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Original Article

Estimated radiation dose according to the craniocaudal angle in cerebral digital subtraction angiography: Patient and phantom study

Yunsun Song [a], Youngeun Kim [b], Seongsik Han [b], Tae Il Kim [b], Joon Ho Choi [b], Jun Young Maeng [b], Youngrak Choi [c], Deok Hee Lee [a,*]

[a] *Department of Radiology, Research Institute of Radiology, University of Ulsan College of Medicine, Asan Medical Center, 88, Olympic-ro 43-gil, Songpa-gu, Seoul 05505, Korea*
[b] *Department of Radiologic Technology, University of Ulsan College of Medicine, Asan Medical Center, Seoul, Korea*
[c] *Siemens Healthineers Ltd., Seoul, Korea*

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ABSTRACT

Background and purpose. – Routine use of cranial angulation with 15–20 degrees, craniocaudal angled (CC) view, for cerebral digital subtraction angiography (DSA) helps minimize bone subtraction artifacts with less overlapping of the vessels, however, it may increase the radiation dose. We designed the phantom and patient studies to determine the effect of the angulation to the radiation dose and the feasibility of true posteroanterior angled (PA) view, in cerebral DSA.
Materials and methods. – In the phantom study, frontal DSA was simulated with variable angulations. In the patient study with thirty-one subjects, one internal carotid arteriogram was obtained with the CC view and the other, PA view in every patient. The dose-area product (DAP) and reference air-kerma (AK) were measured and compared between the angles. A qualitative analysis was performed to assess the diagnostic performance of the DSA over the angles.
Results. – The phantom study confirmed that the greater craniocaudal angles caused higher radiation exposure. Especially, the radiation dose (AK) of the CC view was 5.4% higher than that of the PA view. In the patient study, the radiation dose of the PA view was significantly lower compared to the CC view (1.44 vs. 1.63 mGy, AK). In 4 patients, the dose particularly jumped when applying the CC view as the copper filter was automatically removed. The diagnostic ability of the DSA with the PA view tended to be higher without significance.
Conclusions. – In a daily routine cerebral angiography, a simple modification of the angle may help to minimize the radiation dose.

Introduction

Cerebral digital subtraction angiography (DSA) remains an important diagnostic tool for neurovascular diseases despite the great advancement in non-invasive imaging modalities such as computed tomography (CT) or magnetic resonance (MR) angiography. It is also useful for planning neurointerventional procedures or aneurysm surgery and for follow-up after treatment (aneurysm coiling or clipping) [1,2]. Recently, the number of DSA procedures increased owing to the great progress in endovascular procedures that are increasingly used as minimally invasive treatment [3].

The most negative element of the exam is its radiation hazard not only to the patients but also to the medical and paramedical team. There have been long efforts to avoid or minimize radiation exposure to patients since it has deterministic effects including skin epilation, erythema, and desquamation and also poses stochastic risks of cancer. As low as reasonably achievable, the (ALARA) principle has been the basis of currently available radiation dose reduction techniques that include adjustment of peak kilovoltage (kVp), milliampere (mA), source-to-image distance, collimation, filtration, magnification, and image processing method [4–9].

Beam (tube) angulation is also known to considerably influence patient radiation exposure by increasing tissue penetration in coronary intervention [10,11]. However, there is no report regarding the angulation in the neurovascular field. The standard posteroanterior (PA) projection, craniocaudal angled (CC) view, angulates the X-ray tube, usually 15–20° in a cranial direction, to superimpose the upper margin of the orbits and the top of the petrous ridges [1]. This has been the traditional angiographic view for the carotid injections since it gives a good overview of the arterial structures

* Corresponding author.
E-mail address: dhlee@amc.seoul.kr (D.H. Lee).

