, AChorA, and perforators exist behind the ICA and aneurysms, and are often invisible under the microscopic observation. The major benefit of the endoscopic monitoring for these cases is visualization of the perforators in the dead angles of the microscope. In relatively small aneurysm cases, surgical manipulation under the microscope enables the visualization around the aneurysmal neck by the compression of the ICA or aneurysms. However, the endoscopic observation provides valuable information even in these minor cases. The relationship between the clip blades and perforators is clarified by the endoscope introduced medial to the ICA. In contrast, anatomical information concerning to the clip blades and the aneurysmal neck is clearly revealed when the endoscope is introduced laterally (Fig. 1). Such endoscopic monitoring is extremely useful in IC-AChorA aneurysm cases since the AChorA is thin (0.5–2.3 mm) and is easily occluded by the retraction of the vessel walls. On clipping of IC-AChorA aneurysms, the surgeon needs paying his attention not to stretch the wall of the AChorA, and the magnified endoscopic observation including the origin of the AChorA offers invaluable information.

In most cases of large supraclinoid aneurysms with a posterior projection, the medial sides of aneurysms are difficult to observe with the microscope, and perforators are adhered to the aneurysmal walls. On neck clipping, all perforator should be dissected from the aneurysmal neck, and the endoscopic monitoring, especially simultaneous monitoring with the microscope, is useful for this purpose. The endoscope not only reveals the anatomy of the medial aspect of the aneurysm but also makes it possible to dissect perforators in the dead angles of the microscope. In addition, for clipping of broad neck aneurysms, fenestrated straight or angled clips are sometimes applied. Usually, the medial blade of the fenestrated clip is applied beyond the ICA and is not visible under the microscope. The endoscope can clearly visualize the medial blade (Fig. 2).

This segment of the ICA has a peculiar category of aneurysms known as “blood blister” aneurysms of the anterior wall of the ICA. It is generally accepted that simple neck clipping is risky and that trapping the ICA with or without bypass surgery or clip-on wrapping is recommended. Trapping or clipping the aneurysm to catch the intact wall of the ICA is critical for preventing postoperative rupture. In this regard, the endoscope, which provides higher magnification than the microscope, can provide an accurate margin of the pathological aneurysmal wall and contribute to the durability and safety of the surgical treatment (Fig. 3).

3. Anterior communicating aneurysms

In the pterional approach, the posterior wall of the AcomA, where the hypothalamic artery usually divides, is difficult to observe under the microscope. The endoscope is useful for the observation of this lesion although the space for inserting the endoscope is occasionally limited. In the interhemispheric approach with bifrontal craniotomy, which we adopt to the complex types of AcomA aneurysms including large, high-position, and upward- or posterior-projecting ones, can provide ample working space. Therefore, the microscopic view can confirm the entire aspect of the AcomA complex, and we do not use the endoscope in this approach.

4. Basilar tip aneurysms

Although the basilar tip aneurysm is one of the most difficult to treat with direct clipping, the endoscope is

