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Optimization of radiation settings for angiography using 3D fluoroscopy for imaging of intracranial aneurysms

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ABSTRACT
Mobile 3D fluoroscopes have become increasingly available in neurosurgical operating rooms. We recently reported its use for imaging cerebral vascular malformations and aneurysms. This study was conducted to evaluate various radiation settings for the imaging of cerebral aneurysms before and after surgical occlusion. Eighteen patients with cerebral aneurysms with the indication for surgical clipping were included in this prospective analysis. Before surgery the patients were randomized into one of three different scan protocols according (default settings of the 3D fluoroscope): Group 1: 110 kV, 80 mA (enhanced cranial mode), group 2: 120 kV, 64 mA (lumbar spine mode), group 3: 120 kV, 25 mA (head/neck settings). Prior to surgery, a rotational fluoroscopy scan (duration 24 s) was performed without contrast agent followed by another scan with 50 ml of intravenous iodine contrast agent. The image files of both scans were transferred to an Apple PowerMac® workstation, subtracted and reconstructed using OsiriX® MD 10.0 software. The procedure was repeated after clip placement. The image quality regarding preoperative aneurysm configuration and postoperative assessment of aneurysm occlusion and vessel patency was analyzed by 2 independent reviewers using a 6-grade scale. This technique quickly supplies images of adequate quality to depict intracranial aneurysms and distal vessel patency after aneurysm clipping. Regarding these features, a further optimization to our previous protocol seems possible lowering the voltage and increasing tube current. For quick intraoperative assessment, image subtraction seems not necessary. Thus, a native scan without a contrast agent is not necessary. Further optimization may be possible using a different contrast injection protocol.

KEYWORDS
3D fluoroscopy; aneurysm; fluoroscopy; intraoperative imaging

Introduction

We previously reported the use of intraoperative contrast-enhanced 3D fluoroscopy for the intraoperative visualization of intracranial aneurysms [1] and the post-clip control of vessel patency and aneurysm occlusion [2]. To apply this technique intraoperatively is a novel idea using radiographic devices that have originally been designed and constructed for other purposes. In particular, their primary target was the visualization of bony structures in spine surgery [3] and their use as the basis for neuronavigation in spine surgery and functional neurosurgery. Hence, there are no validated protocols for radiation doses, dose and speed of contrast administration and post-processing of fluoroscopic images in cerebrovascular diseases.

These parameters have partially been adopted from computed tomography angiography (CTA). However, the image acquisition technique is fundamentally different as it does not follow the contrast-flow in a caudocranial direction primarily creating tomographic images but creates tomography-like images from a rotational scan by a mathematical algorithm. Therefore, the parameters resulting in optimum imaging quality have to be evaluated for this particular technique. This study was conducted to determine superior radiation doses for the imaging of intracranial blood vessels prior to microsurgical aneurysm clipping and for the postoperative control of vessel patency and aneurysm occlusion using 3D-fluoroscopy (O-arm).

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This article has been corrected with minor changes. These changes do not impact the academic content of the article.

Methods

The study was approved by the ethics committee of the medical faculty of the University of Wuerzburg (Reference 263/16-ge.). All patients in this analysis were informed of the potential risk of the administration of an iodine contrast agent and radiation exposure and all patients gave their written informed consent.

Inclusion criteria

Patients met the criteria for intraoperative 3D rotational fluoroscopic angiography if they had an incidental intracranial aneurysm, were over 18 years of age, and if microsurgical clipping of the aneurysm was indicated. Exclusion criteria were a history of hyperthyroidism, a known allergy against contrast agent, or serum creatinine concentrations over 100 µmol/l (1.2 mg/100 ml). 18 patients were included in this analysis. Patient characteristics and aneurysm details are listed in Table 1.

Patient positioning and image acquisition

Under general anesthesia, the patients received a central venous catheter in the right jugular vein for infusions of fluid, medication and contrast agent. Arterial blood pressure was continuously monitored via an arterial line in the left radial artery. Since all patients of this series had an aneurysm in the anterior circulation, all patients were placed in a supine position with their head fixed in a carbon Mayfield clamp. Prior to surgery, baseline imaging was performed. The positioning of the O-arm™ Imaging system (Medtronic, Littleton MA) was verified by biplanar fluoroscopy. Subsequently, a 360° rotational native fluoroscopy scan was performed. Thereafter, a second, contrast-enhanced scan was performed using 60 ml of iodine contrast agent (Imeron® 350, Bracco Imaging, Konstanz, Germany). Contrast injection was performed by an automated injector (Acutron CT, Medtron, Saarbrücken, Germany) The contrast agent was infused via the 16 gauge line of a 5-lumen central venous catheter over a period of 24 s. With a delay of 12 s, the 3D scan was started. For image acquisition, the 'high definition mode' or 'enhanced cranial mode', respectively, of the O-arm™ Imaging system (digital flat panel detector 40 × 30 cm, camera resolution 2000 × 1500, reconstruction matrix 512 × 512 x 192) was applied both requiring an image acquisition time of 24 s for the 360-degree gantry rotation. After placement of the clips, all metallic surgical devices and spatula that were potential causes of artifacts were removed and the imaging procedure was repeated. The intraoperative setting is depicted in Figure 1. The timing protocol of fluoroscopy and contrast injection is depicted in Figure 2.

