Comparison of 3D intraoperative digital subtraction angiography and intraoperative indocyanine green video angiography during intracranial aneurysm surgery

*Serge Marbacher, MD, PhD,¹ Itai Mendelowitsch, MD,¹ Basil Erwin Grüter, MD,¹ Michael Diepers, MD,² Luca Remonda, MD,² and Javier Fandino, MD¹

¹Department of Neurosurgery and ²Division of Neuroradiology, Department of Radiology, Kantonsspital Aarau, Switzerland

OBJECTIVE During the last decade, improvements in real-time, high-resolution imaging of surgically exposed cerebral vasculature have been realized with the successful introduction of intraoperative indocyanine green video angiography (ICGVA) and technical advances in intraoperative digital subtraction angiography (DSA). With the availability of 3D intraoperative DSA (3D-iDSA) in hybrid operating rooms, the present study offers a contemporary comparison for rates of accuracy and discordance.

METHODS In this retrospective study of prospectively collected data, 140 consecutive patients underwent microsurgical treatment of intracranial aneurysms (IAs) in a hybrid operating room. Variables analyzed included patient demographics, aneurysm-specific characteristics, intraoperative ICGVA and 3D-iDSA findings, and the need for intraoperative clip re-adjustment. The authors defined the discordance rate of the two modalities as a false-negative finding that necessitated clip repositioning after 3D-iDSA.

RESULTS In 120 patients, ICGVA and 3D-iDSA were used to evaluate 134 IA obliterations. Of 215 clips used, 29 (14%) were repositioned intraoperatively, improving the surgical result in all 29 patients (24%). Repositioning was prompted by visual inspection and microvascular Doppler ultrasonography in 8 (28%), ICGVA in 13 (45%), and 3D-iDSA in 7 (24%) patients. Clip repositioning was needed in 7 patients (6%) based on 3D-iDSA, yielding an ICGVA accuracy rate of 94%. Five (71%) of the ICGVA–3D-iDSA discordances that prompted clip repositioning occurred at the anterior communicating artery complex.

CONCLUSIONS A combination of vascular monitoring techniques most often achieved correct intraoperative interpretation of complete IA occlusion and parent artery integrity. Compared with 3D-iDSA imaging, ICGVA demonstrated high accuracy. Despite the relatively low discordance rate, iDSA was confirmed to be the gold standard. Improved imaging quality, including 3D-iDSA, supports its routine use in IA surgery, obviating the need for postoperative DSA.

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KEYWORDS intraoperative; indocyanine green video angiography; three-dimensional digital subtraction angiography; clipping; hybrid operating room; vascular disorders

SURGICAL treatment of intracranial aneurysms (IAs) requires a careful balance between the most complete aneurysm occlusion and preservation of parent arteries and perforators. Since Allcock and Drake's³ 1963 publication that showed high rates of rebleeding from IA remnants after surgery and that advocated routine postoperative angiography, subsequent series have reported ranges of IA remnants from 1% to 36% and vessel occlusion from 1% to 25%.^{3,12,13,21,37} Given the relatively high

rate of these adverse findings, Grossart and Turner's¹⁷ 1974 study recommended the use of intraoperative angiography to immediately verify the surgical results and alter the therapy if needed. Despite proven effectiveness (6%–35% of relevant information), intraoperative digital subtraction angiography (iDSA) demonstrates relatively high rates of false-negative findings (range 0%–13%) compared with the highest-quality postoperative DSA.^{5,22,28,30,39}

In 2003, Raabe et al.³² introduced indocyanine green

ABBREVIATIONS ACA = anterior cerebral artery; ACoA = anterior communicating artery; CTA = CT angiography; DSA = digital subtraction angiography; IA = intracranial aneurysm; ICGVA = indocyanine green video angiography; iDSA = intraoperative DSA; PCoA = posterior communicating artery.

