Value of 3-Dimensional Digital Subtraction Angiography for Detection and Classification of Intracranial Aneurysm Remnants After Clipping

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BACKGROUND: The current gold standard for evaluation of the surgical result after intracranial aneurysm (IA) clipping is two-dimensional (2D) digital subtraction angiography (DSA). While there is growing evidence that postoperative 3D-DSA is superior to 2D-DSA, there is a lack of data on intraoperative comparison.

OBJECTIVE: To compare the diagnostic yield of detection of IA remnants in intra- and postoperative 3D-DSA, categorize the remnants based on 3D-DSA findings, and examine associations between missed 2D-DSA remnants and IA characteristics.

METHODS: We evaluated 232 clipped IAs that were examined with intraoperative or postoperative 3D-DSA. Variables analyzed included patient demographics, IA and remnant distinguishing characteristics, and 2D- and 3D-DSA findings. Maximal IA remnant size detected by 3D-DSA was measured using a 3-point scale of 2-mm increments.

RESULTS: Although 3D-DSA detected all clipped IA remnants, 2D-DSA missed 30.4% (7 of 23) and 38.9% (14 of 36) clipped IA remnants in intraoperative and postoperative imaging, respectively (95% CI: 30 [12, 49] %; *P*-value .023 and 39 [23, 55] %; *P*-value = <.001), and more often missed grade 1 (< 2 mm) clipped remnants (odds ratio [95% CI]: 4.3 [1.6, 12.7], *P*-value .005).

CONCLUSION: Compared with 2D-DSA, 3D-DSA achieves a better diagnostic yield in the evaluation of clipped IA. Our proposed method to grade 3D-DSA remnants proved to be simple and practical. Especially small IA remnants have a high risk to be missed in 2D-DSA. We advocate routine use of either intraoperative or postoperative 3D-DSA as a baseline for lifelong follow-up of clipped IA.

KEY WORDS: Intracranial aneurysm, Intraoperative, postoperative, Three-dimensional digital subtraction angiography, Aneurysm remnant, Clipping, Hybrid operating room

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Among many proposed intracranial aneurysm (IA) clip remnant grading schemes available today, all are based on two-dimensional (2D) digital subtraction angiography (DSA) and the clinical relevance of these classifications is not apparent for risk stratification of recurrence and rebleeding.[1] Notably, the risk for rebleeding from residual or recurrent IA after clipping is significant higher than for de novo IA and 30 times higher compared to the general population.[2,3]

Considering these serious consequences, it is important to achieve the highest possible detection rate of IA remnants after clipping. Although 2D-DSA remains the gold standard to evaluate the surgical result of IA clipping,[4] evidence is mounting for the superior detectability of postoperative 3D-DSA, especially for small (<2 mm) remnants.[5-8] Comparative data on intraoperative detectability and a reliable consistent method to characterize and size aneurysmal remnants is missing.

ABBREVIATIONS: VRT, volume rendering technique

In this study of prospectively collected data of a cohort who underwent IA clipping, we determine the diagnostic yield for remnant detection by comparing 2D-DSA with their intraoperative and postoperative 3D-DSA results; describe our method to quantify the remnant based on 3D-DSA findings; and identify if any aneurysmal characteristics