Before surgery the patients were randomized into one of three different scan protocols:

Group 1 ($n = 6$): 'enhanced cranial mode'

- Patient size: Large
- Tube voltage 110 kV
- Tube current 80 mA
- Dose length product: 549 mGy cm for each scan

Table 1. Patient characteristics.

Patient #	Group	Aneurysm	Age/gender
1	Enhanced Cranial	MCA left, reperfusion after WEB	52, f
2	Lumbar Spine	MCA right, incidental	67, f
3	Head/Neck	Pericallosal artery, intramural hematoma (dissecting)	52, m
4	Head/Neck	MCA right, incidental	60, m
5	Enhanced Cranial	MCA and ICA right, incidental	52, f
6	Head/Neck	MCA right, incidental	70, f
7	Head/Neck	Pcom right	74, m
8	Head/Neck	MCA right, incidental	64, f
9	Enhanced Cranial	Terminal ICA left, incidental	74, m
10	Lumbar Spine	Pericallosal artery, incidental	65, f
11	Head/Neck	MCA right, incidental	47, f
12	Lumbar Spine	MCA left, SAH (no blood in cisterns)	43, m
13	Lumbar Spine	Acom, incidental	53, m
14	Lumbar Spine	MCA left, incidental	49, m
15	Enhanced Cranial	Acom, incidental	51, f
16	Enhanced Cranial	Acom, incidental	43, f
17	Enhanced Cranial	MCA right, incidental	52, f
18	Lumbar Spine	Terminal ICA left and Acom, incidental	43, m

Patient characteristics (gender, age), location of aneurysm and history of aneurysm of 18 patients enrolled in the study.
Acom: anterior communicating artery; SAH: subarachnoid hemorrhage; ICA: internal carotid artery; MCA: middle cerebral artery.
'Group' indicates study group and refers to the O-arm predefined settings 'enhanced cranial mode – patient large', 'high definition lumbar spine – patient large' and 'high definition head/neck setting – patient large'.

Figure 1. (a–c) Intraoperative setting. Positioning of the O-arm™ Imaging system after fixation of the patients head in a patch clamp (a), transfer of the injection protocol to the automatic injector (b), example for radiation and image settings displayed on the panel of the O-arm™ Imaging system (c).

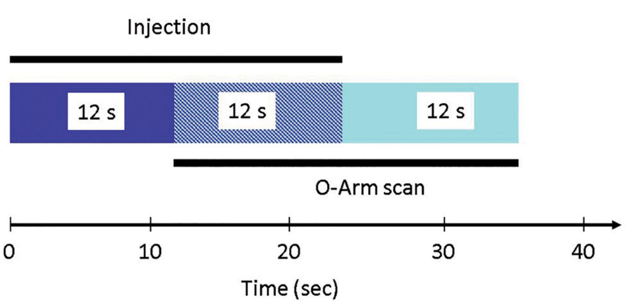

Figure 2. Contrast injection protocol. For image acquisition, a 24 s scan was used ('high definition mode' or 'enhanced cranial mode' of the Medtronic O-arm). Fluoroscopy was started with a delay of 12 s after contrast injection was started. This delay was calculated to be the approximate circulation time of the contrast agent administered via a central venous catheter until it appears in the cerebral circulation.

Group 2 ($n = 6$): 'lumbar spine mode'

- Patient size: Large
- Tube voltage 120 kV
- Tube current 64 mA
- Dose length product 376 mGy cm for each scan

Group 3 ($n = 6$): 'head/neck mode'

- Patient size: Large
- Tube voltage 120 kV
- Tube current 25 mA
- Dose length product 301 mGy cm for each scan

Post-processing of digital imaging and communications in medicine (DICOM) data

The DICOM data couples (native and contrast-enhanced images) were exported, transferred from the O-arm™ Imaging system to an Apple Mac Pro® 6-core workstation and post-processed using OsiriX® imaging (OsiriX MD 10.0). Since it was the aim of this study, to optimize the radiation protocol for intraoperative use, time-consuming reconstructions were not performed and analyzed in this context. Native and contrast-enhanced data sets were subtracted using the OsiriX® software. The raw contrast-enhanced images and the subtracted images were evaluated according to the criteria described below.