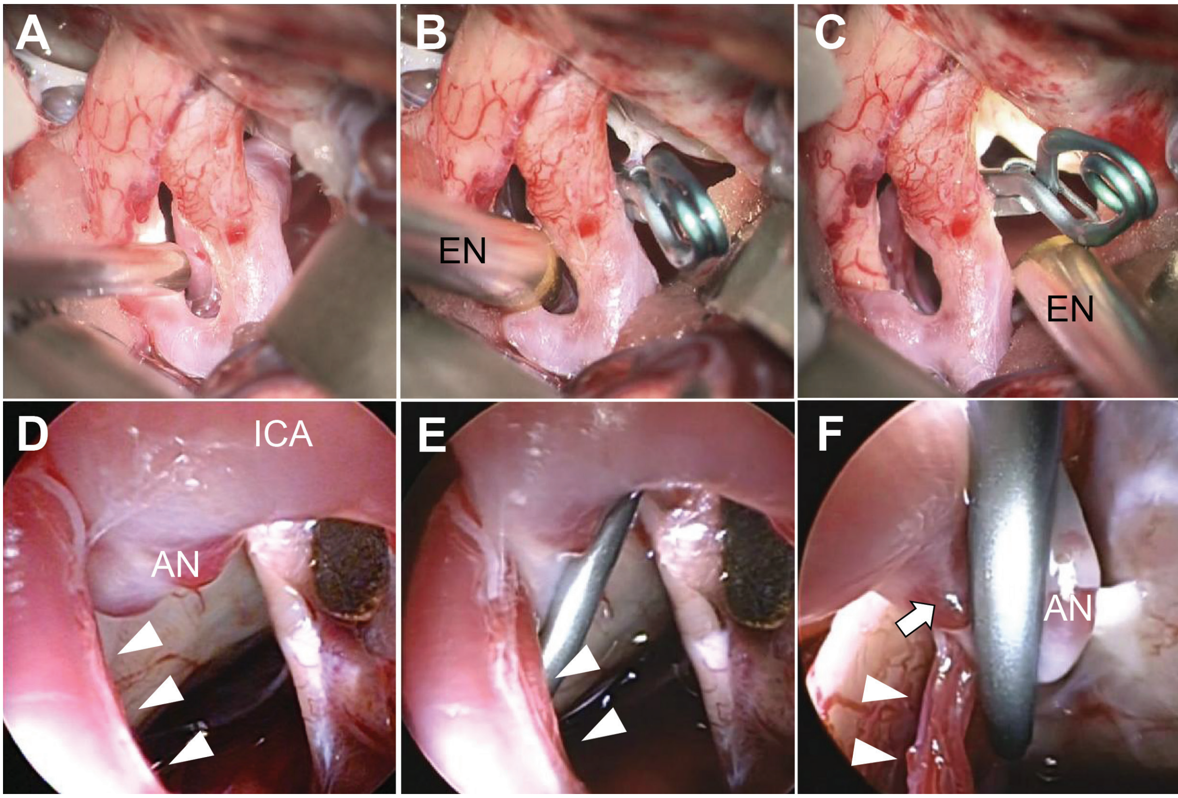

Fig. 1 Intraoperative photographs of an unruptured right IC-PComA aneurysm. A: A right pterional craniotomy was performed. Microscopic view before clip placement showing the aneurysm. B: After the fixation of the endoscope, a straight clip was applied to the aneurysm neck while confirming the preservation of the PComA under the simultaneous endoscopic and microscopic monitoring. C: After clipping, the endoscope was introduced lateral to the ICA. D: The endoscope introduced medial to the ICA showing the anatomical relationship between the aneurysm projecting medially and the origin of the PComA (*arrowheads*). E: Endoscopic view demonstrating the preservation of the PComA. F: Endoscopic observation revealed the information concerning to the clip blade and the aneurysmal neck, and clearly depicted the dog-ear neck remnant (*arrow*). AN: aneurysm, EN: endoscope, ICA: internal carotid artery, IC-PComA: internal carotid-posterior communicating artery.