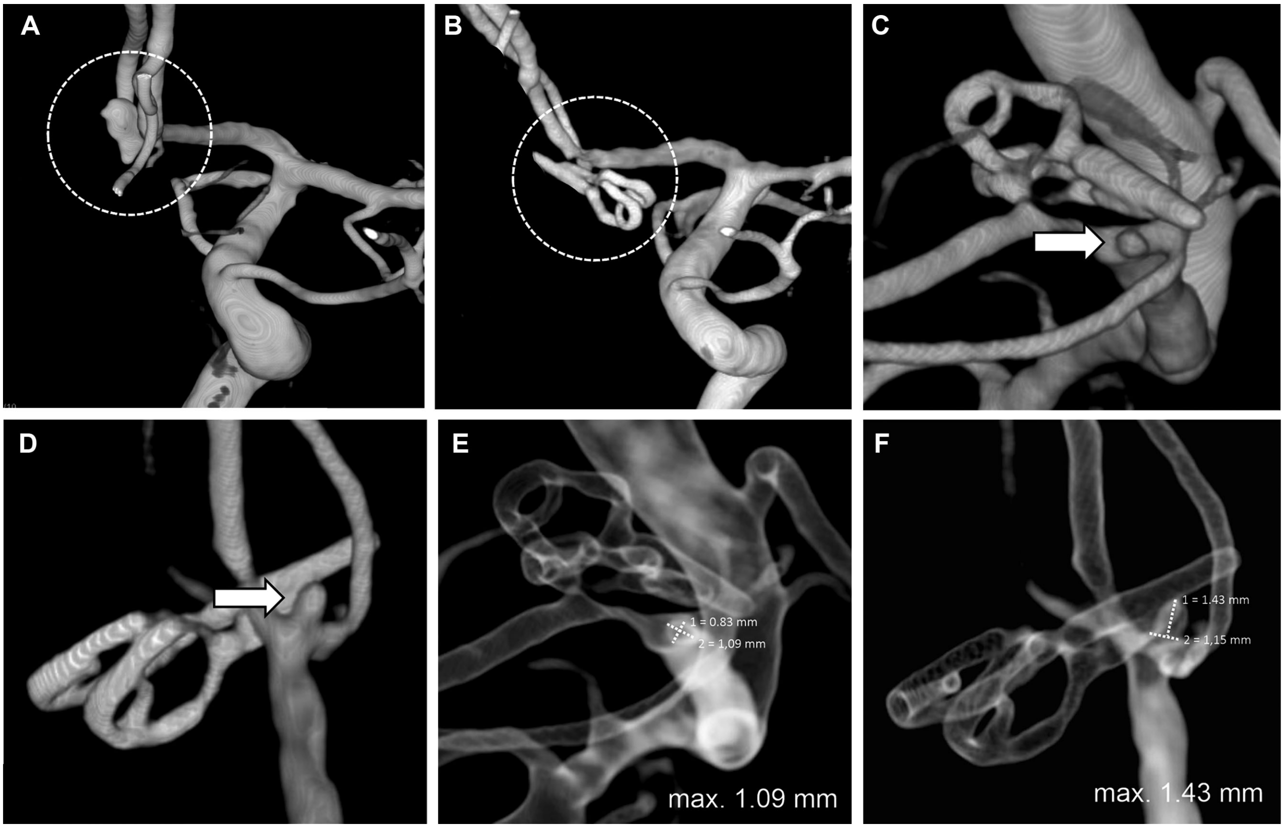

FIGURE 1. *3D-DSA remnant measurement. Surgical result assessed on multiplanar 3D rotational pre-* **A** *and postclipping* **B** *angiography with VRT reconstructions. In case of a remnant, the vascular complex of the clipped IA and parent artery is rotated to the projection of the remnant neck plane aligned in top* **C** *and side* **D** *view. Maximal diameter of remnant height, width, and neck are measured on translucent mode images* **E**, **F**.

themselves might impair the effectiveness of 2D-DSA in detecting remnants.

METHODS

We reviewed our prospectively collected data for 192 consecutive patients who underwent craniotomy and IA clipping and either intraoperative 3D-DSA or postoperative 3D-DSA or both between November 2012 and December 2018. Patient consent was not required for this data analysis. The study was approved by our Institutional Review Board and the Swiss ethics commission (EKNZ Nr.2017-001 671).

Clinical Protocol

All patients who underwent microvascular ligation were exclusively treated with pure titanium clips (Yasargil aneurysm clips, Aesculap AG, Tuttlingen, Germany) and routine multimodal vascular monitoring (ie, visual inspection, Doppler sonography, indocyanine green angiography, 2D- and 3D-iDSA) was performed in a hybrid operating room.[9-11] Any positive finding in intraoperative DSA underwent immediate verification and if the clip(s) needed adjustment the protocol was repeated. In 22 patients in whom the hybrid operating room was not available for logistical reasons, intraoperative DSA was not performed. Postoperatively patients with completely clipped aneurysms confirmed by 3D-DSA underwent follow-up imaging with computed tomography angiography or magnetic resonance angiography at 5, 10, and 20 yr after clipping.[3] Patients with IA remnants that could not be corrected or treated by intraoperative clip repositioning underwent postoperative noninvasive baseline and early follow-up imaging at one year postsurgery. Additional 3D-DSA was only applied to verify uncertainties on noninvasive follow-up imaging.

Pre-, Intra-, and Postoperative DSA

The equipment and setting of our hybrid operating room were described previously.[10-12] The 3D-RAvolumetric sequence was used to

TABLE 1. **3D-DSA Grading Scale**

Grade	Maximum remnant size (mm)[a]
0	Complete occlusion
1	<2.00
2	>2.00 to 4.00
3	>4.00

[a] Size measured perpendicular to the remnant neck plane aligned in top and side view.

