Review Article

Review of Avoidance of Complications in Cerebral Aneurysm Surgery: The Fujita Experience

Abstract

Avoidance of complications during cerebral aneurysm surgery marks the future outcome in the patient. Various modalities such as adequate opening of the Sylvian fissure, motor-evoked potential, endoscope-assisted microsurgery, indocyanine green dye, and dual image video angiography are available to reduce these complications during surgery, either by prevention of injury to the small perforators or the parent artery. We present our experience at the Fujita Health University Banbuntane Hospital, Japan, of the cerebral aneurysm surgery along with the use of these modalities in our patients from September 2014 to December 2016 along with a brief review of the various techniques for avoidance of complications.

Keywords: *Dual image video angiography, endoscope, indocyanine green, microsurgery*

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Introduction

The success of aneurysm surgery lies in complete clipping of aneurysmal neck with preservation of main, branching, and perforating arteries. Microprobe vascular Doppler, motor-evoked potential (MEP) and somatosensory-evoked potentials, endoscope-assisted microsurgery, microscope-integrated indocyanine green video angiography (ICG-VA), endoscope-integrated ICG-VA, and dual image video angiography (DIVA) have all been introduced in cerebrovascular surgery with varying results. With the introduction of intraoperative ICG-VA, the literature is surged with articles mentioning the great reduction in postoperative morbidity, mainly in extracranial-to-internal carotid (IC) bypasses, with the resultant reduction in the usage of other intraoperative imaging modalities in many centers for most of the aneurysm and complex vascular surgeries. MEP monitoring during aneurysm surgery has been advocated and showed to predict postoperative neurological function. Changes in MEPs should be dealt with appropriately during temporary clipping of the parent artery or after permanent clipping of the aneurysm. ICG-VA has its own limitations in giant and complex intracranial aneurysms and in deep-seated large AVMs. This article overviews the different modalities to avoid complications in cerebral aneurysm surgery with the morbidity experience at the Fujita Health University.

Materials and Methods

Cerebral aneurysm patients were reviewed over a period between September 2014 and December 2016 at the Fujita Health University. A retrospective analysis of all patients with unruptured cerebral aneurysm operated in our hospital in the last 2½ years was performed. Patients' demographic data, site of the aneurysm, operation notes, and postoperative morbidities or mortalities were reviewed and recorded. Institutional ethical clearance and patient's consent for publication were taken. According to our department protocol, all patients diagnosed with unruptured cerebral aneurysms who are candidate for treatment will be discussed with neurointervention team of our department. If not considered a good candidate for intervention, the patient will be offered surgery. We use reconstructed computed tomography angiography (CTA) routinely for surgical planning and in case of any ambiguity request a digital subtraction angiography. In our hospital, all neurovascular surgeries are performed with OPMI Pentero Microscope (Carl Zeiss, Oberkochen, Germany) with infra-red 800 camera equipped with FLOW 800 software

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(Carl Zeiss, Oberkochen, Germany). The camera allows us real-time intraoperative ICG-VA while the latter software provides hemodynamic information about blood flow. On exposure of aneurysm, we perform ICG-VA to clarify the aneurysm and its relation to all the surrounding vessels. Furthermore, to evaluate any perforating artery or other structures hidden behind the aneurysm, we introduce a rigid endoscope (Machida, Japan) under microscopic guidance. With this technique, we check for the estimated final location of the aneurysm clip tips to be away from any critical structure. From September 2014 to December 2016, 247 patients underwent craniotomies for clipping of aneurysms. Operative summaries, angiograms, and operative and ICG-VA videos were reviewed. The number, size, and location of aneurysms, the ICG-VA and IA findings, and the need for clip adjustment after ICG-VA and IA were recorded. Whenever the distal blood flow is in question, blood flow measurements with Doppler ultrasound (DVM 4300, Hadeco, Japan) and FLOW 800 software are made. Once again, the endoscope is used to check for the final position of the blades and their relations to other structure and also to make certain that the aneurysm neck is completely obliterated. Based on the location of the aneurysm and probable risks, other monitoring systems such as MEP may be implemented. Position and average size of the aneurysms were seen. Different morbidities with each year are being presented.