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* S.M. and I.M. share first authorship of this work.

video angiography (ICGVA) as a new method to intraoperatively assess vascular flow, reporting comparable efficiency (9% significant findings) and accuracy (90% correspondence) with iDSA.³³ Subsequently, the few published comparisons confirmed ICGVA and iDSA rates of effectiveness (3%–8%) and accuracy (86%–98%).^{4,10,18,43} A number of other studies noted the utility of ICGVA in contributing 2%–38% of significant findings and reported discordance rates with postoperative DSA that ranged from 4% to 14%.^{19,24,27,29,35,36,41} These figures are comparable with the rates of false-negative findings between intraoperative and postoperative DSA. Although DSA is considered the gold standard for intraoperative evaluation, its high false-negative rates prevented its adoption as a standard of care that obviates the need for postoperative DSA.

With significant advances in imaging quality for iDSA and the availability of 3D-iDSA in hybrid operating rooms, our study offers a contemporary comparison of vascular imaging techniques. Compared with conventional DSA, cumulative evidence suggests that 3D-DSA yields more detailed information of the angioarchitecture and significant benefits for evaluation of clipped IAs.^{2,20,23,38,40,44} In this retrospective study of patients treated for IAs, we evaluate the accuracy of routine use of 3D-iDSA and ICGVA and rates of discordance during a 4-year period.

Methods

We retrospectively reviewed our prospectively collected data for 140 consecutive patients who underwent craniotomy and IA clipping in our hybrid operating room between November 2011 and February 2015. Nineteen patients were excluded because they had visual inspection, Doppler ultrasonography, and 3D-iDSA alone without ICGVA; another patient was excluded because he had undergone intraoperative wrapping alone.

Baseline characteristics included patient age, sex, rupture status, Fisher grade (if the lesion was ruptured), IA occlusion technique, number of clips per aneurysm, and IA location and size. We reviewed operative records and videos (including ICGVA) to identify any clip that was repositioned based on visual inspection and/or microvascular Doppler ultrasonography; relevant surgical information provided by ICGVA; and consistency of 3D-iDSA findings with postclipping ICGVA findings and need for surgical intervention. False-positive and false-negative findings without the need for surgical intervention were not recorded. The study was approved by our institutional review board and the Swiss ethics commission.

Clinical Protocol

After admission for elective surgery to the hospital or to our emergency department, patients treated for IAs routinely underwent preoperative assessment by CT angiography (CTA) and 3D-DSA. An interdisciplinary team discussed each case to determine if surgical, endovascular, or both interventions were required based on IA configuration, location, the patient's condition, and resources.²⁶

After exposing the IA angioarchitecture, parent and branching arteries were assessed using microvascular

Doppler ultrasonography (probe 16 MHz, power 6 mW; LOOKI, Atys Medical) before and after clip ligation. If clip position was deemed satisfactory, ICGVA was performed for at least 1 minute; the video analysis was then correlated with the findings from visual inspection and parent artery Doppler ultrasonography. If the IA was correctly occluded, 3D-iDSA was performed. If the clip needed adjustment, the protocol flow was repeated. Before wound closure, all patients underwent intraoperative CT to rule out space-occupying hematoma formation.

Indocyanine Green Video Angiography

Detailed technical aspects of ICGVA application have been described previously.^{32,33} Flow in arteries, branching vessels, and perforators was observed in real time and on video loops. The flow pattern and the aneurysm itself were monitored for at least 1 minute to diagnose potential late filling of the clipped IA. If ICGVA was repeated, dye injection was delayed for 5 minutes or more after the previous injection to reduce residual fluorescent activity.

Intraoperative Digital Subtraction Angiography

The equipment and setting of our hybrid operating room have been described previously.¹⁴ Briefly, the surgical carbon fiber table (Alphamaquet 1150, Maquet AG) was coupled with a C-arm angiography system (Allura Xper FD20, Philips Medical Systems). Use of radiolucent head holders with radiolucent head pins optimized the acquisition of angiograms and intraoperative CT scans (Mayfield, Integra GmbH). At least 3 standard projections (anteroposterior, lateral, and oblique) and rotational angiography were performed by manual arterial injection of contrast agent (IOPAMIRO 300 mg/ml, 5-ml bolus, Bracco Suisse). The volumetric sequence was used to reconstruct 3D angiographic and multiplanar CT data sets. After data sets were compared to preoperative images, the findings were discussed by the attending interventional neuroradiologist and neurosurgeon. There were no associated complications with iDSA.