Evaluation of images

The images before and after placement of the clips were assessed for visibility of the aneurysms, accessibility of distal vessel patency, and complete aneurysm occlusion by two observers (T.W. and T.L.) blinded to the patients' pathology and the assigned radiation protocol using a 6-grade scale: 1 = excellent assessability, all relevant details visible (distal and proximal vessels/clip/clip stenosis), 6 = not visible at all. The observers were allowed to use all means of image reconstruction of the OsiriX software for their evaluation including non–subtracted and subtracted images and maximum intensity projections (MIP).

An interrater reliability analysis was performed using Kappa statistics in order to determine consistency among raters/reviewers (IBM SPSS Statistics 26, SPSS Worldwide, Chicago, IL, USA).

Postoperative digital subtraction angiography (DSA)

All patients received a postoperative DSA, which was performed by the colleagues of the Institute of Neuroradiology and evaluated with regard to aneurysm remnants.

Results

Patient characteristics

18 patients were included in the study. All patients of this series had aneurysms of the anterior circulation as the majority of aneurysms in the posterior circulation were treated by endovascular coiling in our department in the study period. One patient had a history of subarachnoid hemorrhage (SAH) and endovascular obliteration by a WEB-device. Follow-up angiography 6 months later showed reperfusion of the aneurysm and microsurgical clipping was decided. One patient had a history of recent SAH by clinical criteria but no signs of hemorrhage in computed tomography (CT). Another patient had an intramural hematoma around an aneurysm of the pericallosal artery and no SAH (Table 1).

Side effects

No cardiovascular side effects or anaphylactic reactions were noted during or after administration of the contrast agent. One patient with aneurysms of the terminal ICA and anterior communicating aneurysm and a history of alcohol and cocaine abuse had an intraoperative epileptic seizure after craniotomy and opening of the dura mater 30 min after contrast administration.

Workflow

The 3D fluoroscope was positioned during the preoperative preparation (e.g. shaving, disinfection) after Mayfield clamp fixation. The appropriate position was verified using anteroposterior (a.-p.) and lateral fluoroscopy. Acquisitions of the a.-p. and lateral images and the two 3D scans took approximately 2 min and were performed after surgical disinfection of the patients' skin and during the surgeon's hand disinfection. Thereafter, the fluoroscope was positioned inferiorly in order to provide a free operative field. Post-processing by the OsiriX® workstation occurred during surgical drape placement and was performed by the surgical assistant who had received a short briefing of approximately 30 min on the reconstruction procedure prior to surgery. In summary, the entire procedure took 5–6 min and was completely embedded in the normal preoperative workflow.

In two patients, contrast administration failed during the first (preoperative) contrast-enhanced 3D scan due to a leak in the connection line between the syringe and central venous line resulting in an insufficient contrast injection The examination was taken out of the assessment. In another patient, 3D-fluoroscopy was interrupted during contrast administration and no images were generated. No technical problems occurred during the scan procedures after the placement of the clips.

Technical parameters and radiation exposure

The technical parameters of the fluoroscopy, including radiation exposure, are described above (Groups 1–3). The radiation doses in Groups 2 and 3 were in the approximate range of a 1-vessel DSA including oblique projections and a 3D data set off approximately 300 mGy.

Group 1 received doses in the approximate range of complete 4-vessel DSA of approximately 1000 mGy.

Image quality

There was only a minimum interrater variability between the two observers (Kappa = 0.453, $p < 0.001$). In no examination, ratings differed by more than one point. For matters of simplification, ratings of the 2 observers were therefore added. The ratings are presented in Figure 3(a–d).

Scan1: Ratings were 3 ± 0.47 (enhanced cranial mode), 3.3 ± 1.3 (lumbar spine mode) and 4 ± 0.8 (Head/Neck mode), respectively, for the assessment of the native scans, 1.9 ± 0.6 (enhanced cranial mode), 2.7 ± 1.6 (lumbar spine mode) and 3.4 ± 1.0 (Head/Neck mode), respectively, for the assessment of the scans in the MIP of the OsiriX software and 2.2 ± 0.9 (enhanced cranial mode), 3.3 ± 1.6 (lumbar spine mode) and 3.3 ± 1.2 (Head/Neck mode), respectively, for the assessment of the subtracted scans using native images and the MIP mode of the OsiriX software (Figure 3(a)).