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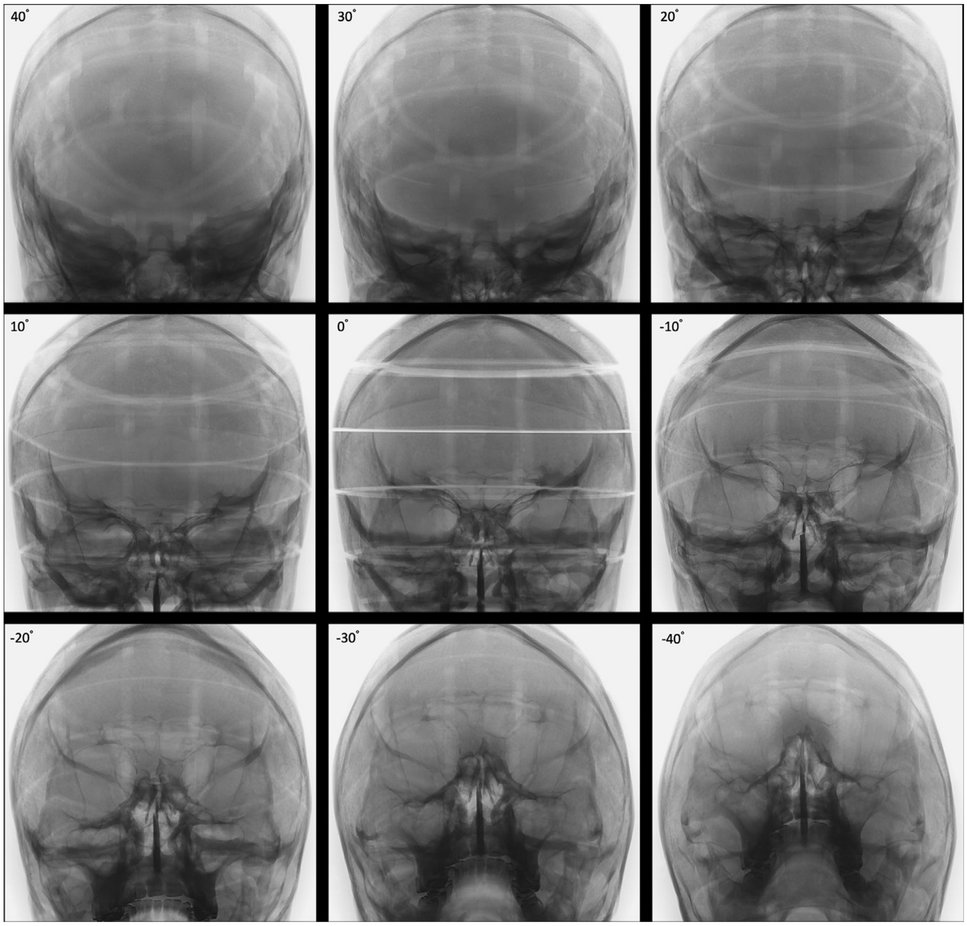

Fig. 1. Application of different cranial angles in the phantom study.

by spreading out MCA branches and minimizes overlap with the skull base [1,2].

Recent angiographic systems have attained much improved image quality, and bone subtraction artifacts may not have a significant impact on the diagnostic performance, at least on the diagnosis of intracranial aneurysms. Therefore, we presumed that the true PA angle, posteroanterior (PA) view, can be applied to cerebral angiography with the purpose of reducing the radiation dose.

Our purpose of this study is to determine that tube angulation can affect the radiation dose in cerebral DSA and if so, to assess how much radiation can be reduced when applying the PA view while performing routine cerebral angiography.

Material and methods

Image equipment and protocols

All angiograms were obtained using a biplane angiography unit (Artis Zee, Siemens, Germany). Radiation dose metrics were acquired using the on-board reference air-kerma (AK, mGy) and dose-area product (DAP, $\mu Gy{\cdot}m^2$) meters. The investigation was comprised of two parts, i.e., a phantom and a patient study. The phantom study was first performed in order to verify our hypothesis that tube angulation would affect the radiation dose. The patient study was conducted to determine if the absence of the angle, i.e. the PA view, could actually significantly reduce the radiation dose. Image protocols in these studies were the same as the optimized routine protocol used in our angiography suite.

