

Optimized angiographic computed tomography with intravenous contrast injection: an alternative to conventional angiography in the follow-up of clipped aneurysms?

Clinical article

Philipp Göllitz, M.D.,¹ Tobias Struffert, M.D., Ph.D.,¹ Oliver Ganslandt, M.D., Ph.D.,² Marc Saake, M.D.,¹ Hannes Lücking, M.D.,¹ Julie Rösch, M.D.,¹ Frauke Knossalla, M.D.,³ and Arnd Doerfler, M.D., Ph.D.¹

Departments of ¹Neuroradiology, ²Neurosurgery, and ³Neurology, University of Erlangen-Nuremberg, Germany

Object. The purpose of this study was to evaluate the diagnostic accuracy of an optimized angiographic CT (ACT) program with intravenous contrast agent injection (ivACT) in the assessment of potential aneurysm remnants after neurosurgical clipping compared with conventional digital subtraction angiography (DSA).

Methods. The authors report on 14 patients with 19 surgically clipped cerebral aneurysms who were scheduled to undergo angiographic follow-up. For each patient, the authors performed ivACT with dual rotational acquisition and conventional angiography including a 3D rotational run. The ivACT and 3D DSA data were reconstructed with different imaging modes, including a newly implemented subtraction mode with motion correction. Thereafter, the data sets were merged by the dual-volume technique, and freely rotatable 3D images were obtained for further analysis. Observed aneurysm remnants were electronically measured and classified for each modality by 2 experienced neuroradiologists.

Results. Digital subtraction angiography and ivACT both provided high-quality images without motion artifacts. Artifact disturbances from the aneurysm clips led to a compromised, but still sufficient, image quality in 1 case. The ivACT assessed all aneurysm remnants as true-positive up to a minimal size of 2.6 × 2.4 mm in accordance with the DSA findings. There was a tendency for ivACT to overestimate the size of the aneurysm remnants. All cases without aneurysm remnants on DSA were scored correctly as true-negative by ivACT.

Conclusions. By using an optimized image acquisition protocol as well as enhanced postprocessing algorithms, the noninvasive ivACT seems to achieve results comparable to those of conventional angiography in the follow-up of clipped cerebral aneurysms. The authors have shown that ivACT can provide reliable diagnostic information about potential aneurysm remnants after neurosurgical clipping with high sensitivity and specificity, sufficient for clinical decision making, at least for aneurysms in the anterior circulation located distal to the internal carotid artery. These preliminary results may be a promising step to replace conventional angiography by a noninvasive imaging technique in selected cases after aneurysm clipping.

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Key Words • aneurysm clipping • follow-up imaging • angiographic computed tomography • noninvasive imaging • vascular disorders

The goal of cerebral aneurysm treatments, whether via a neurosurgical or an endovascular approach, is always complete aneurysm occlusion to minimize the risk of (re)bleeding. Recent studies have reported angiographic aneurysm remnants after microsurgical clipping in 2.3%–14% of patients.^{1,2,9,12,13,16,24} Thus, the postoperative evaluation after microsurgical aneurysm clipping aims to exclude a residual aneurysm neck or an aneurysm reperfusion as a potential source of (re)bleed-

ing.^{6,11} Relevant aneurysm remnants are considered an indication for retreatment.

Often, the noninvasive diagnostic workup of patients with clipped cerebral aneurysms causes problems in terms of imaging because of interfering metal artifacts through the clips. The compromised image quality can lead to limitations in the evaluation of aneurysm remnants. Thus, the gold standard for assessing the aneurysm remnants and visualizing the parent artery after clipping remains conventional angiography.^{26,29} However, disadvantages of conventional angiography are the associated

Abbreviations used in this paper: ACoA = anterior communicating artery; ACT = angiographic CT; CTA = CT angiography; DSA = digital subtraction angiography; ICA = internal carotid artery; MCA = middle cerebral artery; SAH = subarachnoid hemorrhage.