Statistical Analysis

ICGVA and 3D-iDSA images were analyzed to detect significant findings (i.e., IA sac or neck remnants or hemodynamically relevant parent artery stenosis) that prompted additional clip placement or clip repositioning. A model based on a multivariate logistic regression of potential predictor variables (IA size and location; rupture status; Fisher grade; and number of clips applied) could not be established with only 7 events for the outcome variable of ICGVA–3D-iDSA discordance.

Results

Of 140 consecutive patients, the 120 patients who were studied included 39 men and 81 women who averaged 55 years of age (range 19–79 years); these patients underwent treatment for 134 IAs, including 73 (55%) ruptured and 61 (45%) unruptured aneurysms. Most aneurysms were small; specifically, 58% were < 7 mm, and 92% occurred in the anterior circulation at the middle cerebral artery in

TABLE 1. Clinical characteristics of ICGVA and 3D-iDSA discordance and concordance

Variable	Total No. (%)	Discordance	Concordance
Patients	120 (100)	7 (5.8)	113 (94.2)
IAs	134 (100)	7 (5.2)	127 (94.8)
Clips	215 (100)	15 (7.0)	200 (93.0)
Female	81 (67.5)	6 (85.7)	75 (66.4)
Mean age (yrs)	55	60	55
Ruptured IAs	61 (45.5)	4 (57.1)	57 (44.9)
Fisher grade			
1	5 (8.2)	1 (25)	4 (7)
2	11 (18)	1 (25)	10 (17.5)
3	9 (14.8)	1 (25)	8 (14)
4	36 (59)	1 (25)	35 (61.5)
Aneurysm size (mm)			
<7	78 (58.2)	4 (57.1)	74 (58.3)
7–12	52 (38.8)	1 (14.3)	51 (40.1)
13–24	4 (3.0)	2 (28.6)	2 (1.6)
>24	0 (0)	0 (0)	0 (0)
Aneurysm location			
MCA	60 (45.5)	1 (14.3)	59 (47.2)
ACoA	37 (26.5)	5 (71.4)	32 (24)
Proximal ACA	13 (9.8)	0 (0)	13 (10.4)
ICA	11 (8.3)	0 (0)	11 (8.8)
PCoA	8 (6.1)	1 (14.3)	7 (5.6)
AChA	2 (1.5)	0 (0)	2 (1.6)
BA	3 (2.3)	0 (0)	3 (2.4)

AChA = anterior choroidal artery; BA = basilar artery; ICA = internal carotid artery; MCA = middle cerebral artery; PCoA = posterior communicating artery.

60 (46%), anterior communicating artery (ACoA) complex in 37 (27%), proximal anterior cerebral artery (ACA) in 13 (10%), internal carotid artery in 11 (8%), and anterior choroidal artery in 2 (2%). Clinical characteristics stratified by ICGVA–3D-iDSA concordance and discordance are summarized (Table 1).

Of the 215 clips placed in 134 aneurysms, 29 (14%) were repositioned intraoperatively. Of these 29 clips, malposition was detected in 8 (7%) after visual inspection and microvascular Doppler ultrasonography, in 13 (11%) after ICGVA, in 7 (6%) after visualization of IA remnants or parent artery compromise by intraoperative 3D-iDSA, and in 1 (1%) after unexpected intraoperative rupture (Fig. 1). The significant findings detected on 3D-iDSA not visible after ICGVA in 7 patients resulted in a discordance rate of 6% (7/120). Considering all the intraoperative tools used to inspect the completeness of IA occlusion and concomitant integrity of parent arteries, the 29 clips repositioned thus improved the operative safety for all 29, or 24% of patients (Table 2 and illustrative cases in Fig. 2).