Phantom study

ICA angiography was simulated using a RANDO head phantom (Alderson Research Labs, NY, USA). The radiation dosimetry in terms of AK and DAP were obtained with an application of various craniocaudal angles (caudal 40 $\sim$ cranial 40 degrees, 10-degree interval) with varying thickness of the copper filter (0 $\sim$ 0.3 mm). A frontal digital radiograph was obtained with one frame per second for five seconds and repeated five times using the same clinical angiographic imaging unit. The upper margin of the field-of-view (FOV) was adjusted to the inner table of the skull, and the lateral margins were tailored with some spaces that were constant throughout the study (Fig. 1). Other modifiable parameters remained the same throughout the study.

Patient study

Patient studies were prospectively performed using routine cerebral DSA which was performed by single operator from April to May 2017. Thirty-one consecutive patients who underwent cerebral angiography for a known, unruptured intracranial aneurysm were included in this study. We only included the patients who had a small aneurysm less than 5 mm in size for a further diagnostic performance test. The reasons for cerebral angiography included aneurysm confirmation, preoperative evaluation for clipping and preprocedural planning for coil embolization. The appropriate institutional review board approved this study and waived the requirement to obtain written, informed consent from patients.

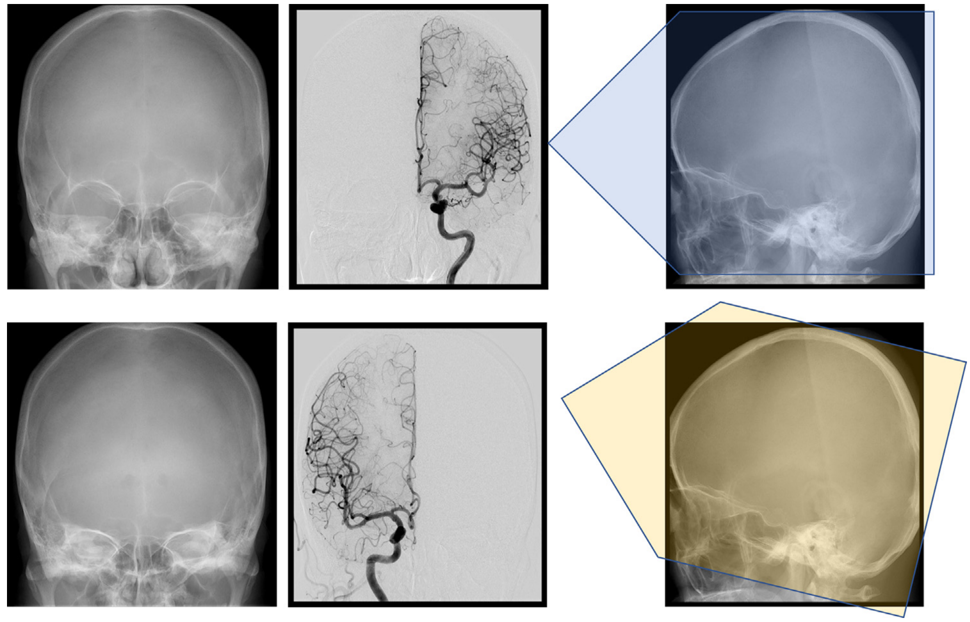

Fig. 2. Bilateral ICA-grams using two, different angles in the same patient. The PA view (upper row) and the CC view (lower row) were applied on the scout and digital subtraction angiography images of frontal view. The colored pentagons indicate the direction of the radiation beam on lateral angiographic view.