Results

In the year 2016, a total of 103 aneurysms were operated, with 76 females and 27 males. Average size was 5.0485 and mean age was 61.55 years. Majority of the aneurysms operated were middle cerebral artery (MCA) (n = 35). In posterior circulation, vertebral artery-posterior inferior cerebellar artery (VA-PICA) aneurysms were 5 and the basilar artery aneurysms were 4. Multiple aneurysms were found in 5 patients. Proximal trap and coating were done in 1 case each. Postsurgery, transient hemiparesis, epilepsy, and hydrocephalus were found in 1 case each. CSDH was found in 8 patients. MEP wave disappearance was found in 1 patient [Tables 1 and 2].

In 2015, 112 patients were operated, with 86 females and 26 males. The average age was 34, and the average size was 6.039. IC aneurysms comprised 46 cases with maximum at IC-posterior communicating. MCA aneurysms comprised 34 in number, A-comm was 14. In the posterior circulation, basilar artery aneurysms were 5 with VA-PICA 3 in number [Table 3]. The proximal trap was done in 2 patients, bypass 1, visual-evoked potential suction decompression in 2, coating was done in PICA aneurysms comprising 6 in number. MEP was seen in 31, and CSDH developed postoperatively in 13 cases.

Thirty-two aneurysms cases were operated between September and December 2014, with females being 26 and 6 males. The average age was 34 and the average size 5.340625. Most of the cases were MCA (N = 12). IC cases were 9 in number and A-comm being 6. Multiple aneurysms were found in 2 cases. The bypass was done in 1 patient. CSF leak and CSDH were present postoperatively in 1 patient each. MEP was found in 1 patient each.

Discussion

Complications occurring during cerebral aneurysm can be grouped into two groups – vascular and nonvascular. Vascular complications include perforating arteries injury, parent artery occlusion, premature aneurysm rupture, and thromboembolism while manipulating atherosclerotic lesion. Nonvascular injuries include focal brain contusion, cranial nerve injury, over draining of CSF, intracerebral hematoma, and surgical site infection. Mortality and morbidity rates are higher in vascular than nonvascular injuries, causing permanent neurological deficit.

The cerebral aneurysms surgery can develop the adverse events in the patients who are faced with both of related and unrelated procedures. As a neurosurgeon, the complication-related surgery might lead to permanent neurological deficit or death. The minimizing of this event should be included in the postoperative planning, surgical techniques, and modern equipment. This makes it essential that all surgical technique must minimize the risk of vessel injury, both during vessel dissection and clip placement. The rate of direct brain injury should be very low because of all surgeries are performed through a standard approach with minimal use of retractors. All cranial nerve injuries will be minimized from direct injury due to gently performing the surgery: well realize the anatomical knowledge and experienced surgeons. For example, optic nerve should not be injured during performing of anterior clinoidectomy for paraclinoid internal carotid artery aneurysm. Other complications, bone flap infection, and postoperative hematoma can be avoided from sterile technique procedure and adequate bleeding coagulation before finishing the surgery.

The planning from 3-dimensional CTA and computational fluid dynamics study in some cases are assigned. The benefits of these studies are helpful for making a decision of operation. Minimal approach to the aneurysm can be achieved after having a good planning. A neuroprotective anesthetic technique should be applied, and the tractionless technique is applied for exposure of brain parenchyma. During operation, efforts are made to preserve veins. Gradual dissection along the veins is made to avoid stretching. Veins are protected with cotton gauze to avoid heating injury during coagulation of adjacent structure. Large aneurysms are treated with multiple clippings to avoid kinking and stenosis of parent artery and perforators. Fenestrated clips are used for aneurysms with atheromatous necks to avoid squeezing and migration of atheroma. The reduction of temporary clipping time has been shown to be related to a decreased occurrence of ischemic events.

Sylvian fissure and aneurysmal dissection with good clipping techniques is the hallmark [Figures 1 and 2].