This article contains some figures that are displayed in color online but in black-and-white in the print edition.

costs and its invasiveness, although the complication rate can be considered low at experienced centers.⁷ Computed tomography angiography has continued to improve as a noninvasive method for aneurysm visualization after clipping, providing results comparable to those achieved using conventional angiography;^{3,4,10,14,25,27} however, CTA is not as accurate as DSA.^{5,23} Magnetic resonance imaging is still limited by severe susceptibility artifacts around the clips.²⁸

As a new method, ACT in combination with intravenous contrast agent injection (ivACT) has been introduced recently for visualization of intracranial vessels.²⁰ In particular, its higher spatial resolution in comparison with CT scanning might lead to improved image quality. Recently published data have shown limitations of ivACT in the assessment of aneurysm remnants after clipping because of metal artifacts.¹⁵ The aim of our study was to evaluate whether ivACT with an optimized acquisition protocol and improved postprocessing algorithms can achieve accuracy comparable to that of conventional angiography in the follow-up of clipped aneurysms.

Methods

Ethics committee approval was obtained before this study. A total of 14 patients (7 women and 7 men) with 19 clipped aneurysms were enrolled in our study. Nine patients had suffered an acute SAH, and 5 patients had an incidental aneurysm finding. The average age of the patient population was 57 ± 9 years (range 39–70 years). Thirteen aneurysms (68%) originated from the MCA, 5 aneurysms (26%) from the ACoA, and 1 aneurysm (5%) emanated from the A₂ segment of the anterior cerebral artery (Table 1). In total, 24 clips were used for treatment; 21 of them were cobalt alloy (Phynox, Aesculap) and 3 were titanium alloy (Sugita, Mizuho). The size of the implanted clips varied from 3.9 to 20 mm. For aneurysm occlusion in 3 cases, 2 clips were necessary, and in 1 case, 3 clips were necessary. In the remaining cases, only 1 clip was used for treatment. According to institutional guidelines, patients undergo reevaluation for aneurysm remnants by DSA including 3D rotational angiography within 6 months after surgery. For study involvement, we selected all patients scheduled for angiographic follow-up in our department during a period of 5 months if informed consent was obtained. The day after conventional angiography, we performed ivACT in every patient after the serum creatinine level was checked.

Digital Subtraction Angiography

Both DSA (including the 3D run) and ivACT were performed using a biplane flat-detector angiographic system (Axiom Artis dBA, Siemens AG Healthcare Sector). Using standard angiographic methods (via the transfemoral route), a diagnostic catheter was used to obtain standard posteroanterior and lateral projections (2D series). After this, 3D rotational angiography was performed using a standard 3D DSA program as provided by the manufacturer (5-second run, Siemens AG Healthcare Sector) with selective, 4-ml/second injection via the ICA using

TABLE 1: Distribution of aneurysm locations and number of clips used

Aneurysm Location	No. of Aneurysms (%)	No. of Clips Used
MCA	13 (68)	15
ACoA	5 (26)	8
A ₂	1 (5)	1

a power injector (MEDTRON). The angiographic data were transferred to a connected workstation (Leonardo, Siemens AG Healthcare Sector) for generating 3D, rotatable, dual-volume images by fusing the subtracted and the nonsubtracted reconstructions. Based on the 3D images, the best projections for the following targeted 2D series were determined. Such a control angiographic investigation of a single clipped aneurysm requires about 40 ml of contrast material (Imeron 300, Bracco Imaging).

Intravenous Angiographic CT

Angiographic CT in combination with simultaneous injection of contrast agent (ivACT) was performed the day after DSA. For image generation, we used a dedicated ACT program (10-second DynaCT, Siemens AG Healthcare Sector) with an unenhanced and a contrast-enhanced run. We applied the “bolus watching” technique,^{21,22} which allows the beginning of data acquisition exactly during arterial opacification. Therefore, 60 ml of contrast agent (Imeron 300, Bracco Imaging) was injected into an antecubital vein at a rate of 5 ml/second using a power injector (MEDTRON) followed by a saline chaser (60 ml, injection rate 5 ml/second). Data acquisition per run was carried out using the following parameters: acquisition time 10 seconds per run, 70 kV, 512×512 matrix, projection on 30×40 cm flat panel, 200° total angle, 0.8° /frame, 250 frames total, and dose 1.2 mGy/frame. For postprocessing, the data set was transferred to a commercially available workstation (Leonardo, Siemens AG Healthcare Sector).