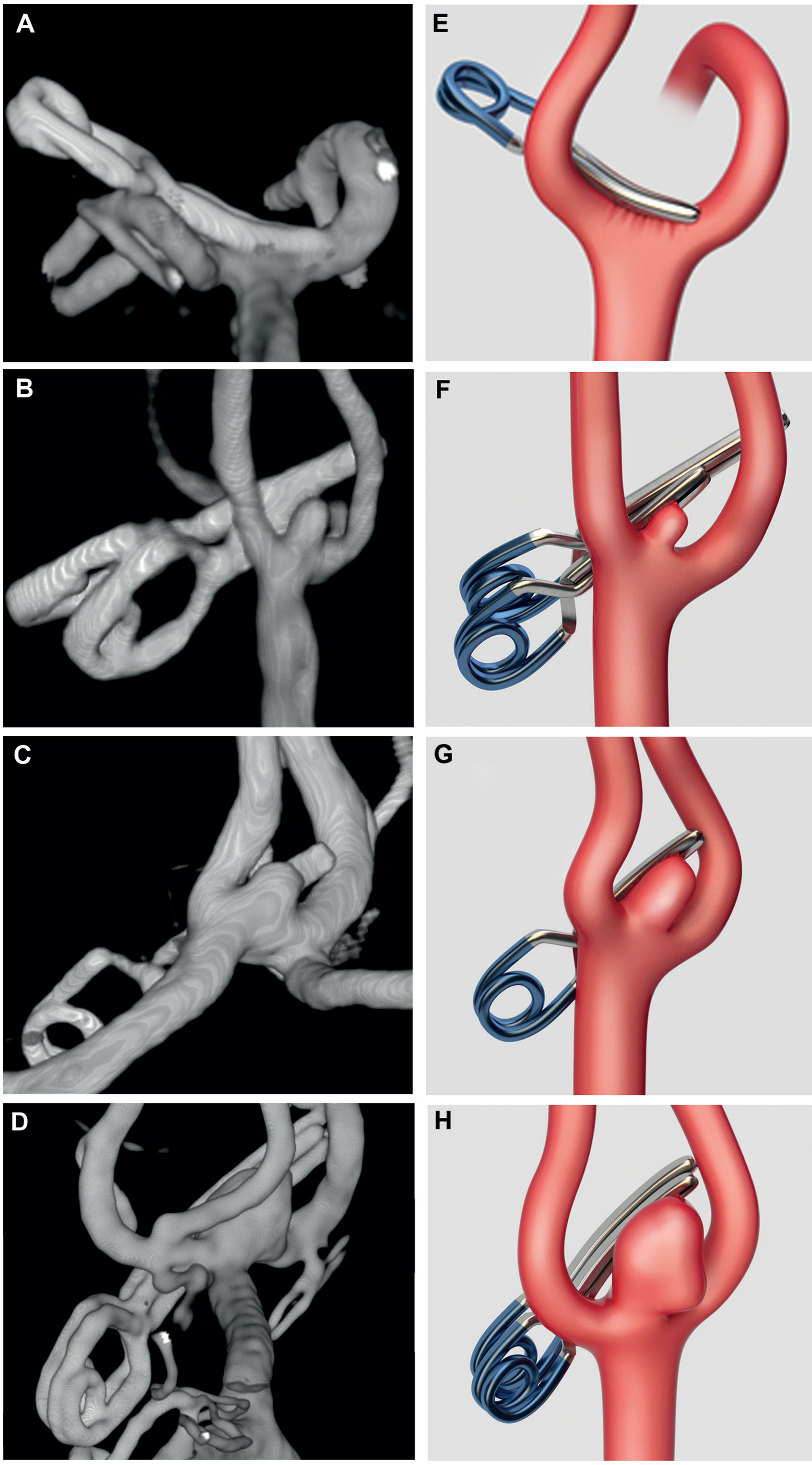

FIGURE 2. *Proposed 3D-DSA grading system. 3D-DSA grade is a measurement reflecting the maximal remnant size.* **A-D**, *3D-DSA images and corresponding illustrations demonstrate grades 0* **E**, *grade 1* **F**, *grade 2* **G**, *and grade 3* **H** *remnants after IA clipping, respectively. Scoring criteria are listed in Table 1.*

reconstruct 3D angiographic and multiplanar data sets. Transparent volume rendering technique (VRT) reconstructions were rendered to determine morphological characteristics in respect of the neck plane to the aneurysm parent artery (Integris 3D-RA Version 6.4.20, Philips Medical Systems, Best, the Netherlands).

Analysis of Aneurysm Remnants

All neuroradiological images were reviewed by M.H., who was not blinded for clinical information. The examiner assessed the clipped aneurysm complex to identify any remnant, initially by 2D-DSA and then on 3D-DSA. In case of uncertainties, the images were reviewed later and discussed with a senior neuroradiologist (L.R., M.D., J.A.). None of these examiners were allowed to postprocess images or to take additional screenshots of 3D-DSA projections other than those taken at the time of the examination. Detected 2D-DSA remnants were categorized according to Sindou's classification and dichotomized as small or large (≥2 mm) remnants.[13]

On 3D-RA and VRT translucent mode images, the IA morphology was assessed in greater detail to obtain remnant dimensions of maximal diameter of height, width, and neck (specified to 2 decimal places). For these measurements, the reviewing neuroradiologist rotated the vascular complex of the parent artery and clipped IA to the direction of the remnant neck plane aligned in top and side view VRT reconstructions (Figure 1). Remnants were graded according to the maximal diameter of height, width, or neck measured in 2-mm increments as follows: 0 = complete occlusion, 1 = size < 2 mm, 2 = size 2 to 4 mm, and 3 = size > 4 mm (Table 1 and Figure 2).

