DOI: 10.5137/1019-5149.JTN.21878-17.2
Received: 14.10.2017 / Accepted: 19.03.2018
Published Online: 09.04.2018

Original Investigation

Assessing Aneurysm Obliteration and Neck Remnants in 225 Clipped Aneurysms Using Indocyanine Green Video Angiography, Micro-Doppler Ultrasonography and Postoperative Digital Subtraction Angiography

Melih BOZKURT, Onur OZGURAL, Gokmen KAHILOGULLARI, Umit EROGLU, Ihsan DOGAN, Haydar SEKMEN, Nihat EGEMEN

Ankara University, Faculty of Medicine, Department of Neurosurgery, Ankara, Turkey

This study was presented as a poster presentation at CNS Meeting, New Orleans, USA, in 2015 (presentation number # 475).

ABSTRACT

AIM: We present our experience of 225 clipped aneurysms in 196 patients to compare indocyanine green video angiography (ICG-VA), micro-Doppler ultrasonography (MDUSG), and postoperative digital subtraction angiography (DSA) in terms of determining aneurysm obliteration, neck remnants, and parent artery patency.

MATERIAL and METHODS: This retrospective study included 196 patients (108 female and 88 male patients) treated between 2013 and 2016. In all cases, aneurysm neck remnants and vessel patency were assessed using ICG-VA and 16-Hz MDUSG. DSA was performed in every case postoperatively within the first 5 days.

RESULTS: The mean patient age was 55.8 years (range, 31-80 years), and the mean follow-up duration was 25 months (range, 2-48 months). Of the 225 clipped aneurysms, 86 were located in the anterior cerebral artery and its branches, 103 in the bifurcation of the middle cerebral artery (MCA) and the branches of the MCA, 34 in the internal cerebral artery and its branches, 1 in the posterior inferior cerebellar artery, and 1 at the basilar apex. We observed 2 neck remnants (0.8%), 2 parent/perforating artery occlusions (0.8%), and 2 residual aneurysm fillings (0.8%). There were no striking differences among the assessed methods.

CONCLUSION: ICG-VA, MDUSG, and dome puncturing are all useful techniques in aneurysm surgery for assessing complete obliteration of the aneurysm. In our experience, all the 3 tools are complementary to each other, and none of them is superior to the others. We recommend the use of all 3 tools to obtain a favorable outcome.

KEYWORDS: Aneurysm, Clipping, Indocyanine green, Neck remnant, Residual aneurysm

INTRODUCTION

The agreeable outcomes of aneurysm surgery rely upon preservation of parent arteries and complete clipping of the aneurysm neck without a residual aneurysm. Although advanced contemporary adjuncts are being used in many neurosurgical centers, the rate of aneurysm remnants after clipping has been reported to range between 1% and 8% and the re-bleeding risk of residual aneurysms has been reported to be 3.7% (8,10,33,36). Additionally, parent artery stenosis or perforating branch occlusion rates have been shown to be 1.6%–2.1% in a large series, and it is usually behind the time to prevent the ischemia related complications (34). These difficulties during aneurysm surgery can be reduced by using intraoperative adjuncts, such as micro-Doppler ultrasonography (MDUSG), intraoperative

Corresponding author: Melih BOZKURT
E-mail: melihbozkurt@hotmail.com

angiography (IA), and indocyanine green video angiography (ICG-VA), contiguous to the application of the principles of microsurgical techniques (20,27).

Kuroiwa et al. was the first to visualize the bridging veins and superior sagittal sinus through the dura mater using intravenously injected indocyanine green in neurosurgical practice in 2001 (21). In 2003, Raabe et al. published their series of 14 patients and assessed vascular flow in 21 clip applications with ICG-VA (30). In subsequent years, multiple centers have successfully utilized ICG-VA in not only aneurysm surgery but also all neurovascular procedures, including extracranial-intracranial bypass and arteriovenous malformation surgeries (2,3,5,6).

In this study, we present our experience of 225 consecutive clipped aneurysms in 196 patients and compare ICG-VA, MDUSG, and postoperative digital subtraction angiography (DSA), which is the gold standard method, in terms of the determination of aneurysm obliteration, neck remnants, and parent artery patency. Our findings may add further information to the literature and may contribute to the selection of adjuncts.

MATERIAL and METHODS

This retrospective study was performed in 196 consecutive patients with a total of 225 aneurysms between 2013 and 2016. All patient data, including the clinical status, preoperative and postoperative radiological findings, operative notes, and videos, were collected from the medical records.

ICG-VA

ICG-VA was performed before and after all 225 clipping procedures. The technique of ICG-VA has been reported previously in detail (18). A 0.2–0.5 mg/kg bolus of ICG was injected intravenously before and after clipping. The dye was visualized using the fluorescent operating microscope OPMI® Pentero™ 900 (Carl Zeiss, Oberkochen, Germany) after wide dissection of the aneurysms.

If occlusion of the parent artery or its branches, a residual aneurysm, or a neck remnant was identified with ICG-VA, clip repositioning was performed or additional clips were applied. There was no complication associated with ICG-VA use in the patients.

MDUSG

For all 225 clippings, a 16-Hz 7-mm golden probe (Rimed, Raanana, Israel) was used. MDUSG was used to determine the patency of the parent artery and detect any residual aneurysm. If a mismatch was noted between MDUSG and ICG-VA, the clip position was carefully re-checked while observing the distal artery flow.