Of the 7 IAs with ICGVA–3D-iDSA discordances, 5 were small (≤ 7 mm) and 5 were located at the ACoA complex. The 3D-iDSA revealed a significant residual aneurysm in 5 patients and relevant parent artery occlusion in 2 patients (Table 2).

FIG. 1. Flowchart of intraoperative clip reposition rate according to various modalities for assessment of aneurysm occlusion and parent artery flow. ICGA = indocyanine green video angiography.

Illustrative Cases

Case 1: Aneurysm Remnant Treated by Additional Clip

This 61-year-old patient presented with an unruptured 7-mm bilobular ACoA aneurysm (Fig. 2A1). After single clip placement and visual control, Doppler ultrasonography showed no residual blood flow in the aneurysm sac and patent parent arteries. ICGVA confirmed complete occlusion and prompt filling of the ipsilateral and contralateral A₂ segments. However, 3D-iDSA revealed a residual aneurysm remnant of the more posteriorly projecting part of the bilobular aneurysm beneath the tips of the clip blades (Fig. 2A2). After applying an additional curved clip, repeated 3D-iDSA demonstrated complete obliteration without any residual aneurysm neck (Fig. 2A3).

Case 2: Aneurysm Remnant Treated by Wrapping

This 68-year-old patient was admitted with SAH caused by a ruptured 6-mm ACoA aneurysm (Fig. 2B1). Visual inspection and microvascular Doppler ultrasonography demonstrated complete aneurysm occlusion and integrity of both A₂ segments. Inspection by ICGVA showed no residual aneurysm filling and patency of parent arteries. Only 3D-iDSA revealed a slight bulging beneath the middle portion of the clip (Fig. 2B2). Since the surgeon judged that repositioning of the clip was unlikely to improve the surgical result, the aneurysm remnant was circumferentially wrapped with temporalis muscle (Fig. 2B3).

Case 3: Aneurysm Remnant Treated by Clip Repositioning

This 60-year-old patient underwent clip ligation of a small 6-mm ACoA aneurysm (Fig. 2C1). Multiple clips

TABLE 2. Clinical characteristics of ICGVA and 3D-iDSA discordance and concordance

Case No.	SAH	Fisher Grade	Aneurysm Location	Aneurysm Size (mm)	No. of Clips	3D-iDSA Findings	Surgical Intervention
1	No		ACoA	7	2	IA remnant	Additional clip
2	Yes	3	ACoA	6	1	IA remnant	Additional wrapping
3	Yes	4	ACoA	3	2	IA remnant	Clip repositioning
4	Yes	2	PCoA	5	2	Parent artery compromise	Clip repositioning
5	No		ACoA	15	2	IA remnant	Clip repositioning
6	No		MCA	14	2	Parent artery compromise	Clip repositioning
7	Yes	1	ACoA	6	3	IA remnant	Clip repositioning

SAH = subarachnoid hemorrhage.

were applied to secure the fundus of the ruptured aneurysm. Visual inspection and ICGVA assessment of the aneurysm sac after clip application was not feasible because of the restricted angle of the surgical exposure. 3D-iDSA demonstrated significant residual aneurysm filling in the extension of the aneurysm tips (Fig. 2C2). Clips were removed one by one and repositioned more deeply. Control 3D-iDSA revealed complete occlusion of the aneurysm (Fig. 2C3).

Case 4: Parent Vessel Impairment Resolved by Clip Repositioning

In this 54-year-old patient, preoperative four-vessel DSA showed a large fetal posterior communicating artery (PCoA) variant as the primary supply to the posterior cerebral artery. The neck of the ruptured aneurysm originated solely off the PCoA itself, a few millimeters off the internal carotid artery (Fig. 2D1). Although visual inspection, Doppler ultrasonography, and ICGVA demonstrated complete aneurysm occlusion, assessment of the parent artery was limited within the deep operative field of this true PCoA aneurysm. Hemodynamically relevant stenosis was detected by 3D-iDSA (Fig. 2D2). Clip repositioning resulted in preservation of the parent artery (Fig. 2D3).