Postprocessing and Image Analysis

Image reconstruction of the ivACT and of the 3D rotational run was performed using the mode “native mask,” kernel type “HU,” and image impression “sharp.” Using these settings, an excellent resolution of the aneurysm clips is achievable. Next, image reconstruction with the mode “subtraction with motion correction,” kernel type “HU,” and image impression “very smooth” was used to visualize the arteries. Using the newly implemented tool “motion correction,” an improved illustration of the cerebral vessels with diminished artifact disturbances can be gained. After that, the 2 reconstructed data sets were fused and loaded into the InSpace function of the workstation (dual-volume technique). Using the volume-rendering technique, freely rotatable 3D images were obtained.

These 3D data as well as the targeted 2D series of the DSA were anonymized and stored in random order. The DSA series were analyzed in the angiography mode of the workstation. The image evaluation of the ivACT

and the 3D rotational run was performed by loading the reconstructed data sets into the InSpace function of the workstation, respectively. Thus, a comparison of the 3D rotational run and the ivACT was possible.

All images were anonymously evaluated by 2 experienced neuroradiologists in consensus reading who were blinded to patient information. Measurements of aneurysm remnants were performed within the targeted 2D series and the corresponding ivACT on the workstation by using an electronic caliper. The quality of the ivACT and DSA images was assessed using the following grading system: 2, no interference; 1, compromised but sufficient image quality; and 0, not diagnostic. The parent artery was assessed as the following: 1, no relevant stenosis (< 50%); or 0, relevant stenosis (> 50%) or occlusion. The aneurysm remnants were graded from Grade I to V according to the Sindou classification.¹⁹

Exemplarily, statistical analysis was performed using SPSS software (SPSS, Inc.) for calculating the correlation between the measurements of the aneurysm remnants by ivACT and DSA (linear 2-sided Pearson test).

Results

In all cases, ivACT and DSA provided adequate images for evaluation without motion artifacts. Metal artifacts caused by the aneurysm clip led to a compromised, but still sufficient, image quality in only 1 case of ivACT. In this case, the metal artifacts were produced by a titanium alloy clip.

Digital subtraction angiography studies including the 3D rotational run could be assessed without interference in all cases. The categorization of the aneurysm remnants according to the Sindou classification¹⁹ was concordant between the two modalities: one aneurysm remnant was classified as Grade I and another remnant as Grade III, which means an accuracy of 100% of ivACT in comparison with DSA concerning the categorization. The 2 aneurysm remnants were assessed as true-positive by ivACT compared with conventional angiography (sensitivity 100%, specificity 100%). All other cases were scored correctly as true negatives by ivACT.

These results point to a high comparability between the modalities. Even small aneurysm remnants with a minimum size of 2.6×2.4 mm could be detected using ivACT, even though the size of the remnants tended to be overestimated by ivACT (Table 2). No relevant stenosis or occlusion of a parent artery was observed in either modality.

Illustrative Cases

Case 1

This 63-year-old man suffered acute SAH from an ACoA aneurysm, which was treated neurosurgically using a cobalt alloy clip. Digital subtraction angiography was performed 6 months after clipping without detecting residual aneurysm or narrowing of the parent artery. Intravenous angiographic CT showed a result identical to DSA (Fig. 1). No artifact disturbances from the clip were observed for either modality.

TABLE 2: Measurements of aneurysm remnants by ivACT and DSA in 2 patients

Aneurysm Location	Size of Aneurysm Remnant (mm)		Sindou Classification Grade		Pearson Correlation Coefficient
	ivACT	DSA	ivACT	DSA	
MCA	5.0×4.1	4.4×3.8	III	III	1.000
ACoA	2.6×2.4	2.4×2.2	I	I	1.000

Case 2

This 67-year-old woman underwent clipping of a left-sided MCA bifurcation aneurysm for the treatment of acute SAH. Digital subtraction angiography including a 3D rotational run and ivACT showed no remnants 6 months after neurosurgical intervention (Fig. 2). This case highlights the fact that ivACT can provide comparable images to the intraarterial 3D rotational run.

Case 3

This 47-year-old woman presented with acute SAH caused by a broad-based MCA bifurcation aneurysm on the left side, which was treated by clipping. Angiographic follow-up revealed a 4.4×3.8 -mm aneurysm remnant (Fig. 3), and ivACT confirmed this finding with the constraint that the size of the aneurysm remnant was slightly overestimated (5.0×4.1 mm). However, ivACT reliably demonstrated the clinically crucial information, namely that the aneurysm remnant has a broad-based configuration that is not suitable for endovascular treatment. By rotating the ivACT images, the emanation of the MCA branches could be clearly seen, which is essential if additional neurosurgical treatment is deemed necessary.