Postoperative DSA

As our department did not have IA, we could not consider the intraoperative results just after surgical clipping. However, all patients underwent DSA between postoperative days 1 and 5. Aneurysm remnants, existence of a residual aneurysm, and parent artery occlusion were assessed.

Surgical Technique

All anterior circulation aneurysms and 1 basilar apex aneurysm were operated via pterional craniotomy or lateral supraorbital craniotomy and trans-sylvian approach. One posterior inferior cerebellar artery (PICA) aneurysm was operated using far lateral approach. If ventriculomegaly was noted or cerebrospinal fluid (CSF) evacuation was needed, a ventriculostomy catheter was placed. MDUSG and ICG-VA were applied before and after clipping. Neurophysiological monitoring was performed, and both motor and sensorial evoked potentials were recorded in all patients.

Dome Puncturing

Complete aneurysm obliteration was verified with dome puncturing after ICG-VA and MDUSG for all aneurysms, using a 28-G insulin needle. If oozing was observed, the clip was re-positioned or an additional clip was applied.

RESULTS

A total of 225 aneurysms in 196 patients (108 female and 88 male patients) underwent surgical clipping, and all patients were included in this study. The mean patient age was 55.8 years (range, 31–80 years), and the mean follow-up duration was 25 months (range, 2–48 months). Of the 225 clipped aneurysms, 76 were located in the anterior communicating artery (AComA), 8 in the distal anterior cerebral artery (DACA), 2 in the A1 segment of the anterior cerebral artery, 94 in the bifurcation of the middle cerebral artery (MCA), 6 in the prebifurcation part of the M1 segment of the MCA (4 involved the anterior temporal artery and 2 involved the lenticulostriate arteries), 3 in the M2 segment of the MCA, 34 in the internal cerebral artery (ICA) and its branches (6 involved the ICA bifurcation, 14 involved the posterior communicating artery (PComA), 2 involved the anterior choroidal artery (AChrA), 10 involved the ophthalmic artery, and 2 involved the superior hypophyseal artery (Sup. Hyp.), 1 in the PICA, and 1 at the basilar apex. Of the 225 aneurysms, 112 had diameters less than 10 mm, 108 had diameters between 10 and 25 mm, and 5 had diameters larger than 25 mm. Of the 196 patients, 95 had unruptured aneurysms (48%) and 101 had ruptured aneurysms (52%). At admission, 10 patients had Hunt-Hess grade 1, 32 had grade 2, 38 had grade 3, 5 had grade 4, and 6 had grade 5 subarachnoid hemorrhage (SAH), among patients who had ruptured aneurysms. Additionally, 22 patients had multiple aneurysms (11.2%)(3 had 4 aneurysms, 3 had 3 aneurysms, and 16 had 2 aneurysms). The general characteristics of the patients are summarized in Table I.

Neck Remnants

After using ICG-VA during operation, 6 neck remnants (2.6%) were noted (3 AComA, 2 MCA bifurcation, and 1 PComA). The distribution of the neck remnants according to the aneurysm sites is summarized in Table II. In all these cases, clip repositioning was performed. Furthermore, additional clips were used for one AComA and one PComA aneurysm. Nevertheless, in one AComA and one MCA bifurcation aneurysm, no neck remnant was observed with ICG-VA, but it was detected on postoperative angiography (0.8%) (Figure 1). MDUSG did not provide adequate data in terms of neck remnants in neither the 6 cases recognized using ICG-VA nor the 2 cases diagnosed using postoperative DSA.

Parent and Perforating Artery Occlusion

After using ICG-VA during operation, 8 parent or perforating artery occlusions (3.5%) were noted (3 AComA, 2 MCA bifurcation, 1 PComA, 1 A1 segment of the anterior cerebral artery, and 1 DACA). The distribution of the parent or perforating artery occlusions according to the aneurysm sites is summarized in Table III. In all these cases, clip re-adjustment was performed. In 2 of the 3 AComA cases, which involved superior aneurysm projection, the aneurysm clip caught the contralateral A2 partially. In the other AComA case, the aneurysm clip occluded the artery of Heubner on the same side. In the case involving the A1 segment of the anterior cerebral artery, the aneurysm clip caught the posterior wall perforating branch, presumably supplying the hypothalamus. In the 2 MCA bifurcation cases, which involved continuity of the neck of the aneurysm with the inferior truncus of the MCA, partial inferior branch occlusion was noted. In the one PComA case, in which the aneurysm was conjoint with the PComA, the aneurysm clip totally occluded the PComA. Postoperative DSA revealed only 2 (0.8%) cases in which a correction maneuver failed to regain flow. One case involved a DACA aneurysm, which was different from the previously mentioned DACA aneurysm, where the aneurysm arose from an azygos artery and was divided into 2 parts by the falx cerebri. The aneurysm clip occluded the right callosomarginal artery, and no parent artery (callosomarginal artery) compromise was observed with ICG-VA and MDUSG. The patient experienced left lower limb monoparesis, and acute ischemia was seen on performing diffusion-weighted imaging (DWI) MRI after the procedure (0.8%) (Figure 2). Postoperative DSA was performed on the second day, and revision surgery and clip repositioning