Atherosclerotic aneurysm is defined as the detection of yellowish plaque located at the dome or neck of an aneurysm. The location of atherosclerotic change might influence the effect of embolic stroke during manipulation or adjustment of the clip force around this area. It is very difficult at that time to judge how to suitably place the clip to prevent emboli migration and obtain maximal exclusion of the aneurysm. Unstable plaque is very weak and easily migrates because of the force of clip compression or manipulation around the plaque. Furthermore, we should confirm the atherosclerotic area with ICG-VA application by detection of filling defect in the atheromatous calcification. There is no area for placement of the clip; it is necessary to perform a dome clip to decrease the risk of rupture in the future. We should leave some part of yellowish plaque because the risk of aneurismal growth in this part is very low according to the low wall shear stress theory. This is the strategic treatment of this type of aneurysm with minimal risk of complication.

Various complications may arise during the clipping procedure, such as compressing the small perforating arteries, especially behind the aneurysmal wall, blood flow compromise to the parent vessel, and thromboembolism during manipulation of the atherosclerotic vessel [Figure 3].

ICG was approved by Food and Drug Administration in 1956 for cardiocirculatory and liver function diagnostic uses and in 1975 for ophthalmic angiography. Raabe *et al*., in 2003 described for the first time the use of ICG-VA in aneurysms surgery; thereafter, ICG-VA became very popular in vascular neurosurgery and has also been used in other kind of procedures such as brain tumor surgery.[1]

ICG is a near-infrared (NIR) diagnostic dye with an absorption and emission peaks of 805 and 835 nm, respectively. It is given by intravenous route with a recommended dose of 0.2–0.5 mg/kg with a maximum daily dose of 5 mg/kg.[2,3] It bounds to proteins, mainly globulins, and remains intravascularly. The liver deals with its metabolism and excretion. Its half-life is about 3–4 min. A NIR sensitive digital camera integrated in the microscope allows to see the ICG diffusion in the cerebral vessels. The procedure can be easily repeated after 5–10 min. Adverse reactions are comparable to those of other types of contrast media, with frequencies of 0.05% (hypotension, arrhythmia, or, more rarely, anaphylactic shock) to 0.2% (nausea, pruritus, syncope, or skin eruptions).[4]

ICG is easy, rapid to perform and noninvasive,[5] good spatial resolution,[6,7] and allows a good evaluation of the complete aneurysm exclusion, neck remnant, blood flow in the parent arteries and perforating arteries.[5,7] On the other hand, it has a limited view to the operating field,[5,8] and in the presence of blood clots, intramural thrombi, or calcifications,[9] it can give a limited ability to visualize the part of the base behind the aneurysm dome in deeply located aneurysms.[6,10]

A large aneurysm series by Özgiray *et al*.,[11] and Washington *et al*.[12] displayed a persistent residual flow in the aneurysm, respectively, in 5% and 4%. They reported that ICG-VA missed small, <2-mm wide neck remnants and a 6-mm residual aneurysm in up to 10% of patients. His conclusion is that in complex aneurysm when hidden parts of the parent, branching, and perforator vessels as well as undissected parts of the aneurysm dome are more difficult to visualize by ICG-VA, digital subtraction angiography (DSA) is still mandatory.[13] Conversely, the study by Hardesty *et al*., comparing 100 patients respectively from intraoperative DSA and ICG-VA eras, did not report any difference about unexpected aneurysm filling (4% vs. 2%), parent vessel compromise (2% vs. 2%), and perioperative strokes (4% vs. 3%).[14] Intraoperative ICG-VA is considered a valuable but primarily cost-effective replacement to routine intraoperative diagnostic angiography. Nevertheless, postoperative DSA still cannot be avoided because of a remaining little percentage of inaccuracy of both intraoperative techniques.[14] Thus, care should be taken when considering ICG-VA as the sole means for intraoperative evaluation of aneurysm clip application.

Intraoperative ICG-VA that is compatible with all microscopic software is used in all patients before and after clipping to check the anatomical architecture of the aneurysm and associated arteries such as the parent and perforator arteries. The patency of these arteries and the completeness of exclusion of the aneurismal neck after clipping the aneurysm can be checked with this device. Additional software of this device, color map, and flow intensity are analyzed for blood flow dynamics which included the sequence of blood flow after aneurysm clipping in cases of suspected incomplete exclusion.