Routine cerebral angiography, which consisted of bilateral internal carotid artery (ICA) and vertebral artery (VA) grams, and 3-dimension rotational angiography for a target lesion, was performed in all patients. While obtaining the DSA on both sides of ICAs, a different craniocaudal angle was applied. The PA view was used for the one side and the CC view for the other side (Fig. 2). The true PA angle (PA view) meant virtually no angulation of the C arm and the petrous ridges were usually placed in the lower third of the orbital margins when the patient's head was placed in the neutral supine position on the excavated headrest provided by the vendor. The standard angle (CC view), which has traditionally been used for frontal ICA angiography, was defined as when the petrous ridges were aligned with the superior orbital rims [1] (Fig. 2). Except for the craniocaudal angles, other parameters, including the field-of-view, source-detector distance, and table height, were the same in both ICA-grams. The kVp and mA were automatically determined by the angiographic system in the fixed routine protocol. Additional copper filtration was routinely applied for radiation dose reduction. Copper filter selection was done automatically by applying the CareFilter protocol (Siemens Healthineers) to balance the radiation dose and the quality of the image.

Diagnostic performance evaluation

We assessed the diagnostic ability of the DSA with the PA view. For a comparison, DSA images in 24 patients (31 aneurysms) were also prospectively collected as a control group. The analysis was done by a neuroradiologist (Y. Song). Visibility of the aneurysms in the DSA images was graded as clearly visible, visible, barely visible, and invisible. 'Clearly visible' means that observer could locate the aneurysm at a glance within a single DSA run. 'Visible' means that observer found the aneurysm eventually with multiple DSA runs. 'Barely visible' means the aneurysm could be noticed on the DSA image only after reviewing the 3D images. 'Invisible' was graded when the aneurysm could not be demarcated. The degree of overlap between the aneurysm and vessels/skull base was evaluated.

Statistical considerations

Continuous variables are expressed as the mean ± standard deviation. Categorical variables are expressed as frequency with percentage. Statistical significance between dose parameters with the PA view and the CC view was determined using paired T-test or Wilcoxon signed-rank test (if the assumption of normality is violated on Shapiro–Wilk normality test) for continuous measures. Diagnostic qualitative tests were analyzed using Fisher's exact test and Wilcoxon rank-sum test. A P-value < 0.05 was considered to be statistically significant. Statistical calculations were computed using STATA version 13.0 (StataCorp LP, College Station, TX, USA).

Results

Phantom study

The AK value of the CC view (cranial 20 degrees) was 5.4% higher than that of the PA view (zero degree) in the group without a copper filter (4.24 vs. 4.03 mGy, P = 0.006). Other groups with filtration showed similar differences between the angles except for the 0.2-mm filter thickness group.

Radiation dose measurement with application of various craniocaudal angles and copper filter thickness are presented in Fig. 3. The graph showed a tendency that greater angulation in the caudal direction from zero degrees was associated with increased radiation dose irregardless of the filter thickness. In the other hand, AK showed only a slight tendency to increase by cranial angulation even though the radiation dose changed somewhat inconsistently, especially when applying 30 degrees of the cranial angle in which the dose invariably dropped in the all filter setting. The impact of the copper filter was evident in that addition of filter thickness made the radiation dose less. Average dose reduction was achieved by 38% (0.1–mm), 56% (0.2–mm), and 65% (0.3–mm) compared to the group without filtration.

Patient study

A total of 31 pairs of ICA-grams were obtained in 31 patients with unruptured intracranial aneurysms. The parameters of both