Table I: General Characteristics of the Patients

Aneurysm location	Number of aneurysms	Ruptured aneurysms	Unruptured aneurysms	Aneurysm size (mm)		
				<10	10-25	>25
A1	2 (0.8%)	1	1	1	1	-
AComA	76 (33.7%)	30	46	40	35	1
DACA	8 (3.5%)	4	4	5	3	-
Prebifurcation M1	6 (2.6%)	2	4	4	2	-
MCA Bifurcation	94 (41.7%)	44	50	47	44	3
M2	3 (1.3%)	-	3	3	-	-
ICA Bifurcation	6 (2.6%)	4	2	3	3	-
PComA	14 (6.2%)	9	5	4	10	-
AChrA	2 (0.8%)	-	2	2	-	-
Ophthalmic Artery	10 (4.4%)	6	4	2	7	1
Sup. Hyp.	2 (0.8%)	-	2	1	1	-
Basilar Artery	1 (0.4%)	1	-	-	1	-
PICA	1 (0.4%)	-	1		1	
Total	196 patients 225 aneurysms	101	124	112	108	5
				225 aneurysms		

Table II: The Distribution of Neck Remnants according to Aneurysm Sites

Neck remnant location after ICG-VA		Correction maneuver	Neck remnant after postoperative DSA
AComA	3	Clip re-adjustment, Additional clip	1
MCA Bifurcation	2	Clip re-adjustment	1
PComA	1	Clip re-adjustment, Additional clip	-
Total	6/225 (2.6%)		2/225 (0.8%)

Table III: The Distribution of Parent and Perforating Artery Occlusions According to the Aneurysm Sites

Parent and perforating artery occlusion after ICG-VA		Correction maneuver	Parent and perforating artery occlusion after postoperative DSA
AComA	3	Clip re-adjustment	-
MCA Bifurcation	2	Clip re-adjustment	1
PComA	1	Clip re-adjustment	-
DACA	1	Clip re-adjustment	1
A1	1	Clip re-adjustment	-
Total	8/225 (3.5%)		2/225 (0.8%)

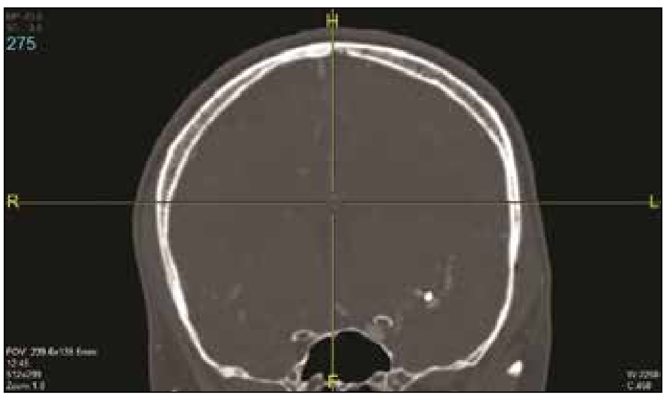

Figure 1: Neck remnant of a middle cerebral artery aneurysm.

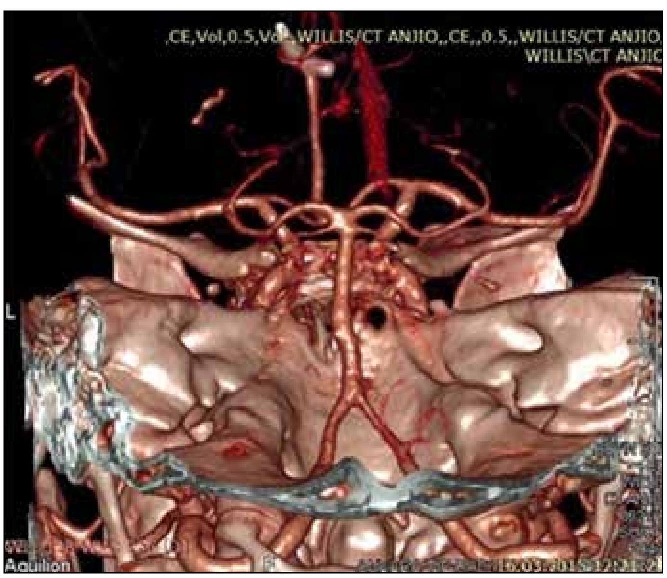

Figure 2: Callosomarginal artery compromise after clip application.

were performed immediately. In the case involving one right MCA aneurysm, acute ischemia was seen on performing DWI MRI after the procedure (Figure 3). Because the patient was asymptomatic, follow-up was performed. Postoperative DSA revealed only 1 (0.4%) case in which a correction maneuver failed to regain flow.

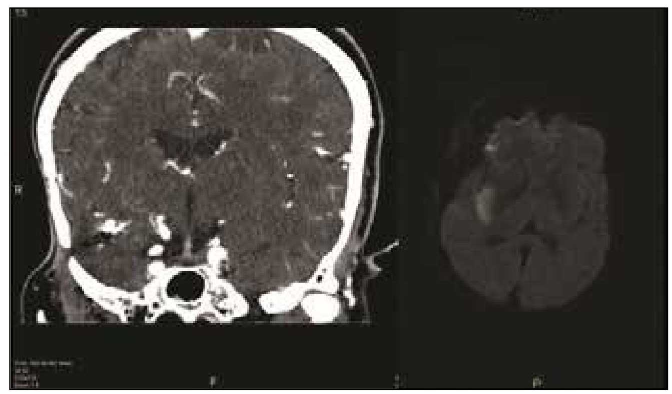
Figure 3: Postoperative diffusion-weighted imaging magnetic resonance imaging of right lenticulostriate compromise of a clipped middle cerebral artery aneurysm.

In 6 of the 8 occlusions mentioned above (75%), MDUSG successfully detected occlusion of the parent arteries. However, MDUSG could not detect occlusion of the perforating arteries in 2 cases (1 AComA case, in which the artery of Heubner was occluded and 1 A1 case, in which the hypothalamic perforator was caught by the clip).