Discussion

In our retrospective review of 120 patients with IAs who underwent clipping in a hybrid operating room, comparable accuracy was afforded by routine use of 3D-iDSA and ICGVA to assess the completeness of IA occlusion and preservation of parent artery patency. Despite the overall low 6% discordance rate that then necessitated clip repositioning, ICGVA inspection of clipped IAs located at the ACoA complex seems to be especially at risk for false-negative outcomes. 3D-iDSA delivered optimal assessment of the angioarchitecture even in complex multi-clip reconstructions. Our study advances the understanding first established by the few earlier comparative studies on this subject, which used portable DSA units to acquire images intraoperatively (Table 3).

Discussion about the risk and benefit of iDSA remains inconclusive. Since the introduction of ICGVA with its negligible risk of procedural complication,³⁴ the debate has been complex, and the value of various intraoperative vessel imaging modalities remains elusive. In many studies that benchmarked ICGVA with postoperative DSA,^{4,10,18,33,43}

accuracy rates were similar to those reported when comparing intraoperative and postoperative DSA.^{5,22,28,30,39} One could argue that ICGVA is nearly as accurate as DSA for intraoperative determination of completeness of aneurysm occlusion and parent artery patency. However, in studies in which patients undergo both ICGVA and intraoperative DSA, discordance rates between the two modalities ranged from 2% to 14%.^{4,10,18,43} Although this rate varied depending on the definition of “concordant results,” discordance was often considered clinically significant when clip adjustment was needed. At times, neck remnants or vessel occlusion is present (and can be visualized by intraoperative DSA but not ICGVA) that cannot be corrected by clip repositioning or wrapping. In these cases, managing intraoperative and early postoperative hemodynamics can still improve patient outcomes. Accordingly, in our study limited to the detection of false-negative findings that necessitated surgical intervention, the 6% ICGVA–iDSA discordance rate was relatively low. If all inconsistent findings between ICGVA and 3D-iDSA (including smallest dog-ear remnants) had been recorded, the discordance rate would likely have been much higher.

Another complexity in evaluating the efficacy and accuracy of ICGVA and iDSA is that no study has directly and univocally compared the two modalities. Caplan and colleagues have compared ICGVA plus iDSA with iDSA alone and reported 10.8% (18.9% if iDSA had also detected the findings of prior ICGVA) of clip adjustments in the ICGVA-plus-iDSA group and 11.7% of clip repositioning in the iDSA-alone group.⁴ Accordingly ICGVA did not significantly reduce the rate of clip adjustment after routine iDSA when compared to iDSA alone (10.8% vs 11.7%) but resulted in a remarkable risk reduction (18.9% vs 10.8%) for clip misplacement within the combined ICGVA-plus-iDSA group.

This study exemplifies the difficulty in interpreting results when the sequence and method themselves mutually influence one other. With ICGVA as an extraordinarily quick and simple intraoperative assessment, the initial clipping strategy may be less aggressive, which increases the likelihood of positive findings and thus an overestimated value of ICGVA. One could also argue that knowing iDSA will follow ICGVA may lead to a less-than-diligent interpretation of ICGVA, increase discordance, and therefore underestimate the accuracy of ICGVA. In the most comprehensive prospective comparison of various intraoperative vascular monitoring techniques in 2011, Gruber et