Statistical Analysis

All analyses were conducted using the statistical software package R (R Core Team, 2019), 3.6.0, using 2-sided statistical tests. No adjustment for multiple testing has been made.

The primary outcome was detection of remnant using intraoperative DSA (n = 23 patients). We compared the primary outcome between 2D-iDSA and 3D-iDSA using Mc Nemar's Chi-squared test. Missing of remnant with 2D-DSA was analyzed for an association with remnant size and use of multiple clips, using multivariable logistic regression.

RESULTS

Patient and Aneurysm Characteristics

In total 232 of 319 identified IAs were clipped using a total of 346 clips in 192 patients. Of these patients (full analysis set) 143 patients received intraoperative DSA only, 27 patients received both intraoperative and postoperative DSA, and 22 patients received postoperative DSA only. Intraoperative verification of remnants detected in 3D-DSA revealed no false-positive findings. There were no associated complications with preoperative and intraoperative DSA. One patient experienced a groin hematoma and one patient an asymptomatic common carotid artery dissection during postoperative DSA. The overall complication rate of pre-, intra- and postoperative 2D- and 3D-DSA was 0.5% (2/406). The remnant analysis set comprised 45 patients with a clipped IA remnant. Of these, 23 patients received intraoperative DSA, 36 patients postoperative DSA, and 14 patients intraoperative and postoperative DSA.

Of all 192 patients, 46% (89/192) presented with ruptured IA (62% [28/45] in patients with remnant, 42% [61/147] in patients without remnant) and 52% (99/192) required more than one clip for IA occlusion (60% [27/45] in patients with remnant, 49% [72/147] in patients without remnant). Patient and IA characteristics are presented overall and according to whether patients had a postclipping IA remnant or not (Table 2).

Diagnostic Yield of 3D- and 2-DSA for Detection of Clipped IA Remnants

Of the 232 clipped IAs, 187 (81%) demonstrated complete occlusion (grade 0) by either intraoperative or postoperative 3D-DSA. Of the 45 (19%) IAs confirmed by 3D-DSA to have a remnant, remnants were <2 mm (grade 1) in 12 (27%) aneurysms, 2 to 4 mm (grade 2) in 19 (42%) aneurysms, and >4 mm (grade 3) in 14 (31%) aneurysms. However, imaging with 2D-DSA missed 17 (38%) of these 45 remnants detected by 3D-DSA. Intraoperative and postoperative 3D-DSA detected 6 of 23 (26%) and 13 of 36 (36%) more clipped IA remnants than 2D-DSA (difference in proportions [95% CI] 3D-DSA—2D-DSA: 30 [12, 49]%, P-value = .023 intraoperatively and 39 [23, 55]%, P-value = <.001 postoperatively). In subgroup analysis, 2D-DSA missed 10 (83%) of 12 small (grade 1 <2 mm) IA remnants, 6 (32%) of 19 grade 2 remnants, and none of the 14 grade 3 remnants. One-year follow-up was available for 77% (140/181) and 84% (38/45) of IA completely clipped and with a remnant, respectively. None of the completely occluded IA showed recurrence (0%) and only one of the incompletely clipped IA demonstrated remnant growth (2.6%).

Associations of 2D-DSA Remnant Missing

Use of 2D-DSA in 16 cases likely missed detection because the remnant was small in 7 (44%), hidden by multiple clips in 6 (38%), or had complex angioarchitecture (ie, overlapping cerebral arteries) in 3 cases (19%); 4 cases had multiple factors (ie, small size or hidden by clip plus complex angioarchitecture). Specifically, compared with 3D-DSA, 2D-DSA studies more often missed remnants <2 mm (odds ratio [OR] [95% CI]: 4.3 [1.6, 12.7], P-value = .005) Our data remain inconclusive whether the use of multiple clips or IA location affect missing of remnants with 2D-DSA (OR [95% CI]: 2.58 [0.14, 15.12], P-value = .38). Location of the 16 remnants not detected by 2D-DSA were at the MCA in 8 (50%), AComA in 7 (44%), and ICA location in 1 (6%). Examples and detailed characteristics of aneurysm remnants missed on 2D-DSA appear in Figure 3 and Table 3, respectively.