Residual Aneurysm Filling

After using ICG-VA during operation, 4 residual aneurysm filling cases (3.3%) were noted (1 MCA, 2 ophthalmic artery, and 1 PComA) (Figure 4). The distribution of the residual aneurysms according to the aneurysm sites is summarized in Table IV. In all these cases, clip re-positioning was performed. Furthermore, additional clips were applied for all 4 cases. Nevertheless, in 1 AComA and 1 ophthalmic artery case, no residual filling was observed with either ICG-VA or MDUSG; however, it was detected on postoperative angiography (0.8%). Both patients underwent a second surgery. Clip re-adjustment was performed, and total occlusion of the aneurysms was achieved.

Dome Puncturing

For all 225 aneurysms, dome puncturing was performed with a 28-G insulin syringe needle after clipping, ICG-VA administration, and MDUSG control. If oozing was observed after dome puncturing, the clip was re-adjusted or an

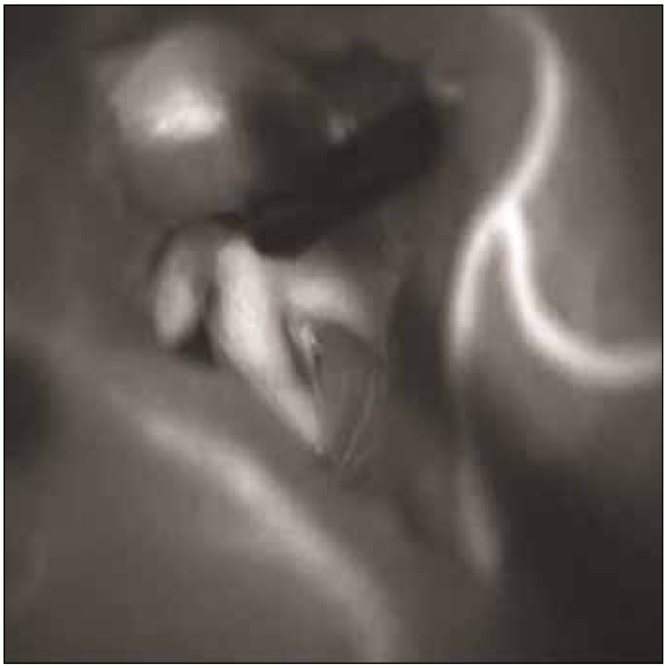

Figure 4: Residual aneurysm filling of a middle cerebral artery aneurysm after indocyanine green video angiography.

additional clip was applied. The mismatch between ICG-VA and dome puncturing after clipping is summarized in Table V. Oozing after dome puncturing was observed in 3 cases, even after ICG-VA and MDUSG application (1 AComA, 1 PComA, and 1 ophthalmic artery aneurysm) (Figure 5). In all cases, additional clips were applied. The superiority rate of dome puncturing over ICG-VA was 1.6%.

There were 11 mortalities (5.6%) [2 (1.02%) among Hunt–Hess grade 2 patients, 3 (1.5%) among Hunt–Hess grade 3 patients, 2 (1.02%) among Hunt–Hess grade 4 patients, and 4 (2%) among Hunt–Hess grade 5 patients]. No mortality was observed among unruptured aneurysm patients. One case of right lower limb monoparesis mentioned above completely resolved in the first-year follow-up.

■ DISCUSSION

Microscope-integrated near-infrared ICG-VA has been used regularly and widely in neurovascular surgery for several years (2,6,16,22,26-28,34,35). It is accepted as a convenient adjunct for assessing cerebral blood flow during surgery for cerebral aneurysms, cerebral arteriovenous malformations (AVMs), and extracranial-intracranial bypass (2,22,30,39,41). ICG-VA is an easily performed procedure, and this diagnostic tool has