Scan 2: Ratings were 3.2 ± 0.4 (enhanced cranial mode), 3.1 ± 1.0 (lumbar spine mode) and 4.2 ± 0.8

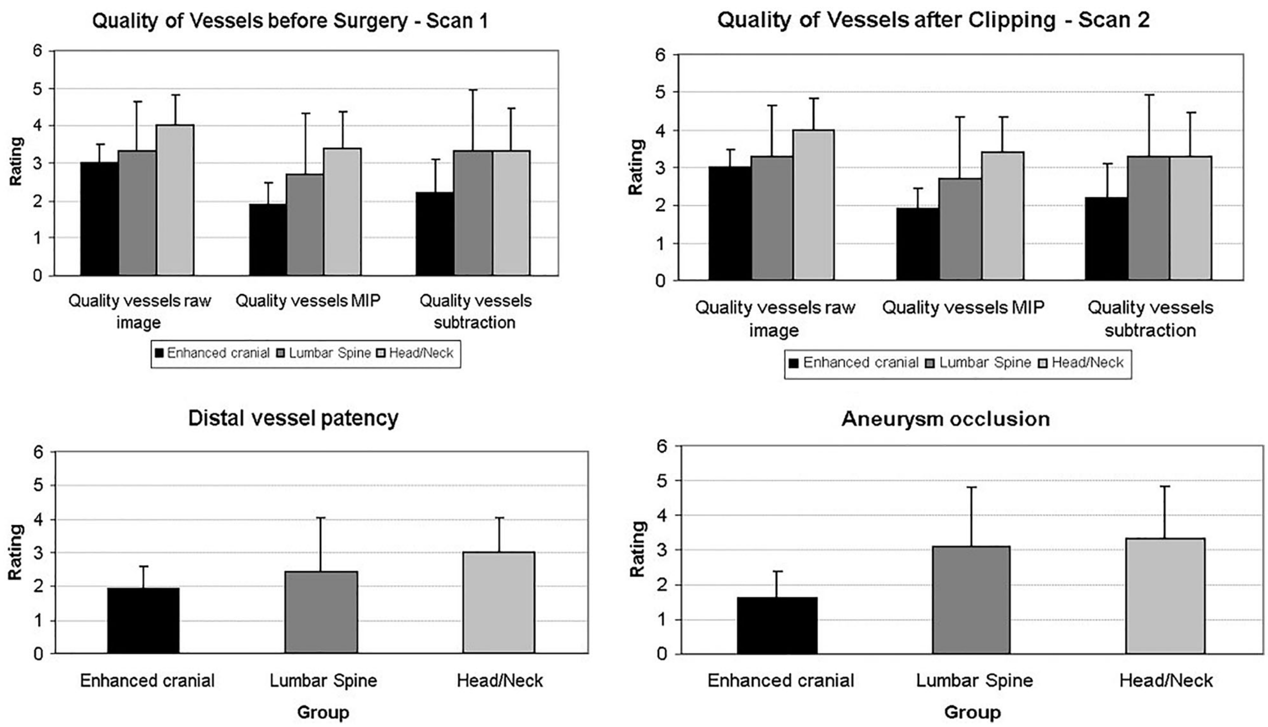

Figure 3. (a–d) Results of the assessment of image quality regarding depiction of the vessel tree before surgery (a), after clipping (b) and of distal vessel patency (c) and aneurysm occlusion (d) after placement of the clip. In subfigures (a) and (b), raw images, maximum intensity projections and subtracted images were assessed separately.

(Head/Neck mode), respectively, for the assessment of the native scans, 1.9 ± 0.5 (enhanced cranial mode), 2.0 ± 1.1 (lumbar spine mode) and 2.9 ± 0.8 (Head/Neck mode), respectively, for the assessment of the scans in the MIP of the OsiriX software and 1.8 ± 0.7 (enhanced cranial mode), 2.9 ± 1.5 (lumbar spine mode) and 3.0 ± 1.0 (Head/Neck mode), respectively, for the assessment of the subtracted scans using native images and the MIP mode of the OsiriX software (Figure 3(b)).

Vessel patency: Ratings were 1.9 ± 0.6 (enhanced cranial mode), 2.4 ± 1.6 (lumbar spine mode) and 3.0 ± 1.0 (Head/Neck mode), respectively, for the assessment of the patency of blood vessels distal from the clip (Figure 3(c)).

Aneurysm occlusion: Ratings were 1.6 ± 0.8 (enhanced cranial mode), 3.1 ± 1.7 (lumbar spine mode) and 3.3 ± 1.5 (Head/Neck mode), respectively, for the assessment of the complete/incomplete occlusion of the aneurysm (Figure 3(d)).

Intraoperative indocyanine green video-angiography (ICG-VA) and postoperative DSA

All patients received postoperative DSA (Table 2). Aneurysm remnants were diagnosed in four cases. In three cases the inferior protocols in the evaluation (Lumbar Spine, Head/Neck) were applied. Patient no. 15 is an exception in this respect, as due to the intraoperative aneurysm rupture, only incomplete elimination was possible, which was visualized by 3D fluoroscopy (enhanced cranial mode) and confirmed in the postoperative DSA.