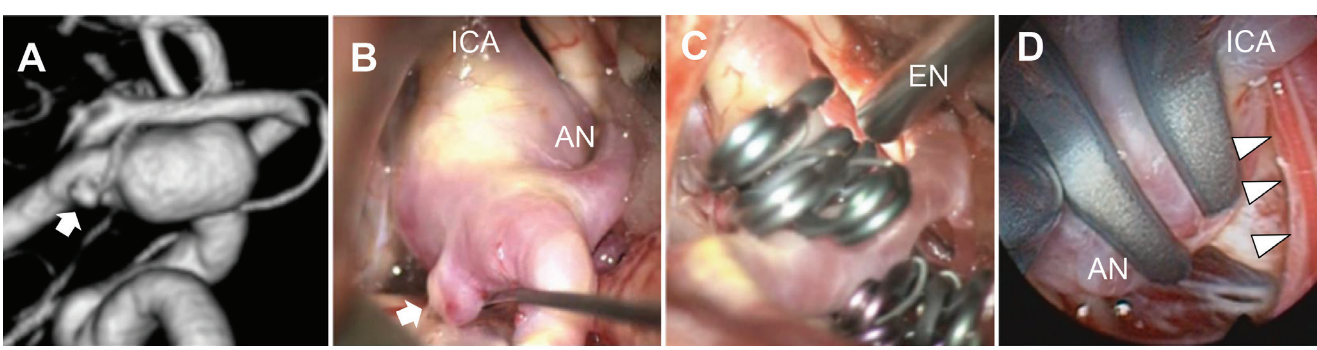

Fig. 2 An illustrative case of unruptured left IC-PComA and IC-AChA aneurysms. A: Preoperative three-dimensional digital subtraction angiography (posterolateral view) showing a posteriorly projecting left IC-PComA large aneurysm and an IC-AChA small aneurysm (*arrow*). B: A left pterional craniotomy was performed, and microscopic view before clip placement showing both aneurysms. C: Two straight ring clips were applied to the proximal neck of the IC-PComA aneurysm, and an angled ring clip and two curved clips were applied to the distal neck. The IC-AChA aneurysm was occluded using two curved mini clips. D: Endoscopic observation after the placement of the clips revealing the occlusion of the aneurysm and the preservation of the PComA (*arrowheads*). AN: aneurysm, EN: endoscope, ICA: internal carotid artery, IC-AChA: internal carotid-anterior choroidal artery, IC-PComA: internal carotid-posterior communicating artery.

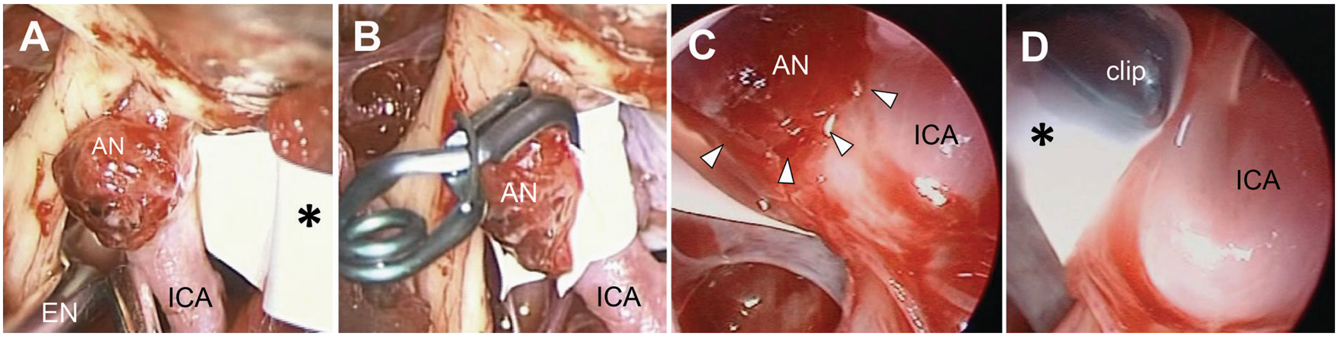

Fig. 3 An illustrative case of a ruptured right blood blister-like aneurysm of the ICA. A: A right pterional craniotomy was performed. Blood blister-like aneurysm was located on the anterior wall of the right ICA. B: After wrapping the aneurysmal lesion with polytetrafluoroethylene (PTFE) membrane, a right-angled clip was applied on the wrap parallel to the ICA. C: The endoscopic view before clip placement. The endoscope introduced medial to the ICA revealed the accurate margin of the pathological aneurysmal wall (*arrowheads*). D: The endoscopic observation after the placement of the clip revealing that the clip blade caught the intact wall of the ICA. The asterisk indicates the wrapping material. AN: aneurysm, EN: endoscope, ICA: internal carotid artery.

exceedingly useful since this lesion is deeply seated below and behind critical neurovascular structures and accompanied by vital perforators. Moreover, the aneurysm lies in large cisternal spaces enough to fix the endoscope in the operative field.

We use the subtemporal approach for this aneurysm, in which the opposite side of the aneurysm is difficult to observe. Because thalamoperforating arteries usually divide from the P1 segment of the posterior cerebral artery, the perforators sometimes adhere to the lateral wall of the aneurysm. Therefore, the dissection and preservation of the thalamoperforating arteries on the contralateral side are key steps in the clipping of this aneurysm without morbidity. The endoscope is introduced through the space either above or below the oculomotor nerve and fixed in front of the basilar artery. This setting of the endoscope provides the view obtained by the pterional approach, and the wide viewing angle of the endoscope clearly reveals perforators (Fig. 4). In addition, the high magnification and direct lightning more accurately reveal the deep surgical field, contributing to successful clipping of this aneurysm.

5. VA aneurysms

VA-posterior inferior cerebellar artery (VA-PICA) aneurysms and VA-dissecting aneurysms are major lesions of this portion. The critical issue on clipping of these aneurysms is the difficulty in confirming the distal portion of the VA. Proximal occlusion is the usual method for control of bleeding caused by aneurysmal rupture during clipping. However, in this segment of the VA, bleeding sometimes cannot be controlled by proximal occlusion because sufficient blood flow comes from the contralateral VA. Clearly, control of the distal portion of the VA is essential. The side view of the endoscope can help to reveal the entire VA from the intracranial entrance to the VA junction (Fig. 5).