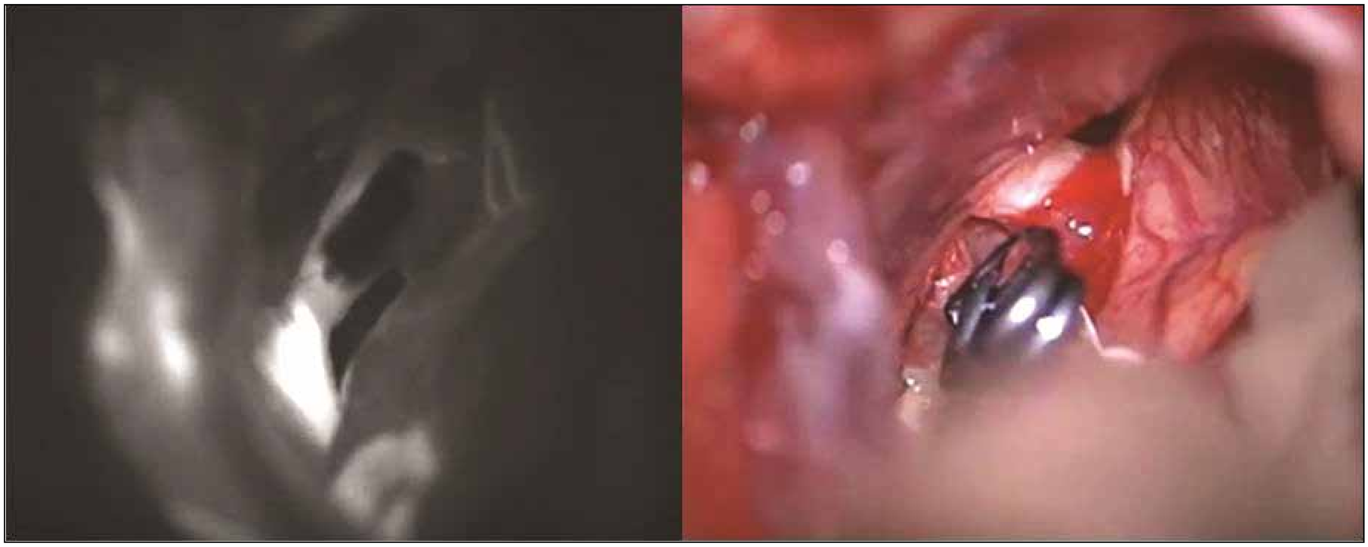

Figure 5: Oozing after dome puncturing. Indocyanine green video angiography could not detect residual filling.

Table IV: The Distribution of Residual Aneurysm Filling according to Aneurysm Sites

Residual aneurysm after ICG-VA		Correction maneuver	Residual aneurysm after postoperative DSA
AComA	1	Clip re-adjustment, Additional clip	1
Ophthalmic Artery	2	Clip re-adjustment, Additional clip	1
PComA	1	Clip re-adjustment, Additional clip	-
Total	4/225 (1.7%)		2/225 (0.8%)

Table V: Residual Aneurysms Detected with Dome Puncturing

Residual aneurysm after dome puncturing		Correction maneuver
AComA	1	Additional clip
MCA	1	Additional clip
PComA	1	Additional clip
Total	3/225 (1.3%)	

additional cost-effectiveness in neurovascular surgery. The procedure can be performed at any point during surgery, and repeated administration is possible with a time interval of 15 minutes between injections to allow clearance (26). ICG-VA is an ideal indicative tool for surgery before the occurrence of vascular-cerebral injury. The speed of image acquisition, convenience of usage during surgery, and improved resolution to assess even small perforating arteries are major advantages of this method (7,13,16,28). On the other hand, false-negative ICG-VA findings must be kept in mind (12).

ICG-VA can demonstrate the anatomy and patency of arteries and perforating branches, morphology of the aneurysm, and any remnant after aneurysm clipping (2,27). In her MCA aneurysm series, Hallout described that surgical management is relatively safe and that the acceptable complication rate is low in patients when ICG-VA is available (15). Some studies explained the importance of ICG-VA for correct dissection of the Sylvian veins during aneurysm surgery (19,23,38). Proper dissection to skeletonize complete vascular anatomy and visualize clipped aneurysms is essential for the reliable use of ICG-VA (33). If any remnant, parent artery, or perforating occlusion is detected, re-clipping or application of additional clips can be performed immediately during the procedure. Therefore, postoperative ischemia-related complications could be reduced (3,18,31). One possible drawback of using ICG-VA according to the literature is issues with deep aneurysm locations (AComA aneurysms) when compared to other non-deep aneurysm locations (MCA aneurysms). In superiorly projected AComA aneurysms, the gyrus rectus may limit visualization, and the contralateral A2 may be hidden behind the aneurysm. This might reduce the benefits of ICG-VA (14,18). This drawback can be overcome through the circumferential dissection of the aneurysm and resection of the gyrus rectus. Nevertheless, a deep location, large size, presence of overlaying vessels, and complex aneurysm can reduce the efficacy of ICG-VA as a diagnostic tool (7,21,28). Conversely, MDUSG, especially with thin probes, is feasible to assess the aneurysm dome and parent artery even in deep areas and with the presence of overlaying vessels, cisternal blood and existence of complex geometrical shapes. Calcification at the aneurysmal neck or presence of an atheromatous plaque in the aneurysm neck affects the ability to obtain images with ICG-VA; however, this is not a problem when using MDUSG (4,14,32).

The time interval between clip position evaluation and clip re-adjustment is very important during intracranial aneurysm surgery when there is doubt regarding the clip position. MDUSG takes the least amount of time to recognize that the clip position is incorrect, particularly during parent artery patency (14,37). During ICG-VA, after the first application, clip malposition can be recognized in about 25 seconds, but in the second application, this takes up to about 15 minutes. This time difference can also be evaluated as an additional risk factor for the occurrence of a neurological deficit. This advantage of MDSUG is lost when the clip closes the perforating arteries because it is very difficult to recognize the patency of the perforating artery with MDUSG, even if micro-Doppler probes are used. ICG-VA is significantly superior for evaluating the patency of perforating arteries. In addition, ICG-VA is superior to the gold standard DSA for evaluating perforating arteries.

The rate of neck remnants in the literature has been reported to be 4–8%, and the re-bleeding risk of remnants is 3–4% (17,27). Thus, recognition of neck remnants during aneurysm surgery is essential. Apparent neck remnants can be easily diagnosed according to the surgeon's vision, but additional diagnostic tools should be used to improve diagnosis. Otherwise, the patient will face additional risk of hemorrhage, and revision surgery may be required. Riva et al. emphasized that ICG-VA is still considered as complementary to, rather than a replacement of, DSA during aneurysm surgery; DSA still remained the best tool for the detection of aneurysm remnants in their study (32). In our series, the overall number of neck remnants was 8 (3.5%), and 6 of them were recognized with ICG-VA. Therefore, the possibility of overlooking a neck remnant during surgery was 25% in our series. Additionally, the overall percentage of mismatch between ICG-VA and postoperative DSA in terms of determining neck remnants was 0.8%. This rate could be considered satisfactory. MDUSG could not diagnose any neck remnants in our series. The size of the remnant, diminished angle of the Doppler device for identifying flow, and difficulty in inserting the Doppler probe beyond the clips may explain these results. Additionally, the Doppler signal of the parent arteries may cause absence of remnant detection. As a result, for identifying neck remnants, ICG-VA can be considered superior to MDUSG.