FIG. 2. Illustrative cases in which 3D-iDSA provided relevant surgical information that remained undetected after visual inspection, Doppler ultrasonography, and ICGVA. **A:** Aneurysm remnant treated by additional clip: 3D-iDSA revealed a residual aneurysm remnant beneath the tips of the clip blades (A2; arrow). After applying an additional curved clip, repeat 3D-iDSA demonstrated complete aneurysm obliteration (A3; arrow). **B:** Aneurysm remnant treated by wrapping: 3D-iDSA revealed a slight bulging beneath the middle portion of the clip (B2; arrow). Although clip repositioning was unlikely to improve the surgical result, the aneurysm remnant could be circumferentially wrapped (B3; arrow). **C:** Aneurysm remnant treated by clip repositioning: 3D-iDSA demonstrated significant residual aneurysm filling in the extension of the aneurysm tips (C2; arrow). Each clip was removed and repositioned more deeply to completely occlude the aneurysm (C3; arrow). **D:** Parent vessel impairment resolved by clip repositioning: after hemodynamically relevant stenosis was detected by 3D-iDSA (D2; arrow), the clip was repositioned, and the parent artery preserved (D3; arrow). Figure is available in color online only.

TABLE 3. Literature comparing ICGVA to iDSA

Authors & Year	No. of Patients	% of Cohort w/ ICGVA & iDSA	% of Post-ICGVA Clip Adjustment	% Correspondence Btwn ICGVA & iDSA
Raabe et al., 2005*	62	84 (62/74)	9 (10/110)	90 (54/60)
Gruber et al., 2011*	104	100 (104/104)	6 (7/123)	98 (120/123)
Washington et al., 2013*	49	32 (49/155)	4 (2/49)	86 (42/49)
Caplan et al., 2014*	37	36 (37/97)	8 (3/37)	89 (33/37)
Defillo et al., 2014*	230	98 (230/235)	6 (13/230)	96 (221/230)
Present study†	120	86 (120/140)	11 (13/120)	94 (113/120)

* The authors used a portable DSA unit.

† Surgeries performed in a hybrid operating room.

al. included Doppler ultrasonography, ICGVA, iDSA, endoscopy, and electrophysiological monitoring. The authors concluded that the value of each tool cannot be considered separately; rather, the combination of adjuncts will perform better than the best single tool.¹⁸ Furthermore, some of the assessment methods have distinct advantages, such as the ability of ICGVA to clearly assess blood flow of visible small perforating vessels. Even the best iDSA quality lacks this resolution in the submillimeter range.^{9,33}

While visual inspection, Doppler ultrasonography, and ICGVA are performed in a relatively straightforward manner, iDSA demands greater technical efforts. This has prompted various authors to search for predictors when iDSA would be most needed. However, the great variety of the angioarchitecture of each aneurysm makes prediction of selective use of iDSA very difficult, even in seemingly simple cases.^{22,42} Prospective assessment of selective iDSA revealed that clip adjustments are needed in 4.4% of patients in whom iDSA was thought to be unnecessary. Based on the low iDSA complication rate, Klopfenstein et al. concluded that iDSA should be considered in the majority of cases.²² In a 2016 prospective study, Washington et al. confirmed that the surgeon's prediction of the necessity of intraoperative angiography is not accurate enough to justify its use on a selective basis only.⁴² Both preoperative and immediate postclipping assessment resulted in false-negative rates of 8% and 6%, respectively. With the decreasing exposure and experience to open IA surgery, it is unlikely that the surgeon's judgment will improve. Rather, information from iDSA will gain in value.

Taken together, the frequency of false-negative findings on ICGVA,^{4,8,19,24,27,29,35,36,41,43} the high rate of unexpected findings on iDSA,^{5,22,28,30,39} and the difficulty in predicting which subgroups of patients are most likely to have surgical difficulties^{8,22,42} highlight the need for unselected quality control in IA surgery. Although iDSA represents the gold standard of care,^{7,22,33,34,39} its imaging quality cannot yet supplant postoperative DSA, thereby forcing clinicians to carefully balance its risk (0.4%–0.99% in more recent large series^{3,39}) and benefit. The inferiority of iDSA is attributed mainly to suboptimal fluoroscopic visibility and nonstandard patient positioning.²¹ Its false-negative findings arise from small remnants often obscured by surrounding vessels compared with the best projections of postoperative DSA. However, multiplanar 3D-DSA virtually rotates the clipped IA complex in any direction, ob-

viating the need for a specific projection and minimizing interference with clip mass or adjacent vessels (Fig. 3).