DISCUSSION

In our cohort of 192 consecutive patients who underwent IA clipping, diagnostic yields for remnant detection demonstrated that both intraoperative and postoperative 3D-DSA were more

TABLE 2. Patient and IA Characteristics

Variable	Overall	No remnant	Remnant	*P* value
Number of patients	192	147	45	
Female sex	122 (63.5)	95 (64.9)	27 (60.0)	.699
Age at intervention (years)	54.3 (12.0)	54.9 (10.7)	52.4 (15.5)	.218
Ruptured IA	89 (46.4)	61 (41.5)	28 (62.2)	.023
WFNS score				.392
1	43 (48.3)	27 (44.3)	16 (57.1)	
2	20 (22.5)	15 (24.6)	5 (17.9)	
3	10 (11.2)	6 (9.8)	4 (14.3)	
4	11 (12.4)	10 (16.4)	1 (3.6)	
5	5 (5.6)	3 (4.9)	2 (7.1)	
Fisher score				.237
1	6 (6.8)	2 (3.3)	4 (14.8)	
2	8 (9.1)	6 (9.8)	2 (7.4)	
3	18 (20.5)	12 (19.7)	6 (22.2)	
4	56 (63.6)	41 (67.2)	15 (55.6)	
Number of IA				.012
1	115 (59.9)	78 (53.1)	37 (82.2)	
2	48 (25.0)	42 (28.6)	6 (13.3)	
3	15 (7.8)	14 (9.5)	1 (2.2)	
4	6 (3.1)	6 (4.1)	0 (0.0)	
5	8 (4.2)	7 (4.8)	1 (2.2)	
Number of clipped IA				.108
1	161 (83.9)	118 (80.3)	43 (95.6)	
2	26 (13.5)	24 (16.3)	2 (4.4)	
3	3 (1.6)	3 (2.0)	0 (0.0)	
5	2 (1.0)	2 (1.4)	0 (0.0)	
Multiple clipped IA	31 (16.1)	29 (19.7)	2 (4.4)	.027
Number of clips per IA				.405
1	93 (48.4)	75 (51.0)	18 (40.0)	
2	65 (33.9)	48 (32.7)	17 (37.8)	
>2	34 (17.7)	24 (16.3)	10 (22.2)	
IA size				.05
<7 mm	141 (73.4)	113 (76.9)	28 (62.2)	
7 to < 13 mm	46 (24.0)	32 (21.8)	14 (31.1)	
13 to < 24 mm	5 (2.6)	2 (1.4)	3 (6.7)	
IA neck size				.127
<2 mm	11 (5.7)	10 (6.8)	1 (2.2)	
2 to < 4 mm	110 (57.3)	89 (60.5)	21 (46.7)	
4 to < 6 mm	54 (28.1)	36 (24.5)	18 (40.0)	
>6 mm	17 (8.9)	12 (8.2)	5 (11.1)	
IA shape				.335
Blister	2 (1.0)	2 (1.4)	0 (0.0)	
Fusiform	10 (5.2)	6 (4.1)	4 (8.9)	
Saccular	180 (93.8)	139 (94.6)	41 (91.1)	
Polylobulated IA	57 (29.7)	42 (28.6)	15 (33.3)	.671
Calcified IA	37 (19.3)	30 (20.4)	7 (15.6)	.613
IA location				.103
ICA	15 (7.8)	11 (7.5)	4 (8.9)	
A1ACA	1 (0.5)	1 (0.7)	0 (0.0)	
AComA	62 (32.3)	42 (28.6)	20 (44.4)	
PrcA	4 (2.1)	3 (2.0)	1 (2.2)	
MCA	94 (49.0)	78 (53.1)	16 (35.6)	
PcomA	10 (5.2)	9 (6.1)	1 (2.2)	
BA	2 (1.0)	0 (0.0)	2 (4.4)	
PCA	3 (1.6)	2 (1.4)	1 (2.2)	
PICA	1 (0.5)	1 (0.7)	0 (0.0)	

TABLE 2. Continued				
Variable	Overall	No remnant	Remnant	*P* value
IA location categorized				.204
ACA	67 (34.9)	46 (31.3)	21 (46.7)	
ICA	15 (7.8)	11 (7.5)	4 (8.9)	
MCA	94 (49.0)	78 (53.1)	16 (35.6)	
posterior	16 (8.3)	12 (8.2)	4 (8.9)	
Intraoperative vasospasm	20 (10.4)	15 (10.2)	5 (11.1)	1
Number of projections (2D-iDSA)				.052
3	136 (80.0)	111 (82.8)	25 (69.4)	
4	27 (15.9)	20 (14.9)	7 (19.4)	
5	6 (3.5)	3 (2.2)	3 (8.3)	
6	1 (0.6)	0 (0.0)	1 (2.8)	
Number of projections (2D-pDSA)				.083
3	22 (44.9)	13 (50.0)	9 (39.1)	
4	12 (24.5)	7 (26.9)	5 (21.7)	
5	7 (14.3)	5 (19.2)	2 (8.7)	
6	8 (16.3)	1 (3.8)	7 (30.4)	

IA = intracranial aneurysm; ICA = internal carotid artery; A1ACA = A segment of ACA; AComA = anterior communicating artery; PrcA = pericallosal artery; MCA = middle cerebral artery; PComA = posterior communicating artery; BA = basilar artery; PCA = posterior cerebral artery; PICA = posterior inferior cerebellar artery; DSA = digital subtraction angiography.

sensitive than conventional 2D-DSA. First, 3D-DSA detected 38% more clip remnants overall than 2D-DSA and 83% more by subgroup of remnants < 2 mm, confirming with multivariate analysis evidence that these grade 1 remnants were more likely missed with 2D-DSA. Second, our method to measure and grade remnants based on their maximal 3D-DSA diameter proved to be simple and practical.