A residual aneurysm after clipping is considered a problem in aneurysm surgery. Many studies have demonstrated the residual aneurysm rates after clipping (1,9,24,29). The rate varies from 2% to 8% (2). Moon et al. reported a fully occluded aneurysm sac without vessel compromise in 119 of 127 aneurysms (93.7%) detected using ICG-VA. However, a small portion of the clipped aneurysm was filled with bright fluorescent material in 6 patients, and small perforators or branched arteries were not seen in 2 cases (0.8%), as assessed with ICG-VA and intraoperative and postoperative DSA (26). Wang et al. used ICG-VA in 145 intracranial aneurysms. In 2 aneurysms (1.3%) incomplete occlusion was found after clipping. Both clips were adjusted, and complete obliteration was confirmed with ICG-VA and angiography (39). Intraoperative DSA remains the gold standard for the evaluation of residual filling. However, the dependency on a neurovascular team during surgery and the long time required for the procedure cause DSA to be far from practical (11,25,28,40).

In our series, 4 (1.7%) residual aneurysm fillings were seen using ICG-VA during surgery. In all of these 4 cases, MDUSG could detect the residual flow in the aneurysm sac. Therefore, it was possible to re-adjust the clip intraoperatively. Therefore, our residual aneurysm fillings number down to 2 cases (0.8%) determined with postoperative DSA. In these 2 cases, ICG-VA and MDUSG could not determine filling. The rate shows the specificity of ICG-VA in terms of residual aneurysm filling, which was 98.6% in our cases. For determining residual aneurysm filling with ICG-VA, the scavenging speed of the florescent agent can be a drawback. Residual florescent activity in the aneurysm sac can mimic residual filling and cause false-positive results. Therefore, surgeons should not use ICG-VA unless it is necessary before clipping the aneurysm, particularly if it is successful in identifying a resected aneurysm and recognizing this complication with higher sensitivity.

Ozgiray et al. demonstrated false-positive and false-negative results with ICG. In 3.6% of cases, ICG showed no aneurysm filling, but dome puncturing showed filling. Conversely, in 0.9% of cases, because of the residual intravasal activity, ICG-VA showed aneurysm filling, but dome puncturing did not show filling (27).

In terms of assessing the complete obliteration of the aneurysm sac, dome puncturing was the most sensitive method as a part of a microsurgical technique rather than a diagnostic tool in our series. Even ICG-VA and MDUSG did not reveal any aneurysm filling dome puncturing must be applied to all cases not before ICG-VA or MDUSG control. None of these diagnostic tools mentioned above can show that the connection between the aneurysm sac and systemic blood flow is completely cut off as precisely and as fast as dome puncturing.

Chen et al. demonstrated a parent artery occlusion rate of 16.6% during aneurysm clipping (5). The ability to detect the occlusion of the parent artery or perforating branches during the procedure is one of the most important parts of aneurysm surgery in terms of expecting a high quality of life. Because it will be 100% too late to recover the results of this complication. ICG-VA and MDUSG have the same ability to detect parent artery occlusion because of the relatively large size of the parent artery. On the other hand, owing to the small size of the perforating branches, ICG-VA is superior to MDUSG for detecting occlusion of the perforating branches. In our series, this mismatch was 25%. Much the same as assessing residual aneurysm filling, using ICG-VA before clipping should be avoided so that an accurate result can be obtained when evaluating perforating artery patency (14).

Intraoperative somatosensory evoked potentials monitoring is also an effective and feasible tool for preventing ischemic complications (3). For estimating the possible consequences of compromising normal arterial flow, neurophysiological monitoring and assessment of both motor and sensorial evoked potentials are mandatory to obtain an idea about the neurological status of patients.

The focus of vascular and especially aneurysm surgery is to provide complete aneurysm obliteration, maintain parent/perforating artery flow, and avoid any remnant aneurysm. Among the 3 above-mentioned techniques, each has its own advantages and limitations, and the possibility of using all 3 techniques together in combination is worth considering. It should be emphasized that rather than functioning separately, these techniques can have synergic effects on the surgical outcome.

An intracranial aneurysm is never like any other intracranial aneurysm. Surgeons dealing with aneurysm surgery may face many problems, even during the most successful surgeries. The microsurgery technique and surgeon's experience, as well as some diagnostic tools, can help to solve these problems. A diagnostic tool that can detect all problems that can occur during aneurysm surgery with high precision has not yet been developed. In addition, no diagnostic tool is fast, simple, reliable, repeatedly used, and cheap (4,14). As a result, none of the diagnostic tools can be considered sufficient. In the present study, the use of ICG-VA in a relatively large number of aneurysm patients was evaluated. The advantages and disadvantages of this technique were compared with those of MDUSG, dome puncturing, and postoperative DSA. ICG-VA increases intraoperative information obtained regarding aneurysm geometry and provides surgical strategy optimization, particularly in case of non-complex aneurysms, aneurysms that do not project in multiple directions, and small aneurysms that are <10 mm in diameter. Therefore, the use of only ICG-VA for non-complex aneurysms can be considered as a sufficient modality in many cases, and time may not be taken for using the other diagnostic tools. On the other hand, while dealing with a complex aneurysm, in the presence of cisternal blood, and in the case of the parent artery or perforating artery arising from the aneurysm sac, it is certainly not an adequate examination; unfortunately, it provides the surgeon an unnecessary confidence. The application of microsurgery techniques such as dome puncturing and the use of intraoperative DSA, if possible, will complete these deficiencies of ICG-VA and should be considered superior to ICG-VA. Additionally, avoiding the application of ICG-VA before clipping is very important to be able to exclude residual intravasal activity and therefore to evaluate the filling of the residual aneurysm and parent and perforator arteries in a healthy manner.