Dissecting VA aneurysms have been cured with endovascular treatment recently, and the opportunity to treat them by clipping has been declined. However, VA dissection involving the PICA often needs direct surgery such as proximal occlusion or trapping of the VA with revascularization of the PICA. For occlusion of the VA, confirmation of the pathological dissecting wall and the preservation of VA perforators are necessary. The endoscope can reveal the hidden portion of the VA under the microscope.

Endoscopic ICG Video Angiography

Intraoperative microscopic fluorescence video angiography has been widely used for preventing unexpected occlusion of arteries around aneurysms on clipping surgery recently.[13–18,32] However, the observation field is limited under the microscope, making it difficult to confirm the blood flow in the arteries behind the structures such as the parent arteries and aneurysms. In order to overcome this problem, we reported a new technique of intraoperative endoscopic ICG video angiography to assess the blood flow in vasculatures in the dead angle.[20]

The ICG endoscope system consists of a xenon light source device (Visera CLV-S40Pro; Olympus Optical, Tokyo, Japan), a video processor system (Visera OTV-S7Pro; Olympus Optical), and a newly designed camera head with an image sensor highly sensitive to infrared light and a cut filter to collect

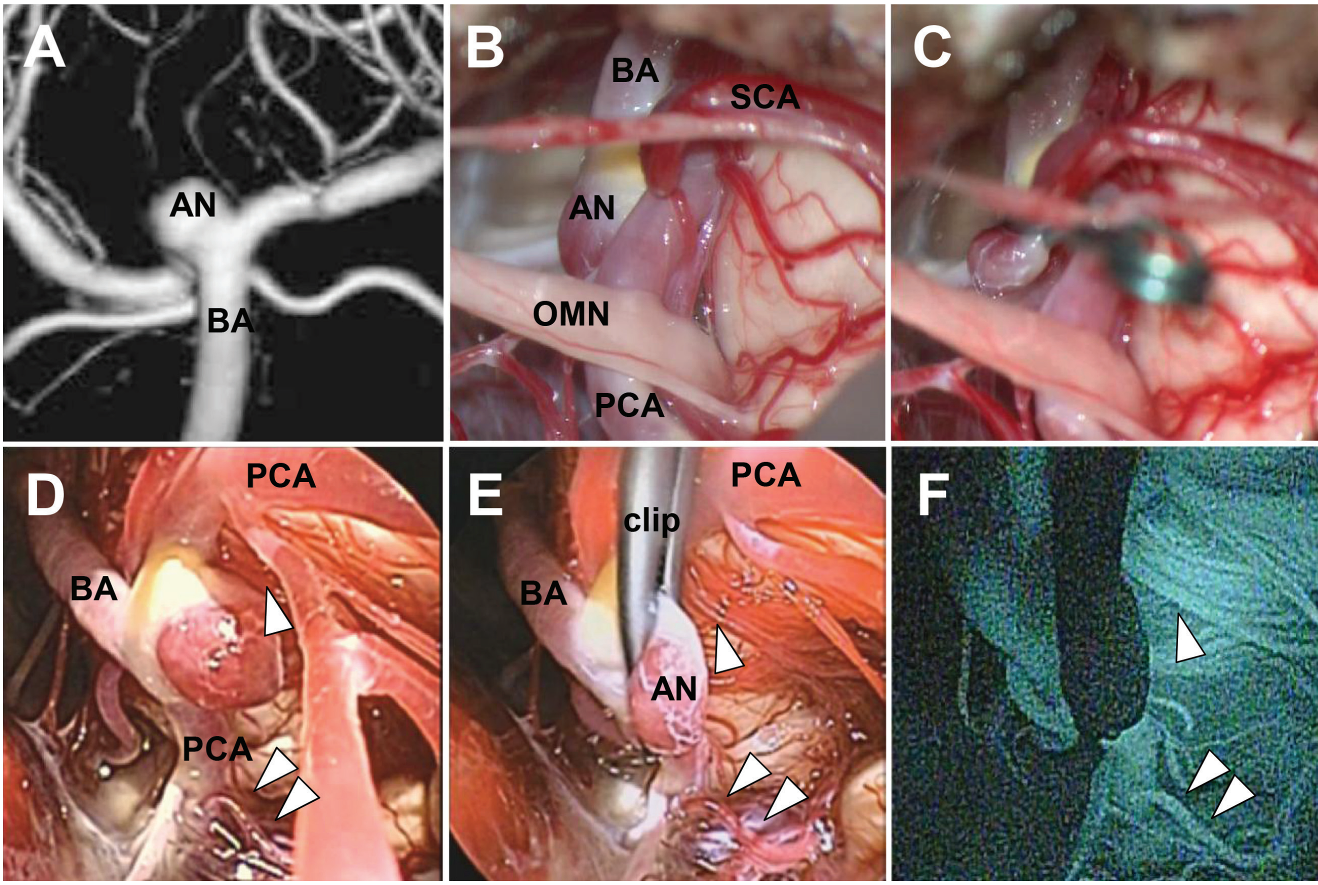

Fig. 4 An illustrative case of an unruptured basilar tip aneurysm. A: Preoperative three-dimensional digital subtraction angiography (anteroposterior view) showing a basilar tip aneurysm. B: Microscopic view before clip placement showing the aneurysm via a right subtemporal approach. C: Microscopic view after placement of a clip. A curved clip was applied to the aneurysmal neck under endoscopic monitoring. D: The endoscope inserted anterior to the basilar artery revealing the thalamoperforating arteries (*arrowheads*). E: Endoscopic view showing the anatomical preservation