One patient had an aneurysm spurium and was treated by wrapping.

In two cases, an assessment could not be performed due to severe spasm formation of the cerebral vessels during the course of the disease.

Correlation with ICG-VA showed negative agreement in three cases of incomplete occlusion. A positive correlation regarding aneurysm remnant in DSA and in ICG both was shown in patient no. 18. However, an aneurysm rupture occurred in patient no. 15 after ICG-VA, which had previously shown complete occlusion. Furthermore, due to a technical problem, ICG-VA could not be used in patient no. 14.

Discussion

It has been previously reported that cerebral blood vessels can be depicted in good quality using intraoperative 3D rotational fluoroscopy and intravenous

Table 2. Intaoperative ICG and postoperative DSA.

Patient #	Group	Aneurysm	Age/gender	Post OP DSA	ICG
1	Enhanced Cranial	MCA left, reperfusion after WEB	52, f	CO	CO
2	Lumbar Spine	MCA right, incidental	67, f	CO	CO
3	Head/Neck	Pericallosal artery, intramural hematoma (dissecting)	52, m	Remnant	n/a
4	Head/Neck	MCA right, incidental	60, m	CO	CO
5	Enhanced Cranial	MCA and ICA right, incidental	52, f	CO	CO
6	Head/Neck	MCA right, incidental	70, f	CO	CO
7	Head/Neck	Pcom right	74, m	CO	CO
8	Head/Neck	MCA right, incidental	64, f	CO	CO
9	Enhanced Cranial	Terminal ICA left, incidental	74, m	CO	CO
10	Lumbar Spine	Pericallosal artery, incidental	65, f	Remnant	CO
11	Head/Neck	MCA right, incidental	47, f	remnant	CO
12	Lumbar Spine	MCA left, SAH (no blood in cisterns)	43, m	n/a	CO
13	Lumbar Spine	Acom, incidental	53, m	CO	CO
14	Lumbar Spine	MCA left, incidental	49, m	n/a	technical problems
15	Enhanced Cranial	Acom, incidental	51, f	Remnant	co before rupture
16	Enhanced Cranial	Acom, incidental	43, f	CO	CO
17	Enhanced Cranial	MCA right, incidental	52, f	CO	CO
18	Lumbar Spine	Terminal ICA left and Acom, incidental	43, m	Remnant	Remnant

Patient characteristics (gender, age), location of aneurysm, results of intraoperative ICG and postoperative DSA of 18 patients enrolled in the study. CO: complete occlusion; n/a: not applicable.

contrast agent [1]. Furthermore, it has been demonstrated that a postoperative control of vessel patency is possible [2,4]. However, especially the correct occlusion of the aneurysm is not displayed with high quality. From the previous findings, we concluded that the parameters of contrast administration and radiation dose can possibly be optimized in order to improve the quality of defining the vessel and aneurysm anatomy and of post-clip follow-up in terms of complete aneurysm occlusion and adequate perfusion of peripheral vessels.

In our previous studies, parameters of contrast injection and radiation dose were extrapolated from CT-angiography and predefined O-arm settings. The present investigation was conducted in order to evaluate if lower or higher radiation doses were able to improve the quality of imaging. The particular focus was put on the quality of postoperative control. This includes a quick time-sparing evaluation of the acquired images because time is short to react and replace the clip, especially if the clip causes vessel stenosis and ischemia. For this reason, we decided to refrain from creating and evaluating 3D-reconstructions in this present study which would be much more time-consuming and, therefore, not useful for the particular purpose of intraoperative assessment.

The method of visually assessing the raw images using the OsiriX software may be subjective but was a methodological aspect that was chosen on purpose. The images have to be evaluated visually using simple techniques because the surgical consequence on inappropriate findings has to follow quickly, particularly if the finding is an occlusion of a branching vessel. For reasons of saving time, only four modes of images may be evaluated: (1) Assessment of the raw images, (2) assessment of the raw images using predefined functions, particularly the MIP, (3) assessment of digitally subtracted images (contrast-enhanced versus-native images) and (4) assessment of digitally subtracted images in the MIP function. More advanced functions of the post-processing software would be too time-consuming for practical intraoperative use. Perhaps more elaborate reconstructions can be integrated in the future as hardware and software development in medical technology advances quickly.