In preoperative diagnostics, 3D-DSA has long established itself as superior to conventional 2D-DSA and rotational DSA. Compared with 2D-DSA, 3D-DSA achieved lower radiation doses, reduced amount of contrast agent, and shorter examination times, and yielded significantly more detected aneurysms and more precise visualization of vascular anatomy.[14-17] Consistent with the literature we assume that the high proportion of multiple IA in our study reflects the improved IA detection rate by routine use of preoperative 3D-DSA. In contrast to preoperative diagnostics, there is still no consensus regarding the ideal imaging strategy for peri- and postoperative evaluation of the surgical result after clip placement.[18,19] One of the largest series of an unselected patient cohort with clipped IAs demonstrated that even when surgeons are competent and have extensive experience with IA surgery, patients should undergo postoperative DSA, since unexpected findings are observed in up to one-sixth of patients.[20]

The few studies examining the diagnostic yield of 3D-DSA have all been performed postoperatively (Table 4). Without intraoperative verification it is not possible to differentiate whether a suspected remnant in 3D-DSA is indeed a remnant or a false positive finding. Our results confirm for the first time that the high sensitivity of 3D-DSA is real and not based on false-positive findings. Despite the large numbers of missed remnants in intra- and postoperative 2D-DSA, it remains difficult to evaluate the true diagnostic yield of 3D-DSA, because knowledge that 3D-DSA will follow 2D-DSA may result in a less aggressive strategy to assess 2D-DSA projections. Nowadays, imaging quality in the hybrid OR equals that of the angiography suite and might explain the counterintuitive finding that remnants were even more frequently missed in postoperative than intraoperative 2D-DSA.

Until today IA clip remnants are classified on 2D-DSA images using a descriptive 2-tier (complete, incomplete) or 3-tier (complete occlusion, residual neck, and residual aneurysm) scale.[1] Differences between grades are often defined by the neck or overall size of the IA remnant (2 mm) and the proportion of the IA remnant size is compared with presurgical IA morphology (remnant ≤ or ≥50% or 75% of initial IA size).[1,21,22] Considering that >80% of small remnants (<2 mm) are missed in 2D-DSA precise discrimination between IA recurrence at the site of the clipped IA and remnant growth is virtually impossible. Long-term follow-up studies based on 3D-DSA data would be necessary to determine the true risk of recurrence for completely clipped IA and the risk of recurrence and rupture for small (<2 mm) IA remnants.

Controversies persist about whether there is an association between the size of a clipped IA remnant and risk of regrowth or hemorrhage.[23-26] A more benign prognosis of a clipped remnant may not necessarily relates to its size.[23,26] An increasing body of evidence suggests that pathobiological factors, other than remnant size, play an important role for risk stratification of the natural course of a clipped IA remnant.[27] Intentional remnants, for