of the thalamoperforating arteries after clipping. F: Endoscopic ICG video angiography after clipping confirming the preservation of the blood flow in the thalamoperforating arteries. AN: aneurysm, BA: basilar artery, OMN: oculomotor nerve, PCA: posterior cerebral artery, SCA: superior cerebellar artery.

fluorescence from ICG. The viewing angle of the endoscope is 30° or 70°, and the outer diameter is 4.0 mm. The craniotomy and subarachnoid dissection are performed in the usual manner. After exposure of the aneurysm, the endoscope is manually introduced near the aneurysm under the microscope to visualize the area behind the aneurysm. Before and after clip placement, microscopic and endoscopic ICG video angiography is performed (Fig. 4).

In our series of 9 clipping cases (IC-PComA 4, middle cerebral artery 2, IC-AChorA 1, IC-ophthalmic 1, IC posterior paraclinoid 1), we evaluated the efficacy of endoscopic ICG video angiography.[33] This procedure clearly demonstrated the blood flow of the arteries and aneurysms in the dead angles of microscopic fluorescence video angiography in all but a case in which the adequate placement of the endoscope was difficult because of the limited space. Newly developed ischemic lesions were not observed on the postoperative computed tomography (CT) scans, and the outcomes were excellent in all cases. There was no complication related to the procedure. Endoscopic ICG video angiography was especially useful in IC-PComA aneurysm cases for the observation of the blood flow at the origins of the perforators behind the parent arteries and aneurysms.

Two more reports dealing with ICG video angiography in aneurysm surgery have been published since our first report, and showed the effectiveness of the new techniques.[34,35] One is a case report with an unruptured AcomA aneurysm, and endoscopic ICG video angiography provided additional information by magnifying areas of the interest and improving the ability to observe the posterior area of