To date, DSA is still considered the gold standard for the imaging of cerebral aneurysms [5,6] as well as the use of ICG-VA which we also use in our daily routine. All patients of this series received postoperative DSA for aneurysm and clip control. ICG-VA is a fast and non-irradiant technology. But it is a visual technique that only visualizes structures that are in the microscopic field of view. Furthermore, it does not provide a 3D-visualization of the sites. Branching vessels or parts of the aneurysm may be concealed and escape the microscopic view. Concerning DSA as the gold standard in imaging cerebral aneurysms, the point of view has been challenged in the last few years. Computed tomography angiography (CTA) demonstrated similar precision and comparable depiction of vessel and aneurysm morphology using advanced image processing technologies [7,8]. Therefore, CTA has become the first-line diagnostic tool for stroke. Its advantages are that it takes but a couple of minutes and is a simple procedure that does not require a larger setup. Magnetic resonance angiography (MRA) has been a primary focus in recent years and has been investigated for its accuracy to show the vessel anatomy and configuration of intracranial aneurysms [9,10]. This technique has demonstrated a good correlation with DSA findings for the detection of aneurysms and estimation of aneurysm size. Its advantage is that it is radiation-free. Currently, it is the standard follow-up examination after endovascular obliteration of intracranial aneurysms [10,11]. However, it also requires a time-consuming setup and is, therefore, not useful for intraoperative control after microsurgical occlusion of aneurysms, even if a magnetic resonance imaging (MRI) scanner is present in the operating room (OR). Furthermore, metal-clips cause a local artifact that does not allow an assessment of aneurysm occlusion [7].

In many departments, angiography facilities and CT scanners to perform DSA and CTA are not localized in the OR. If they are, this means an interruption of the procedure [12] Intraoperative CT is a rather rapid procedure, but it interrupts the workflow because patients have to be transferred into the CT-scanner. Fluoroscopy scanners have the advantage that they can be repositioned any time during surgery, completely integrated into the operating field and workflow and reused whenever it is necessary.

Previous investigations showed high-quality images [1,2,4]. Previously, we used different radiation protocols due to the lack of an official protocol for this technique. Furthermore, the contrast agent had been injected 'free-hand' and it could not be guaranteed that the manual injection was continuous and exactly complied with the 24-s interval of the protocol. In the present study, an automated injector was used assuring compliance with the study protocol. In our previous series, we observed differences in image quality which suggested that there may be space for an optimization of the protocol of the procedure concerning (a) the radiation dose and (b) the dynamics of contrast injection. The present study evaluated the possible optimization of the radiation dose in a structured and prospective way.

Patients were allocated to one of three study groups with higher or lower tube voltage and current. Similar to our previous patients, we observed variations within those groups. In each group, good results with respect to image quality were seen. In average, however, the image quality in group 1 (enhanced cranial mode) was best. Whether this is due to the slightly reduced tube voltage or the increased tube current or both, cannot be determined in this study setup. Patients without a malignant disease such as our patients are a particularly sensitive patient collective when it comes to clinical studies and especially radiation as a potentially harmful measure. Thus, larger studies are not warranted. Considering these results, it might now be the next step to further reduce the tube voltage and/or increase the tube current. At this stage of the project, we cannot determine the impact of the thickness of the skull on the image quality of intracranial structures, in particular contrast-filled vessels. This may be another factor influencing image quality. In catheter DSA, initial single fluoroscopic shots taken before the start of the rotational scan automatically determine the optimum radiation parameters for the two scans that are used for subtraction angiography. In 3D rotational DSA, radiation parameters are somewhat lower. Tube voltages are around 90 mV, currents around 50 mA according to our own institutional observations. Altogether, there may be further potential to optimize the radiation settings.

One rather unexpected finding is that digital subtraction of native versus contrast-enhanced images does not result in a gain of image-quality compared to the contrast-enhanced images alone using the MIP function of post-processing software (Figure 4(a–e)). This may be due to the MIP function itself being a well-developed function particularly conceived for the imaging of structures such as blood vessels and automatically erasing intracranial soft tissue using mathematical algorithms [13]. For assessment of blood vessels and distal perfusion, we supposed that this may be sufficient.

We previously found that 3D reconstructions using the OsiriX software were highly superior to non-subtracted contrast-enhanced images. This is true for the depiction of aneurysms before surgery as well as for post-clip control. However, 3D image-reconstruction was not the issue of this present study. One possible reason for this observation might be that subtraction only works if there is an exact overlay of native and contrast-enhanced images. Figure 4(e) shows that this is possible at times. Theoretically, all artifacts should be calculated out of the image so that only the contrast-filling remains. But if there is an only minimal shift between the images for what reason ever, artifacts will not be counted out and digital subtraction is of little use For the purpose of image fusion in tumor surgery or neuromodulation, all modern neuronavigation systems have an automatical adaptation of image overlay for fine-adjustment, for example, using bony structures as a reference [14,15]. However, none of them has a digital subtraction function to subtract the fine-adjusted images in a second step. In contrast, the OsiriX software has a digital subtraction function but unfortunately no automatic adjustment for image overlay. The problem of exact overlay and a further