■ CONCLUSION

ICG-VA, MDUSG, and dome puncturing have some advantages and drawbacks, and in our opinion, one of these tools cannot be considered as a paramount tool. The tools should be considered complementary to each other in terms of determining the crucial components of aneurysm surgery, such as effective clipping, residual aneurysm control, and parent and distal vessel patency and flow.

REFERENCES

1. Alexander TD, Macdonald RL, Weir B, Kowalczuk A: Intraoperative angiography in cerebral aneurysm surgery: A prospective study of 100 craniotomies. Neurosurgery 39: 10-17, 1996
2. Balamurugan S, Agrawal A, Kato Y, Sano H: Intraoperative indocyanine green video-angiography in cerebrovascular surgery: An overview with review of literature. Asian J Neurosurg 6: 88-93, 2011
3. Byoun HS, Bang JS, Oh CW, Kwon OK, Hwang G, Han JH, Kim T, Lee SU, Jo SR, Kim DG, Park KS: The incidence of and risk factors for ischemic complications after microsurgical clipping of unruptured middle cerebral artery aneurysms and the efficacy of intraoperative monitoring of somatosensory evoked potentials: A retrospective study. Clin Neurol Neurosurg 151: 128-135, 2016
4. Caplan JM, Sankey E, Yang W, Radvany MG, Colby GP, Coon AL, Tamargo RJ, Huang J: Impact of indocyanine green videoangiography on rate of clip adjustments following intraoperative angiography. Neurosurgery 75: 437-444, 2014
5. Chen SF, Kato Y, Oda J, Kumar A, Watabe T, Imizu S, Oguri D, Sano H, Hirose Y: The application of intraoperative near-infrared indocyanine green videoangiography and analysis of fluorescence intensity in cerebrovascular surgery. Surg Neurol Int 2: 42, 2011
6. Czabanka M, Pena-Tapia P, Schubert GA, Woitzik J, Vajkoczy P, Schmiedek P: Characterization of cortical microvascularization in adult moyamoya disease. Stroke 39: 1703-1709, 2008
7. Dashti R, Hernesniemi J: Intraoperative assessment of a quality of microneurosurgical clipping: Role of indocyanine green videoangiography. World Neurosurg 82: 589-590, 2014
8. David CA, Vishteh AG, Spetzler RF, Lemole M, Lawton MT, Partovi S: Late angiographic follow-up review of surgically treated aneurysms. J Neurosurg 91: 396-401, 1999
9. Drake CG, Allcock JM: Postoperative angiography and the “slipped” clip. J Neurosurg 39: 683-689, 1973
10. Feuerberg I, Lindquist C, Lindqvist M, Steiner L: Natural history of postoperative aneurysm rests. J Neurosurg 66: 30-34, 1987
11. Fischer G, Stadie A, Oertel JM: Near-infrared indocyanine green videoangiography versus microvascular Doppler sonography in aneurysm surgery. Acta Neurochir (Wien) 152:1519-1525, 2010
12. Gekka M, Nakayama N, Uchino H, Houkin K: Factors influencing cerebral aneurysm obliteration and reliability of indocyanine green video-angiography. Acta Neurochir (Wien) 160: 269-276, 2018
13. Goehre F, Jahromi BR, Elsharkawy A, Lehto H, Shekhtman O, Andrade-Barazarte H, Munoz F, Hijazy F, Makhkamov M, Hernesniemi J: Lateral supraorbital approach to ipsilateral PCA-P1 and ICA-PCoA aneurysms. Surg Neurol Int 6: 91, 2015
14. Gruber A, Dorfer C, Standhardt H, Bavinzski G, Knosp E: Prospective comparison of intraoperative vascular monitoring technologies during cerebral aneurysm surgery. Neurosurgery 68: 657-673, 2011
15. Hallout S: Surgical treatment of middle cerebral artery aneurysms without using indocyanine green videoangiography assistance: Retrospective monocentric study of 263 clipped aneurysms. World Neurosurg 84: 972-977, 2015
16. Hardesty DA, Thind H, Zabramski JM, Spetzler RF, Nakaji P: Safety, efficacy, and cost of intraoperative indocyanine green angiography compared to intraoperative catheter angiography in cerebral aneurysm surgery. J Clin Neurosci 21: 1377-1382, 2014
17. Jabbarli R, Pierscianek D, Wrede K, Dammann P, Schlamann M, Forsting M, Muller O, Sure U: Aneurysm remnant after clipping: The risks and consequences. J Neurosurg 125:1249-1255, 2016
18. Jing Z, Ou S, Ban Y, Tong Z, Wang Y: Intraoperative assessment of anterior circulation aneurysms using the indocyanine green video angiography technique. J Clin Neurosci 17:26-28, 2010
19. Joo SP, Jung SH, Kim SH, Kim TS: Correct plane of the sylvian vein dissection for middle cerebral artery aneurysm using indocyanine green videoangiography. World Neurosurg 97:453-458, 2017
20. Kapsalaki EZ, Robinson JS, Grigorian AA, Fountas KN: The role of intraoperative micro-Doppler ultrasound in verifying proper clip placement in intracranial aneurysm surgery. J Clin Neurosci15:153-157, 2008
21. Kuroiwa T, Kajimoto Y, Ohta T: Development and clinical application of near-infrared surgical microscope: Preliminary report. Minim Invasive Neurosurg 44: 240-242, 2001
22. Lane BC, Cohen-Gadol AA: A prospective study of microscope-integrated intraoperative fluorescein videoangiography during arteriovenous malformation surgery: Preliminary results. Neurosurg Focus 36: E15, 2014
23. Liu J, Li X, Sun S, Wang Y, Zang P: Indocyanine green videoangiography in clipping of paraclinoid aneurysms. Turk Neurosurg 24:319-322, 2014
24. Macdonald RL, Wallace MC, Kestle JR: Role of angiography following aneurysm surgery. J Neurosurg 79: 826-832, 1993
25. Mielke D, Malinova V, Rohde V: Comparison of intraoperative microscopic and endoscopic ICG angiography in aneurysm surgery. Neurosurgery 3: 418-425, 2014
26. Moon HS, Joo SP, Seo BR, Jang JW, Kim JH, Kim TS: Value of indocyanine green videoangiography in deciding the completeness of cerebrovascular surgery. J Korean Neurosurg Soc 53:349-355, 2013
27. Ozgiray E, Akture E, Patel N, Baggott C, Bozkurt M, Niemann D, Baskaya MK: How reliable and accurate is indocyanine green video angiography in the evaluation of aneurysm obliteration? Clin Neurol Neurosurg 115:870-878, 2013
28. Pahl FH, Oliveira MF, Brock RS, Lucio JE: Application of indocyanine green video angiography in surgical treatment of intracranial aneurysms. Arq Neuropsiquiatr 73:607-610, 2015
29. Puppa AD, Rustemi O, Scienza R: The ‘ICG entrapment sign’ in cerebral aneurysm surgery assisted by indocyanine green videoangiography. World Neurosurg 97:287-291, 2017
30. Raabe A, Beck J, Gerlach R, Zimmermann M, Seifert V: Near-infrared indocyanine green video angiography: A new method for intraoperative assessment of vascular flow. Neurosurgery 52:132-139, 2003