Case 4

This 51-year-old man suffered acute SAH. The angiographic evaluation revealed 2 aneurysms originating from the MCA bifurcation on each side and 1 from the ACoA. First, the right-sided MCA aneurysm and the ACoA aneurysm were treated neurosurgically. Then, the left-sided MCA aneurysm was treated by microsurgical clipping. The clip used for treating the ACoA aneurysm consisted of titanium alloy, and the others were cobalt alloy. Angiographic follow-up demonstrated that the MCA bifurcation aneurysms were completely occluded, and the ACoA aneurysm exhibited residual filling (Fig. 4). Intravenous angiographic CT and DSA provided comparable images that clearly demonstrated the aneurysm remnant, which was considered too small for endovascular treatment. The size of the aneurysm remnant was slightly overestimated by ivACT. Differences between the various clips concerning the artifacts were not observed in this case. Only one examination step was necessary to evaluate all treated aneurysms by ivACT.

Discussion

Noninvasive follow-up imaging after neurosurgical clipping of aneurysms is often a technically challenging

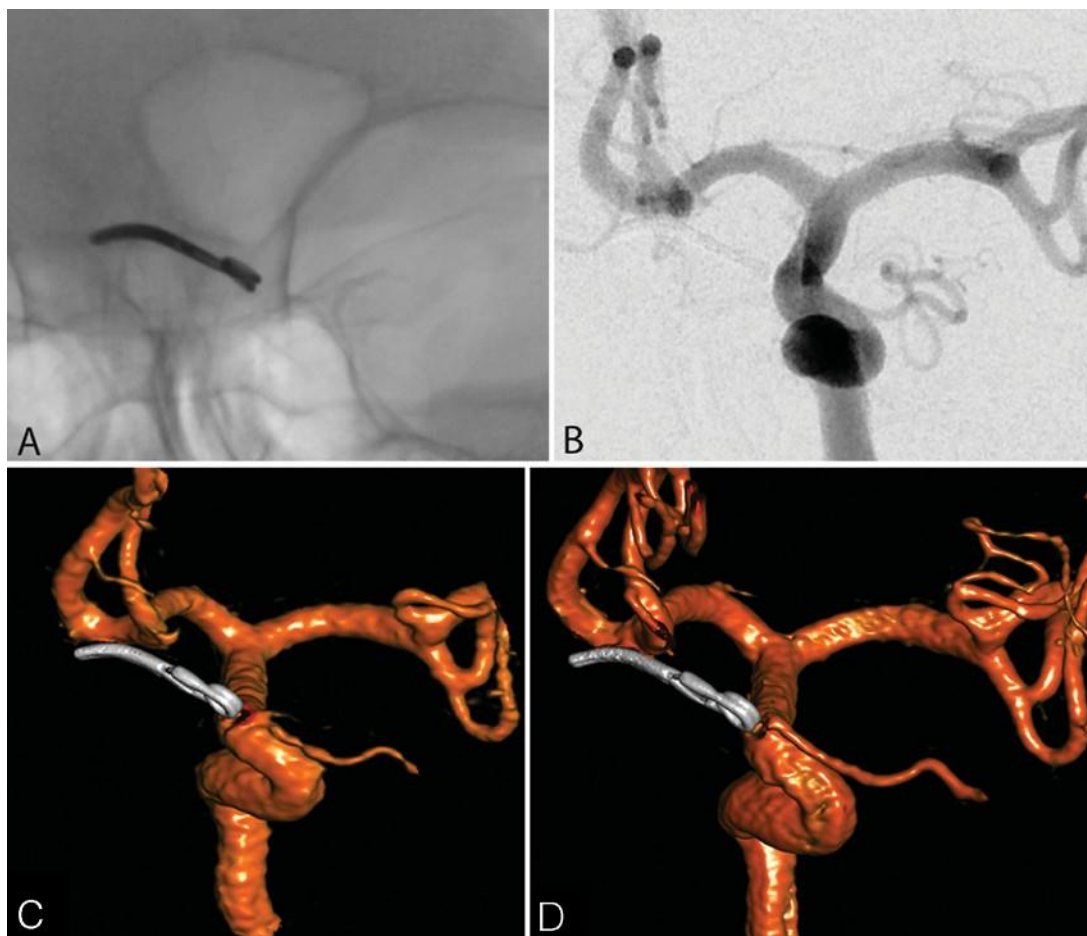