The pulsed wave devices used for MDU allow depth focusing on the region of interest, thus avoiding artifacts caused by adjacent vascular structures. When narrowing of an adjacent vessel by the aneurysm clip occurs, there is an immediate increase in systolic and mean flow velocity within the narrowed vessel segment. Furthermore, alterations in Doppler curve spectrum occur. The degree of stenosis can be assessed by qualitative and quantitative criteria.[15] No change in flow characteristics will occur distal to a stenosis when the stenosis is compensated. On the other hand, noncompensated ("hemodynamically relevant") stenosis will result in a poststenotic reduced blood flow velocity. Systolic blood flow velocity as well as pulsatility is reduced in particular. Proximal to the stenosis, a decrease above all in diastolic blood flow velocity will occur accompanied by an increase in pulsatility. The Doppler

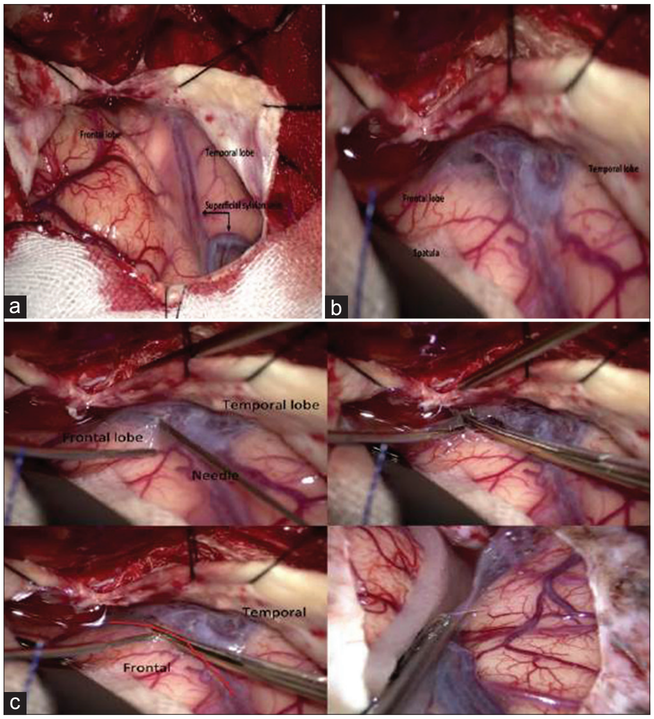

Figure 1: (a) Anatomical surface of Sylvian fissure under magnification. (b) Spatula is placed for mild retraction before opening Sylvian fissure. (c) Technique of opening the Sylvian fissure - gentle opening of the Sylvian fissure with a needle, sharp cutting of the arachnoid trabeculae with scissors, and gentle retraction of frontal and temporal lobes with cottonoid patty in between

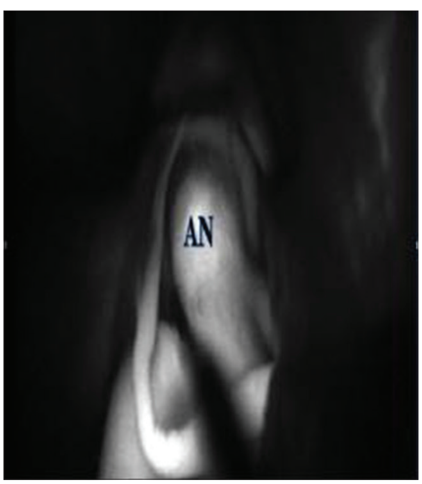

Figure 3: Microscope indocyanine green video angiography

spectra and flow velocities should be identical before and after clipping. Increase or decrease in flow velocity as well as any change in flow spectrum has to be regarded as pathological. An exception is the turbulent flow in the vessel segment directly at the attachment of the aneurysm neck which may disappear after clipping. A stenosis can certainly be detected by Doppler ultrasonography if the vessel diameter is narrowed more than or about 50%. The stenosis is described as decompensated or "hemodynamically relevant" from about 80% reduction of the diameter.[16]