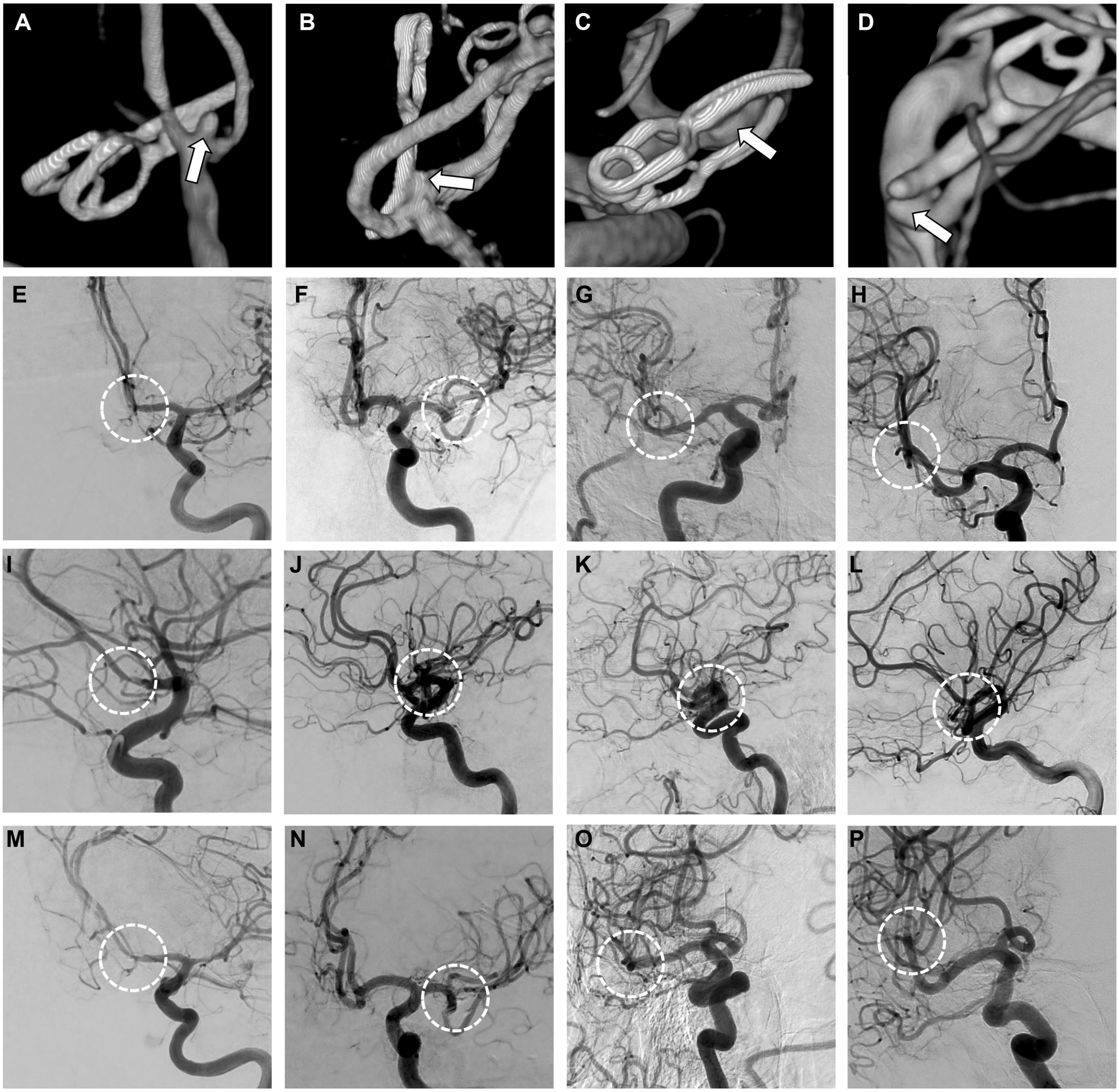

FIGURE 3. *3D-DSA remnants missed in 2D-DSA. Left to right: 3D-DSA* **A-D** *and antero-posterior* **E-H**, *lateral* **I-L**, *and oblique* **M-P** *2D-DSA projections. Reasons for missing an IA remnant on 2D-DSA and 3D-DSA were small remnant size* **A**, *complex angioarchitecture with overlapping parent arteries* **B**, *hiding by single or multiple clips* **C**, *or a combination of these factors* **D**.

example preservation of a branch or perforating artery, seem to be benign compared with the unintentional remnants.[23] Young age and positive rupture status are predisposing risks for IA recurrence and remnant growth after clipping.[23,28-30] Therefore, clinically meaningful risk stratification might include more than only remnant size as predictive measure.

Limitations

We have to acknowledge potential sources of bias associated with this study. First, although the examiner MH assessed the clipped aneurysm initially by 2D-DSA and only then on 3D-DSA the prospective nature of the evaluation prevented blinding of clinical information. Second, image postprocessing

TABLE 3. IA Remnant Characteristics

Variable	Detected with 3D-DSA	Detected with 2D-DSA	Missed with 2D-DSA	*P* value
n	45	28	17	
Remnant 2D-DSA				< .001
<2 mm	20 (44.4)	3 (10.7)	17 (100)	
>2 mm	25 (55.6)	25 (89.3)	0 (0.0)	
Remant 3D-DSA				< .001
<2 mm	12 (26.7)	2 (7.1)	10 (58.8)	
2 to 4 mm	19 (42.2)	12 (42.9)	7 (41.2)	
>4 mm	14 (31.1)	14 (50.0)	0 (0.0)	
Sindou's classification				**na**
III	6 (21.4)	6 (21.4)	–	
IV	15 (53.6)	15 (53.6)	–	
V	7 (25.0)	7 (25.0)	–	
IA location				**.489**
ICA	4 (8.9)	3 (10.7)	1 (5.9)	
AcomA	20 (44.4)	13 (46.4)	7 (41.2)	
PrcA	1 (2.2)	1 (3.6)	0 (0.0)	
MCA	16 (35.6)	8 (28.6)	8 (47.1)	
PcomA	1 (2.2)	1 (3.6)	0 (0.0)	
BA	2 (4.4)	2 (7.1)	0 (0.0)	
PCA	1 (2.2)	0 (0.0)	1 (5.9)	
IA location categorized				.626
ACA	21 (46.7)	14 (50.0)	7 (41.2)	
ICA	4 (8.9)	3 (10.7)	1 (5.9)	
MCA	16 (35.6)	8 (28.6)	8 (47.1)	
Posterior	4 (8.9)	3 (10.7)	1 (5.9)	
Number of clips				.372
1	18 (40.0)	11 (39.3)	7 (41.2)	
2	17 (37.8)	9 (32.1)	8 (47.1)	
>2	10 (22.2)	8 (28.6)	2 (11.8)	
DSA timing				.568
Intra- and postoperative	14 (31.1)	10 (35.7)	4 (23.5)	
Intraoperative	22 (48.9)	12 (42.9)	10 (58.8)	
Postoperative	9 (20.0)	6 (21.4)	3 (17.6)	
Number of projections (2D-iDSA)				.413
3	25 (69.4)	14 (63.6)	11 (78.6)	
4	7 (19.4)	4 (18.2)	3 (21.4)	
5	3 (8.3)	3 (13.6)	0 (0.0)	
6	1 (2.8)	1 (4.5)	0 (0.0)	
Number of projections (2D-pDSA)				.028
3	9 (39.1)	5 (31.2)	4 (57.1)	
4	5 (21.7)	2 (12.5)	3 (42.9)	
5	2 (8.7)	2 (12.5)	0 (0.0)	
6	7 (30.4)	7 (43.8)	0 (0.0)	