Fig. 1. Case 1. **A:** Unenhanced posteroanterior angiogram showing the clip position after treatment of an ACoA aneurysm. **B:** Digital subtraction angiogram with contrast material injection via the left ICA showing no aneurysm remnant. **C:** The corresponding ivACT showing the same finding in dual-volume technique. **D:** Corresponding 3D DSA image.

procedure, since metal artifacts in the clips can compromise image quality and subsequent image evaluation. Because of technical advances, especially in terms of CT and CTA, improvements in noninvasive imaging have been

achieved.^{3,4,10,14,25,27} Computed tomography angiography as a noninvasive follow-up method is already a standard of care in many institutions, but the accuracy of conventional angiography (DSA) has not fully been reached.^{5,23}

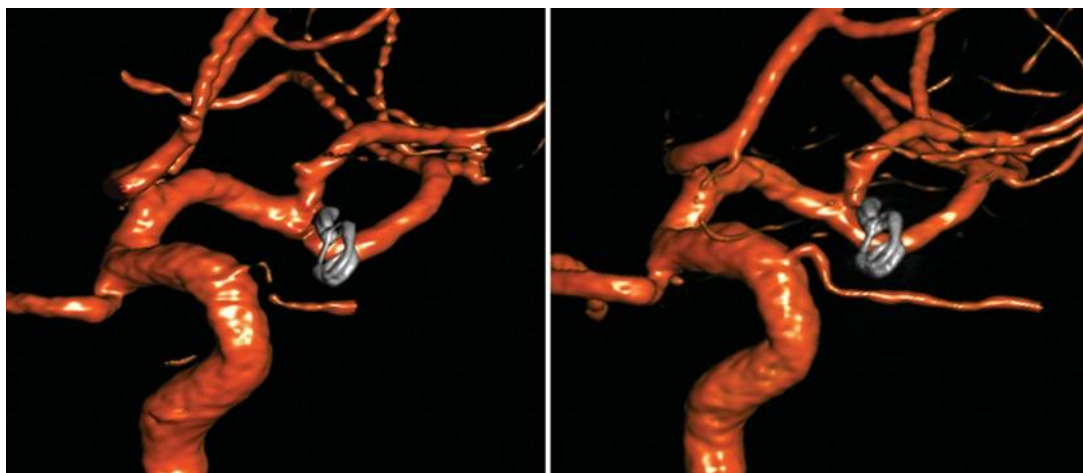


Fig. 2. Case 2. **Left:** Intraarterial 3D rotational run showing the status after clipping of a left-sided MCA bifurcation aneurysm without aneurysm remnant. **Right:** Correlating ivACT demonstrating the same result. The quality of the dual-volume images of both modalities seems comparable.