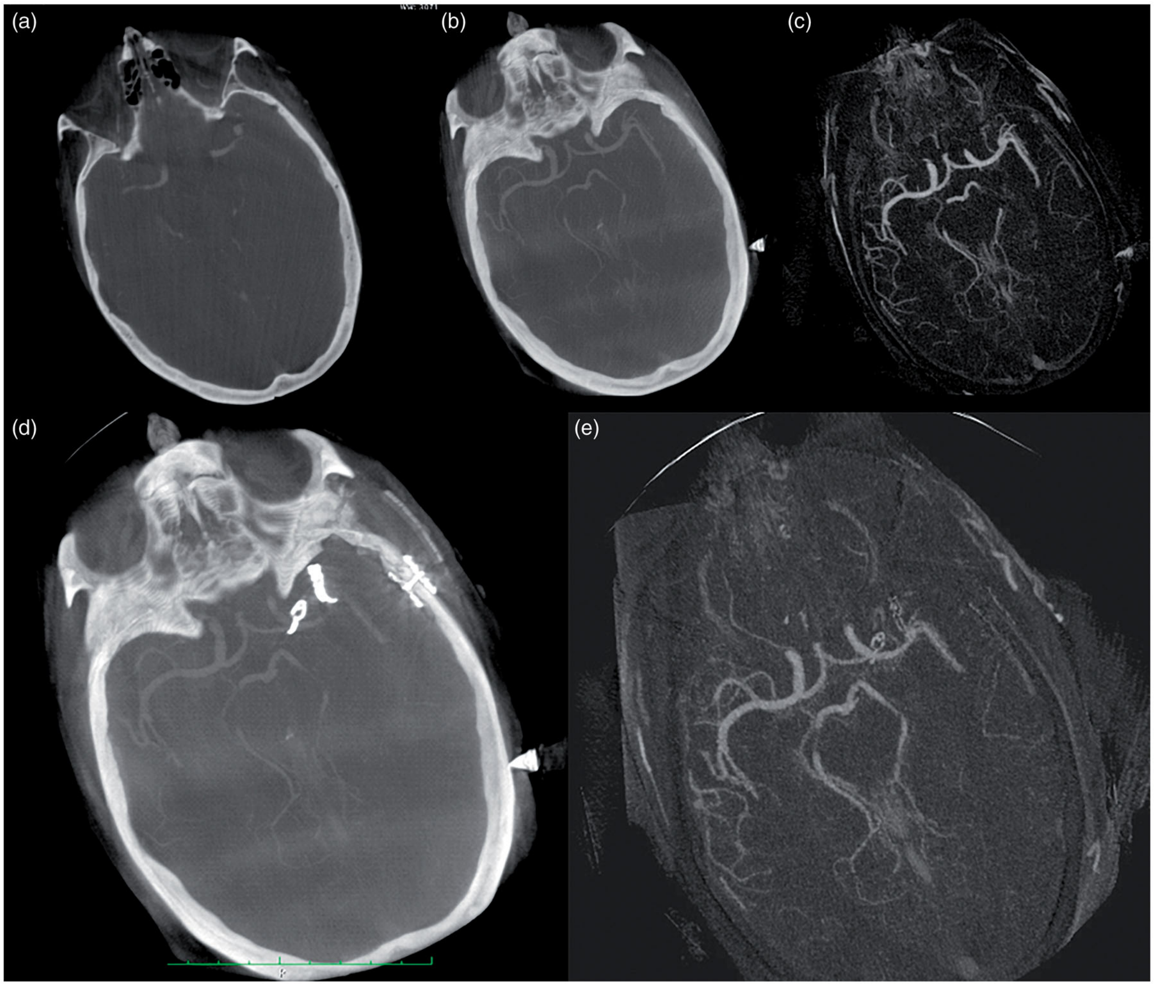

Figure 4. (a–e) Small aneurysm of the carotid bifurcation and MCA in basic (raw) images (a), using the MIP function of the OsiriX software (b) and MIP function of the subtracted images (c) before placement of the clip. Postoperative control in basic image (d) and subtracted images (e). Neither preperatively nor after placement of the clip, subtraction of native and contrast-enhanced images showed a gain of image quality.

gain of image quality could possibly be solved by the addition of the respective software components.

It should be emphasized that radiation settings do not alone determine the quality of vascular imaging. The flooding of the contrast agent is likely to play an equally important For CTA, this was extensively examined in the past. Maintaining stable blood pressure is certainly a prerequisite for good-quality contrast imaging but not in a proportional function [16]. To date, there is still no clear algorithm for the timing of contrast agents in CTA. For that reason, manufacturers added bolus tracking in the field of CTA [17]. In 3D-rotational fluoroscopy, this issue may be even more challenging because the arteriogram is – at least in peripheral vessels – hard to distinguish from the venogram. The latter, however, is not useful for the purpose of imaging cerebral imaging and may worsen image quality.