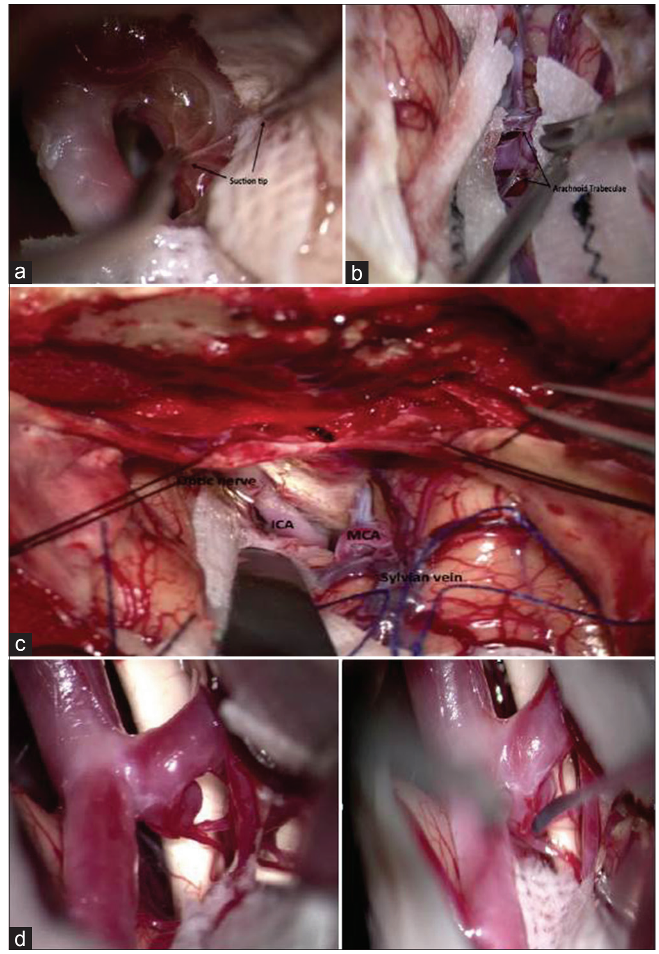

Figure 2: (a) Traction on arachnoid trabeculae with suction tip. (b) Sharp cutting of arachnoid trabeculae with microscissors. (c) After dissection of Sylvian fissure, the major vascular structure is exposed and preserved. (d) Sharp aneurysmal dissection: avoiding premature rupture

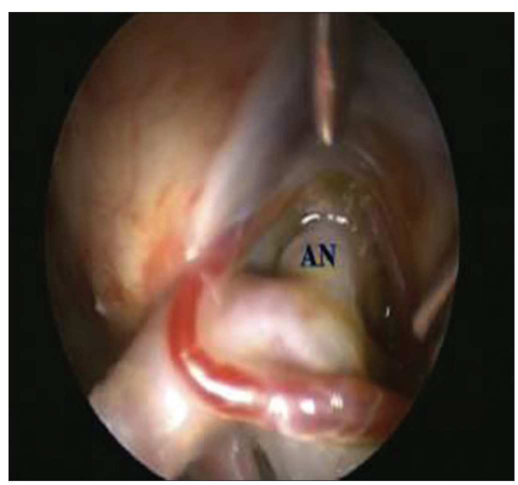

Figure 4: Endoscope-assisted surgery showing aneurysm and perforators if any

Bailes *et al*.[17] investigated 35 patients who underwent surgery for the treatment of 42 intracranial aneurysms by means of microvascular Doppler ultrasonography. They found an incidence of 31% for unexpected stenosis of adjacent arteries.

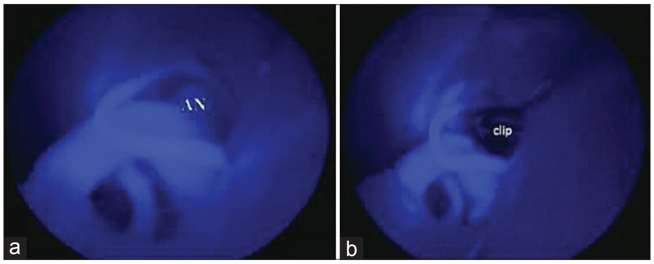

Figure 5: (a) Endoscope indocyanine green video angiography. (b) Postclip endoscope indocyanine green video angiography