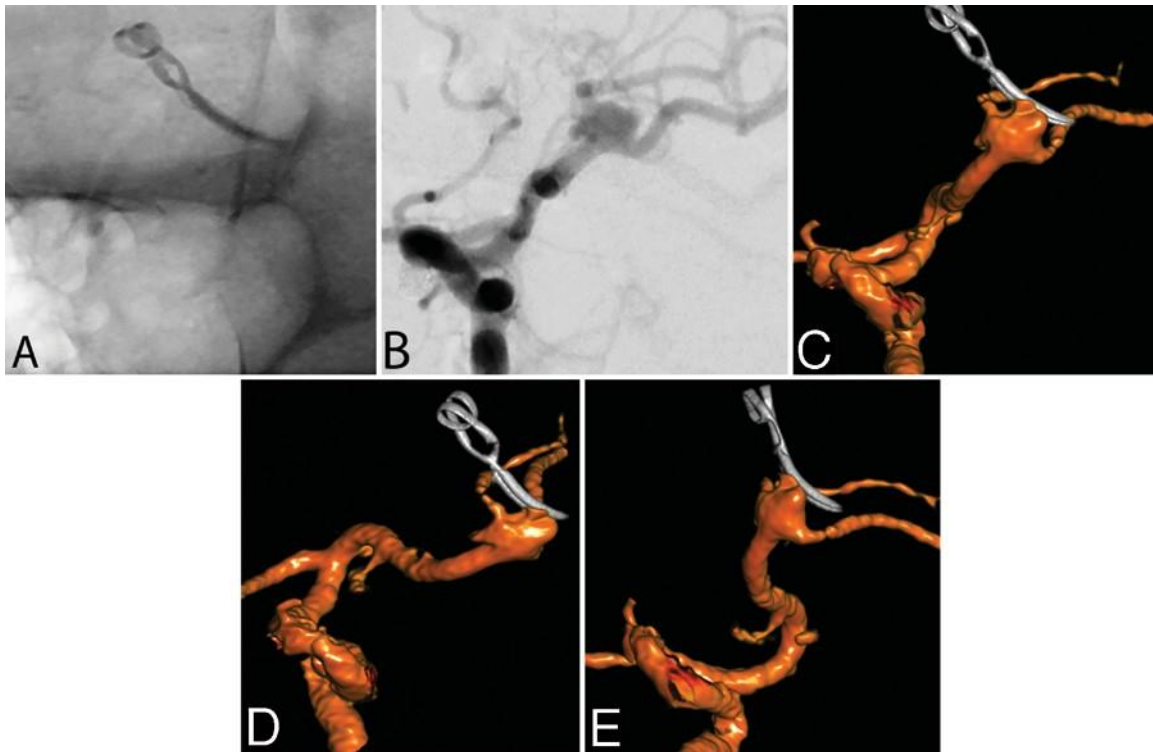


Fig. 3. Case 3. **A:** Unenhanced posteroanterior angiogram showing the clip position after neurosurgical treatment of an MCA bifurcation aneurysm on the left side. **B and C:** Digital subtraction angiography (**B**) and ivACT image (**C**) demonstrating a broad-based aneurysm remnant. The images provide comparable results, although the ivACT image slightly overestimates the size of the aneurysm remnant. **D and E:** Rotated views of the ivACT image that highlight the emanating MCA branches, which is crucial for retreatment.

Thus, DSA is still considered to be the gold standard in the follow-up of patients who have undergone microsurgical clipping to assess aneurysm remnants, if intraoperative angiography has not been performed. However, the disadvantage of DSA remains its invasiveness with the

risk of serious procedural complications, although these risks can be considered low in experienced hands.⁷

With the combination of ACT and intravenous contrast medium injection (ivACT), a new tool for cerebral vessel imaging has recently been introduced, and its fea-