Conclusion

This present study is a structured and prospective evaluation of various radiation protocols for intraoperative cerebral angiography using a mobile 3D-fluoroscope. Since this is a novel technique, algorithms have to be developed. In contrast to our former protocol, that lower tube voltage and higher tube current seem to be of advantage in order to optimize image quality. This is the basis and the first step for further work targeting further optimization. Apart from the radiation settings, this may also include contrast-timing and post-processing software.

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Ethical approval and consent to participate

All patients in this analysis were informed of the potential risk of the administration of an iodine contrast agent and radiation exposure and all patients gave their written informed consent.

The study was approved by the ethics committee of the medical faculty of the University of Wuerzburg (Reference 263/16-ge.).

Disclosure statement

The project was supported by the External Research Fund of Medtronic Inc. The funder was not involved in the study design, collection, analysis, interpretation of the data or the decision to publish.

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Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

[1] Westermaier T, Linsenmann T, Keßler AF, et al. Intraoperative cerebral angiography by intravenous contrast administration with 3-dimensional rotational fluoroscopy in patients with intracranial aneurysms: a feasibility study. Neurosurgery. 2015;11(2):119–126.

[2] Westermaier T, Linsenmann T, Homola GA, et al. 3D rotational fluoroscopy for intraoperative clip control in patients with intracranial aneurysms–assessment of feasibility and image quality. BMC Med Imaging. 2016;16(1):3.

[3] Sembrano JN, Santos ERG, Polly DW. New generation intraoperative three-dimensional imaging (O-arm) in 100 spine surgeries: does it change the surgical procedure? J Clin Neurosci. 2014;21(2):225–231.

[4] Linsenmann T, Lilla N, Stetter C, et al. Imaging of cerebral AVM and arteriovenous fistulas and occlusion control using intraoperative 3D rotational fluoroscopy. World Neurosurg. 2018;117:e500–e506.

[5] Washington CW, Zipfel GJ, Chicoine MR, et al. Comparing indocyanine green videoangiography to the gold standard of intraoperative digital subtraction angiography used in aneurysm surgery. J Neurosurg. 2013;118(2):420–427.

[6] Sun G, Ding J, Lu Y, et al. Comparison of standard- and low-tube voltage 320-detector row volume CT angiography in detection of intracranial aneurysms with digital subtraction angiography as gold standard. Acad Radiol. 2012;19(3):281–288.

[7] Pechlivanis I, Koenen D, Engelhardt M, et al. Computed tomographic angiography in the evaluation of clip placement for intracranial aneurysm. Acta Neurochir. 2008;150(7):669–676.

[8] Westerlaan HE, van der Vliet V, Hwe JM, et al. Magnetic resonance angiography in the selection of patients suitable for neurosurgical intervention of ruptured intracranial aneurysms. Neuroradiology. 2004;46(11):867–875.

[9] Roth C. Value of CT and MR angiography for diagnostics of intracranial aneurysms. Radiologe. 2011;51(2):106–112.

[10] Li MH, Li YD, Tan HQ, et al. Contrast-free MRA at 3.0 T for the detection of intracranial aneurysms. Neurology. 2011;77(7):667–676.

[11] Lubicz B, Neugroschl C, Collignon L, et al. Is digital substraction angiography still needed for the follow-up of intracranial aneurysms treated by embolisation with detachable coils? Neuroradiology. 2008;50(10):841–848.

[12] Bier G, Bongers MN, Hempel JM, et al. Follow-up CT and CT angiography after intracranial aneurysm clipping and coiling-improved image quality by iterative metal artifact reduction. Neuroradiology. 2017;59(7):649–654.

[13] Kwon O, Kang ST, Kim SH, et al. Maximum intensity projection using bidirectional compositing with block skipping. J Xray Sci Technol. 2015;23(1):33–44.

[14] Rohde V, Spangenberg P, Mayfrank L, et al. Advanced neuronavigation in skull base tumors and vascular lesions. Minim Invasive Neurosurg. 2005;48(1):13–18.

[15] Giordano M, Gallieni M, Zaed I, et al. Use of frameless stereotactic navigation system combined with intraoperative magnetic resonance imaging and 5-aminolevulinic acid. World Neurosurg. 2019;131:32–37.

[16] Puskas Z, Schuierer G. Determination of blood circulation time for optimizing contrast medium administration in CT angiography. Radiologe. 1996;36(9):750–757.

[17] Terasawa K, Hatcho A, Muroga K. Assessment of contrast enhancement using the variable contrast medium injection method in 3D-CTA of the head. Nihon Hoshasen Gijutsu Gakkai Zasshi. 2005;61(1):126–134.