Table 1: Demographic characteristics of unruptured aneurysms between September 2014 and December 2016

	September-December		
	2014	2015	2016
Female	26	86	76
Male	6	26	27
Average age	65.53125	34	61.55339
Average size	5.340625	6.039090	5.048543
Multiple aneurysm	2	0	5
Bypass	1	1	0
Proximal trap	0	2	1
Coating	0	PICA 6	1
VEP suction decompression	0	2	0
MEP	1	31	1

VEP – Visual-evoked potential; MEP – Motor-evoked potential; PICA – Posterior inferior cerebellar artery

Table 2: Complications in operated cases

	September-December		
	2014	2015	2016
CSF leak	1	0	0
CSDH	1	13	8
Transient 3rd nerve palsy	-	-	-
Transient hemiparesis	-	-	1
Epilepsy	-	-	1
Hydrocephalus	-	-	1

CSF – Cerebrospinal fluid; CSDH – Chronic subdural hematoma

Endoscopy assists the surgeon to achieve the aim of complete obliteration of the aneurysm while preserving normal neural and vascular elements. Its function turns vital in certain aneurysm locations when the aneurysm neck is usually surrounded by a bunch of perforators. These locations according to our experience and the literature include but not limited to the ICA-choroidal segment, ICA-communicating segment, MCA-M1, and MCA bifurcation. M1 aneurysms have specific anatomical proximities which increase the chance of injury during surgical or interventional treatments.[18] Aneurysms projecting superiorly are associated with lateral lenticulostriate artery (LSA) and frontal cortical branches while those projecting inferiorly accompany temporal cortical branches. Yeon *et al*. also showed that the closer an MCA-M1 aneurysm to the ICA bifurcation, the higher the

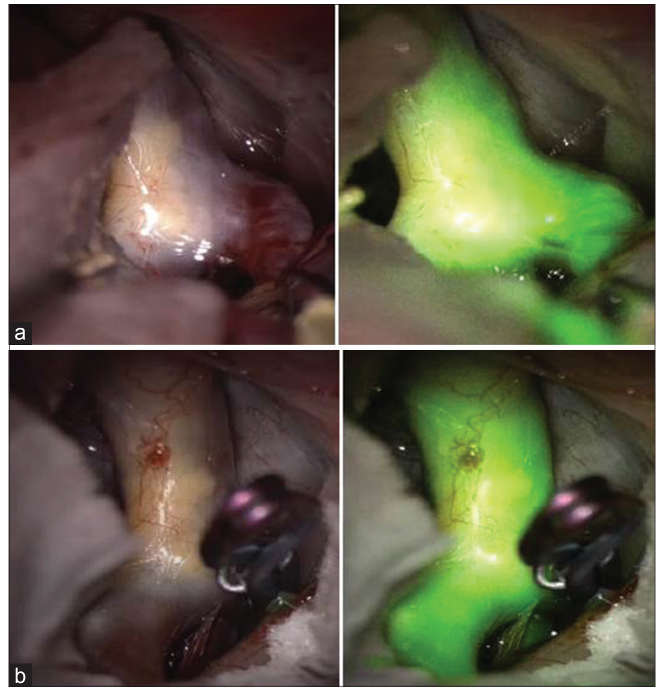

Figure 6: (a) Dual image video angiography - right internal carotid artery - ACh aneurysms - preclipping. (b) Dual image video angiography - right internal carotid artery - ach aneurysm - postclipping

chance of perforators injury [Figure 4].[19] In another report by Iwama *et al*., the authors underlined the importance of the LSAs while operating a superior wall type aneurysm at the MCA-M1.[20] Actually, we recommend and perform intraoperative MEP monitoring for all cases with this aneurysm location. Aneurysms in proximal MCA require special attention during localization and dissection of the aneurysm as some tiny perforators located at the posterior MCA wall and obscured by the temporal lobe may be damaged. In this scenario, endoscopy may come to help the surgeon with checking the final results after clipping.

Surgery of AChA and ICA bifurcation aneurysms is also associated with an increased chance of morbidity,[21] which may be explained by their proximities to the early ACA-A1 and MCA-M1 perforating arteries. These locations are among the hot spots where endoscopy may assist the surgeon to identify perforators attached to the medial wall of the aneurysms and prevent morbidity.