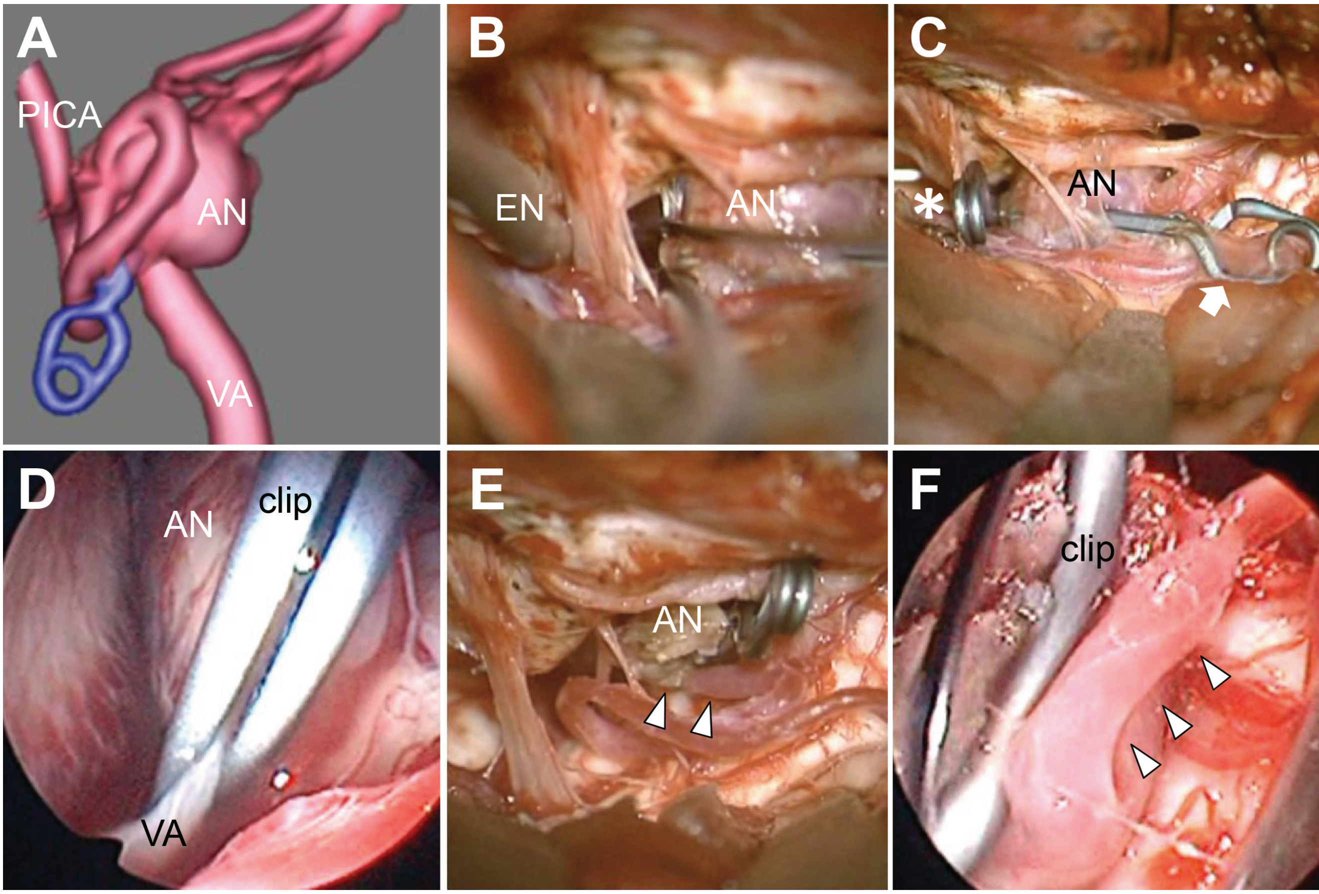

Fig. 5 An illustrative case of regrowth of a VA-PICA aneurysm. A: Preoperative three-dimensional computed tomography angiography (lateral view) showing regrowth of a VA-PICA aneurysm with a previous clip. B: A right lateral suboccipital craniotomy was performed. Confirmation of the distal portion of the right VA was difficult. C: Temporary clipping of the distal VA was achieved with the help of the endoscopic monitoring. After trapping the right VA, the previous clip (*arrow*) was removed. D: The endoscopic observation confirmed temporary clipping of the distal VA. E: A straight clip was applied to the aneurysmal neck. F: The endoscope revealed complete occlusion of the aneurysm and preservation of the right PICA (*arrowheads*). The *asterisk* indicates temporary clip. AN: aneurysm, EN: endoscope, ICG: indocyanine green, PICA: posterior inferior cerebellar artery, VA: vertebral artery.

the aneurysmal clip.[34] The other one is a consecutive series of 30 aneurysms in which the authors evaluated the usefulness of this new technique. Endoscopic ICG video angiography provided the neurosurgeon with information that could not be obtained by microscopic ICG video angiography in 42.3% of the cases.[35]

Conclusion

Simultaneous endoscopic and microscopic guidance can reveal important information hidden from the microscope, and can be used to monitor the working environment under direct continuous visualization. Thus, this method increases the safety and durability of the aneurysmal clipping. In addition, endoscopic ICG video angiography that provides real-time assessment of the blood flow in the dead angles could further promote the outcome of the surgery.

Conflicts of Interest Disclosure

The authors have no personal, financial, or institutional interest in any of the drugs, materials, or device in the article. All authors who are members of The Japan Neurosurgical Society (JNS) have registered online Self-reported COI Disclosure Statement Forms through the website for JNS members.

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