Accumulating evidence suggests that 3D-DSA is superior to conventional DSA in terms of evaluating IA morphology and parent artery configuration and in detecting residual IA after clipping.^{2,20,23,38,40,44} When compared with 3D-DSA, Kang et al. reported that conventional DSA, even when optimized by rotation angiograms, depicted less than 50% of postoperative residual IA and 16% of dog-ear-like remnants.²⁰ Ahn and Kim reported a nearly double postclipping IA remnant detection rate of 19.3% for 3D-DSA versus 10.9% for 2D-DSA.² Noninvasive postoperative CTA demonstrated excellent accuracy in the evaluation of uncomplicated IAs of the anterior circulation, and it replaced routine use of 2D-DSA in many neurosurgical centers.^{6,8,11} Whether postoperative optimized CTA also poses a challenge to the current gold standard of 3D-DSA remains a matter of debate.^{15,16,31} To date, DSA is still considered the most accurate technique for assessing clipped aneurysms,²⁵ and some authors insist on routine use of postoperative 3D-DSA to validate the surgical result after aneurysm clipping.¹

We have confirmed excellent imaging quality and unrestricted viewing angles of 3D-iDSA, immediately evaluating the completeness of IA occlusion and the patency of parent arteries, even in complex multiclip reconstructions. Routine intraoperative 3D visualization of the clipped IA optimized our understanding of the angioarchitecture and facilitated decision making and strategy for intraoperative improvement of the surgical result if needed. In our institution, 3D-iDSA has replaced the postoperative modality as quality control and serves as a baseline for lifelong follow-up of the clipped IA in these patients.

Conclusions

Our study confirms the great utility of both ICGVA and 3D-DSA for intraoperative assessment of the surgical result after IA clipping, corroborating earlier findings that these techniques are complementary rather than competitive. Despite its relatively low discordance rate, iDSA is the confirmed gold standard regarding surgical outcome. Improved iDSA quality in a hybrid operating room, including the capacity of 3D-iDSA to supplant postoperative DSA, supports its routine use in IA surgery. With the increased prevalence of hybrid operating rooms deliver-

FIG. 3. Intraoperative vascular monitoring by visual inspection, ICGVA, and 2D- and 3D-iDSA. Although visual inspection before and after aneurysm clipping (**A**) and ICGVA (**B**) confirmed complete aneurysm occlusion, the best 2D-iDSA projection (**C**) suggested a false-negative finding (**C**; arrow). In this case of a deep-seated aneurysm located on the ACoA complex, the ICGVA's angle of vision limits visualization of the part of the base behind the clipped aneurysm. Multiplanar 3D-iDSA (**D**) completes intraoperative assessment with virtual rotation of the clipped aneurysm complex in any direction; aneurysm remnants (arrow) detected that were not visible in the surgical field. An = aneurysm; LA1 = left proximal segment of ACA; LA2 = left distal segment of ACA; RA1 = right proximal segment of ACA; RA2 = right distal segment of ACA. Figure is available in color online only.

ing high-quality 3D imaging, our study serves as a base to compare the results of future studies.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Marbacher, Fandino. Acquisition of data: Mendelowitsch. Analysis and interpretation of data: Marbacher, Mendelowitsch, Grüter. Drafting the article: Marbacher, Mendelowitsch, Diepers. Critically revising the article: Marbacher, Fandino. Reviewed submitted version of manuscript: Marbacher, Grüter, Diepers, Remonda, Fandino. Statistical analysis: Marbacher. Administrative/technical/material support: Remonda, Fandino. Study supervision: Fandino.

Correspondence

Itai Mendelowitsch: Kantonsspital Aarau, Switzerland. itai.mendelowitsch@ksa.ch.