The first report of endoscope guided clipping in aneurysm surgery was published by Fischer and Mustafa.[21] They used this method in 24 patients with 30 aneurysms and emphasized the benefits of endoscopy in improving the visualization of the pertinent anatomy. Taniguchi *et al*. reported benefits of endoscopy to clarify the anatomy in 81.5% of 44 cases operated for cerebral aneurysms.[22] Interestingly, in 16.7% of their cases, the anatomy could be recognized only after endoscopy leading to clip adjustment in 9.3% of the surgeries. Wang *et al*. performed endoscope-assisted microsurgery to treat 24 cases of ruptured aneurysms and found it very practical for

Table 3: Location of unruptured aneurysms

	September-December		
	2014	2015	2016
IC-PComm	3	17	17
IC-Acho	0	6	6
IC-top	2	5	0
IC-fusiform	0	1	0
C23	4	17	12
Total IC	9	46	38
BA-SCA	1	3	1
BA-top	0	2	3
Total BA	1	5	4
A1	0	0	4
AComm	6	14	9
A23	3	8	3
Total A	9	12	16
MCA	12	21	35
M1 superior	0	8	5
M1 inferior	0	3	0
M23	0	2	0
Total M	12	34	40
PICA	0	1	0
VA-PICA	0	3	5
VA fusiform	0	1	0
P23	1	0	0

IC – Internal carotid; PComm – Posterior communicating; Acho – Anterior choroidal; BA – Basilar artery; SCA – Superior cerebellar artery; A – Anterior cerebral artery; Comm – Communicating; MCA – Middle cerebral artery; PICA – Posterior inferior cerebellar artery; VA – Vertebral artery; P – Posterior cerebral artery

providing the surgeon with good definition of surrounding structures such as cranial nerves, parent arteries, and perforators.[23] In another report by Profeta *et al*., 52 patients with 58 aneurysms were operated with applying endoscope-assisted microsurgery over a period of 3 years.[24] In four cases, endoscopy disclosed inappropriate clip placement requiring re-positioning or addition of an extra clip. The authors recommended endoscopy for certain aneurysm surgeries, especially for those developed from the AComA. In another clinical study of endoscope-assisted microsurgery of 50 cerebral aneurysms, the endoscopy showed incomplete clipping in two cases leading to additional clipping [Figure 5].[25]

In spite of normal monitoring after clipping, sometimes, a postoperative neurological deficit happens. Distal emboli during the vascular manipulation, irreversible brain ischemia due to prolonged proximal closure, or permanent damage of perforators due to a misplaced clip can be the underlying causes. However, we still do not know whether discovering these events (i.e., emboli or irreversible ischemia) intraoperatively improves the outcome. To overcome these obstacles, we use intraoperative MEP, especially when there is a high risk of distal emboli (e.g., severe atherosclerosis of the parent artery) or the aneurysm is placed in proximity to numerous perforators (e.g., proximal MCA aneurysms). This is in concordance with the studies reporting more difficult clipping and worse outcome for atherosclerotic-calcified aneurysms.[26,27] Vasospasm of a major or perforating artery can be another source of postoperative deficits despite a safe and uneventful clipping of the aneurysm. Although rare, isolated symptomatic perforators vasospasm has been reported, and it further signifies the importance of these vessels.[28]

DIVA provides real-time simultaneous visualization of aneurysm and vessels and surrounding structures including brain, nerves, and surgical clips. DIVA makes it easier to understand anatomic relationships between intracranial structures, despite a higher visual contrast between vessels and background. It also provides better vision of the depth of field. DIVA has the potential to become a widely used intraoperative tool to check patency of intracranial vessels. It should be considered as an adjunct to standard ICG-VA for better understanding of vascular anatomy in relation to surrounding structures and can have an impact on decision-making during surgery [Figure 6].

Conclusion

A good preoperative planning always reflects to the outcome of treatment. Multimodality of assisted devices can be helpful during surgeries and minimize the vessel injury. The surgical skill and experience of the surgeon also influence the complication rate.

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Conflicts of interest

There are no conflicts of interest.

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