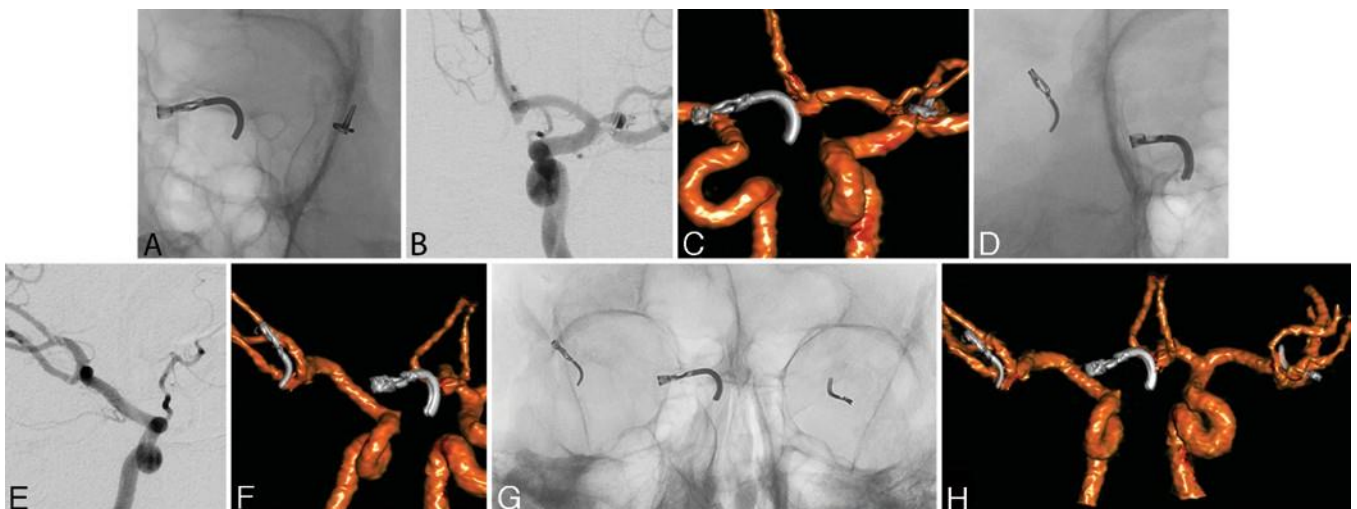


Fig. 4. Case 4. **A, D, and G:** Unenhanced posteroanterior angiograms showing the status after clipping of the bilateral MCA bifurcation aneurysms and of an ACoA aneurysm. **B and E:** Digital subtraction angiograms showing that both MCA bifurcation aneurysms are completely occluded and revealing a remnant of the ACoA aneurysm. **C and F:** The ivACT images lead to the same results and detect the aneurysm remnant as well, although it is slightly overestimated. **H:** As an advantage, the ivACT offers the option of evaluating all clipped aneurysms at once in only a single examination step.

sibility has already been proven.²⁰ In particular, because of its higher spatial resolution over CT, improvements in noninvasive imaging can be expected. However, recently published data have shown limitations of ivACT in the assessment of aneurysm remnants after neurosurgical clipping.¹⁵ Because of metal artifacts, especially in cases of multiple or oversized clips, the image quality and evaluation of ivACT was compromised in 30% of the examinations. In the reported study, only patients treated with titanium clips were examined; the performance of cobalt-containing alloy clips was not investigated. In contrast to these data, we evaluated the accuracy of ivACT compared with DSA in the follow-up of clipped aneurysms by using an optimized acquisition protocol as well as enhanced postprocessing algorithms. Additionally, the majority of our patient population was treated using cobalt alloy clips, which are considered to produce more artificial disturbances than titanium alloy clips.

We performed ivACT with a dual rotational 10-second acquisition run by using the “bolus watching” technique for best arterial vessel opacification. For image evaluation, the unenhanced and contrast-enhanced runs were fused using a dual-volume technique, which allows the reconstruction of freely rotatable 3D images. In the postprocessing of the ivACT data, newly implemented reconstruction modes with the function “subtraction with motion correction” were used (Siemens AG, Healthcare Sector). These reconstruction modes allow an improved visualization of the intracranial vessels with diminished artifact disturbances.

Applying these techniques, our preliminary results show a high comparability between ivACT and DSA in the follow-up of clipped aneurysms. In our series, ivACT demonstrated the same accuracy in the detection of aneurysm remnants as DSA. All complete aneurysm occlusions were scored correctly as true-negative by the ivACT. From these results, a high sensitivity as well as a high specificity can be deduced for the ivACT in comparison with the DSA. The size of the observed aneurysm remnants were slightly overestimated by ivACT compared with DSA. However, the images obtained using ivACT seem to provide reliable information concerning crucial points for a potential re-treatment, that is, aneurysm neck configuration or emanating vessel branches.

The disturbances through metal artifacts seem to be less compromising by applying the described reconstruction modes for the ivACT. The high spatial resolution of the ACT leads to a sharp delineation of the clips. In our study, 1 titanium alloy clip produced interfering artifacts. This is in contrast to published data of CT studies, which have described reduced artifacts through titanium alloy.^{17,18} On the other hand, the cobalt alloy clips predominantly used in our study caused no substantial artifacts. Thus, a titanium alloy clip may be less suitable for an ivACT examination. However, the visibility of smaller peripheral vessels might be compromised by metal artifacts. Here, the development of reconstruction modes to reduce metal artifacts might further improve image quality. A dedicated comparison with CTA was not performed. We intend to perform comparative studies of CTA and ivACT, since the feasibility of ivACT has now been shown.