IA = intracranial aneurysm; DSA = digital subtraction angiography; **- = no values**; **na = not applicable**; ICA = internal carotid artery; AComA = anterior communicating artery; PrcA = pericallosal artery; MCA = middle cerebral artery; PComA = posterior communicating artery; BA = basilar artery; PCA = posterior cerebral artery.

parameters may affected size measurements of 3D-DSA reconstructions. While we were able to actually verify clipped IA remnants found in intraoperative 3D-DSA, we cannot exclude false-positive findings in postoperative 3D-DSA.

CONCLUSION

The results provide further support that postoperative 3D-DSA has a better diagnostic yield than 2D-DSA in the evaluation of clipped IAs and suggest that 3D-DSA is also superior when used intraoperatively. 3D-DSA allows more precise visualization of smallest remnants irrespective of complexity of local angioarchitecture or number of clips. Our method of quantitative grading of 3D-DSA remnants based on the maximal remnant size proved to be simple and practical. The reproducibility of the proposed 3D-DSA clip remnant classification and its clinical implication need to be determined in future studies.

TABLE 4. Literature Comparing 3D- to 2D-DSA for Evaluation of Clipped IA Remnants

Authors (year)	Number of clipped IA	% of remnants on 2D-DSA	% of remnants on 3D-DSA	% of missed remnants on 2D-DSA	% of missed remnants <2 mm*
Kang et al (2004)	88	18.2 (16/88)	42.1 (37/88)	56.8 (21/37)	76 (19/25)
Ahn et al (2010)	202	10.9 (22/202)	19.3 (39/202)	43.6 (17/39)	73.6 (14/19)
Pedicelli et al (2013)	111	4.5 (5/111)	17.1 (19/111)	73.7 (14/19)	100 (0/14)
Kumar et al (2014)	54	53 (29/54)	66.7 (36/54)	19.4 (7/36)	85.7 (6/7)
Present study	232	12.5 (29/232)	19.4 (45/232)	37.7 (17/45)	83.3 (10/12)

IA = intracranial aneurysm; * = including small, dog-ear, and neck-only remnants.

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COMMENT

The authors presented a well-designed study to compare the diagnostic yield to detect remnants in clipped intracranial aneurysms (IA) using intra- and postoperative 2D-DSA and 3D-DSA. In their series, remnants were detected in 19% and 12% using 3D-DSA and 2D-DSA, and this was mainly the result of a better detection of small remnants with 3D-DSA. These results support the hypothesis that the diagnostic yield of 3D-DSA outperforms 2D-DSA for the evaluation of IA remnants.

This study underlines once more the importance of follow-up imaging of IAs following microsurgical clipping. Despite extensive surgeon's experience[1] and the inclusion of various technical evolutions like intraoperative Doppler or flow assessment, and intraoperative indocyanine green video-angiography, clipped IA remnants may occur. A recent systematic review and meta-analysis,[2] reported on a cumulative risk of 9.6%–22% for aneurysm recurrence or de novo formation 20 years after microsurgical clip ligation.[1] Therefore, future studies evaluating remnants after clipping and endovascular treatments using 3D-DSA would be highly interesting, particularly as previous studies reported a high risk for rebleeding from residual or recurrent clipped IAs. Research on factors associated with regrowth and rupture of clipped IA remnants could also benefit from the better diagnostic yield of 3D-DSA. However, in clinical practice a postoperative modern state-of-the-art CTA after using titanium clips is usually sufficient and reliable when used in combination of the above-mentioned other techniques. It has been used at our department already for more than 20 years pre- and postoperatively in non-complex aneurysms.[3]

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