31. Raabe A, Nakaji P, Beck J, Kim LJ, Hsu FP, Kamerman JD, Seifert V, Spetzler RF: Prospective evaluation of surgical microscope-integrated intraoperative near-infrared indocyanine green videoangiography during aneurysm surgery. J Neurosurg 103: 982-989, 2005
32. Riva M, Amin-Hanjani S, Giussani C, De Witte O, Bruneau M: Indocyanine green videoangiography in aneurysm surgery: Systematic review and meta-analysis. Neurosurgery 2017 (Epub Ahead of Print)
33. Roessler K, Krawagna M, Dorfler A, Buchfelder M, Ganslandt O: Essentials in intraoperative indocyanine green videoangiography assessment for intracranial aneurysm surgery: Conclusions from 295 consecutively clipped aneurysms and review of the literature. Neurosurg Focus 36: E7, 2014
34. Sharma M, Ambekar S, Ahmed O, Nixon M, Sharma A, Nanda A, Guthikonda B: The utility and limitations of intraoperative near-infrared indocyanine green videoangiography in aneurysm surgery. World Neurosurg 82: e607-e613, 2014
35. Simal-Julian JA, Miranda-Lloret P, Evangelista-Zamora R, Sanroman-Alvarez P, Perez de San Roman L, Perez-Borreda P, Beltran-Giner A, Botella-Asuncion C: Indocyanine green videoangiography methodological variations: Review. Neurosurg Rev 38: 49-57, 2015
36. Sindou M, Acevedo JC, Turjman F: Aneurysmal remnants after microsurgical clipping: Classification and results from a prospective angiographic study (in a consecutive series of 305 operated intracranial aneurysms). Acta Neurochir (Wien) 140:1153-1159, 1998
37. Stendel R, Pietila T, Hassan AA, Schilling A, Brock M: Intraoperative microvascular doppler ultrasonography in cerebral aneurysm surgery. J Neurol Neurosurg Psychiatry 68: 29-35, 2000
38. Toi H, Matsushita N, Ogawa Y, Kinoshita K, Satoh K, Takai H, Hirai S, Hara K, Matsubara S, Uno M: Utility of indocyanine green video angiography for sylvian fissure dissection in subarachnoid hemorrhage patients-sylvian ICG technique. Neurol Med Chir 58(2):85-90, 2018
39. Wang S, Liu L, Zhao Y, Zhang D, Yang M, Zhao J: Evaluation of surgical microscope-integrated intraoperative near-infrared indocyanine green videoangiography during aneurysm surgery. Neurosurg Rev 34: 209-215, 2010
40. Washington CW, Zipfel GJ, Chicoine MR, Derdeyn CP, Rich KM, Moran CJ, Cross DT, Dacey RG Jr: Comparing indocyanine green videoangiography to the gold standard of intraoperative digital subtraction angiography used in aneurysm surgery. J Neurosurg 118:420-427, 2013
41. Woitzik J, Horn P, Vajkoczy P, Schmiedek P: Intraoperative control of extracranial-intracranial bypass patency by near-infrared indocyanine green videoangiography. J Neurosurg 102: 692-698, 2005