The option of the ivACT to reconstruct 3D images, which can be freely rotated in all dimensions, improves the image evaluation because projections can be gained that are not adjustable with targeted 2D series, and for image analysis overlaying, offending vessel branches can be cut. In comparison with the intraarterial 3D rotational run, ivACT seems to provide an equivalent image quality. Moreover, the uniform contrast mixing within the vessels evoked by the intravenous injection prevents high-contrast artifacts, which can occur in a 3D DSA through direct intraarterial contrast medium injection.

As a major advantage, ivACT is a noninvasive procedure. Thus, angiographic complications, such as cerebrovascular ischemic events, can be avoided. Additionally, ivACT can be performed on an outpatient basis. Moreover, the acquisition of ivACT takes only a few minutes and is less time consuming than DSA. Also, even if there is more than 1 clipped cerebral aneurysm (for example, in Case 4), only 1 examination step is necessary for the acquisition of the ivACT and for the evaluation of all aneurysms at once. In contrast, DSA requires several contrast injections for each aneurysm so that the necessary amount of contrast material for an angiographic follow-up of multiple clipped cerebral aneurysms can reach or even exceed that needed for ivACT.

In addition, the increased number of 2D and 3D DSA series needed in the evaluation of multiple clipped aneurysms leads to increased radiation exposure to the patient. The measured weighted CT dose index of a 3D DSA amounts to approximately 9 mGy, and the dose length product to 180 mGy × cm.⁸ Preliminary internal data showed an effective dose for 3D DSA at a level of 1.2 mSv and that for a biplane DSA series at a level of 1 mSv. Reliable dose measurements for ivACT are not available, but referring to preliminary internal investigations, the effective dose should be at a level of about 1.5 mSv. Thus, especially in the follow-up of multiple clipped cerebral aneurysms, the use of ivACT could lessen the amount of radiation exposure to the patient compared with DSA. In general, a constant dose optimization is crucial, and further radiation dose measurements are mandatory.

Our study is limited by the small number of patients and the low absolute number of aneurysm remnants (the prevalence of 11% aneurysm remnants is within the normal range^{1,2,9,12,13,16,24}), but it seems sufficient to demonstrate that an optimized ivACT image can provide comparable results to DSA with high accuracy in the follow-up of clipped aneurysms, at least for aneurysms of the anterior circulation located distal to the internal carotid artery. Further validation with a larger patient population and clipped aneurysms located within the posterior circulation should be added to our results.

Perhaps in future, if more and more multifunctional hybrid operating rooms equipped with flat panel technology are available, the intraoperative use of ivACT might become an alternative to intraoperative angiography since it has the advantage of being noninvasive, and no special angiographic skills or materials are necessary.

Limitations of ivACT could arise from the number of clips used. Most patients in our study population were treated using a single clip. We did not observe substan-

tial metal artifacts in any of our patients treated with 2 or more clips, but it is possible that the image quality of ivACT could be compromised in such cases, perhaps depending on clip orientation. Thus, patients with more than 2 clips used for treatment of a single aneurysm might not be candidates for ivACT. In addition, noncompliant or restless patients might not be suitable for an ivACT examination because image quality depends strongly on an acquisition without motion disturbance, and therefore patient cooperation is needed.

An objective for further investigations could be the implementation of image reconstruction modes with automated metal artifact reduction.

Conclusions

Our preliminary data of the diagnostic follow-up of clipped aneurysms within the anterior circulation indicate that noninvasive, intravenous ACT using an optimized acquisition protocol and newly implemented, enhanced postprocessing algorithms can provide images with comparable accuracy to DSA. The image information of aneurysm remnants obtained by ivACT seems to be reliable in comparison with DSA and might turn out to be sufficient for adequate clinical decision making. Further evaluation with a larger patient population is mandatory to validate these observations and to fully implement this new technique into the clinical routine.

Disclosure

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 to the study and manuscript preparation include the following. Conception and design: Doerfler. Acquisition of data: Göllitz, Struffert, Saake, Lücking, Rösch. Analysis and interpretation of data: Göllitz. Drafting the article: Göllitz, Knossalla. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Göllitz. Administrative/technical/material support: Doerfler. Study supervision: Ganslandt, Doerfler.

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Address correspondence to: Philipp Göllitz, M.D., Department of Neuroradiology, University of Erlangen-Nuremberg, Schwabachanlage 6, 91052 Erlangen, Germany. email: philipp.goelitz@uk-erlangen.de.