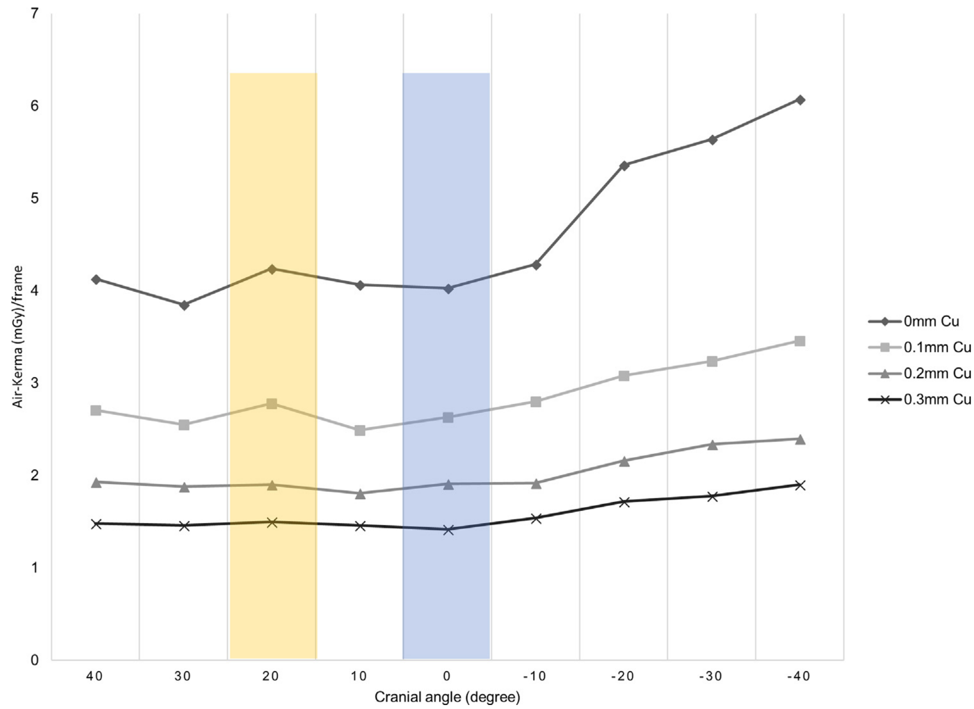

Fig. 3. Air-Kerma values (mGy/frame) depending on the various cranial angles and copper filter thicknesses in the phantom study. The PA view and the CC view are marked in blue and yellow areas respectively.

Table 1
Comparison of radiation doses and parameters in two protocols in a patient study.

Parameters	PA view (n = 31)	CC view (n = 31)	P-value[a]
Cranial angle	1.7 ± 4.1	19.4 ± 4.4	< 0.001
kVp	72.9 ± 2.2	73.1 ± 2.2	0.46
mA	162.9 ± 20.7	162.8 ± 20.9	0.87
Copper filter (mm)	0.71 ± 0.69	0.58 ± 0.71	0.04
0 mm	12 (38.7%)	16 (51.6%)	
0.1 mm	17 (54.8%)	13 (41.9%)	
0.2 mm	1 (3.2%)	1 (3.2%)	
0.3 mm	1 (3.2%)	1 (3.2%)	
DAP (μGy·m^2)	508.6 ± 206.7	566.1 ± 222.5	0.03
AK (mGy)	33.2 ± 13.2	37 ± 14	0.02
Frames	23 ± 0.9	22.8 ± 0.8	0.11
DAP/f	22.1 ± 8.9	24.9 ± 9.8	< 0.001
AK/f	1.44 ± 0.6	1.63 ± 0.6	< 0.001

Data presented as mean ± SD or n (%). PA: postero-anterior; CC: craniocaudal angled; DAP: dose-area product (μGy·m^2); AK: reference air-kerma (mGy); f: frame.
[a] Wilcoxon signed-rank test.

PA and CC view groups are summarized in Table 1. The mean cranial angles were 1.7 degrees in the PA view group and 19.4 degrees in the CC view group. In the PA view group, overall radiation doses were significantly lower in terms of the AK/frame (1.44 vs. 1.63 mGy, P < 0.001) and the DAP/frame (22.1 vs. 24.9 μGy·m^2, P < 0.001) and which was approximately an 11% reduction of the radiation dose (Fig. 4).

The copper filters were automatically introduced in 61.3% (n = 19; 0.1 mm (17), and 0.2 mm (1), 0.3 mm (1)) of the PA view and in 48.4% (n = 15; 0.1 mm (13), 0.2 mm (1), and 0.3 mm (1)) of the CC view. The thickness of the copper filter was altered in four patients in whom the 0.1-mm-thickness copper filter was automatically applied on the PA view which was not applied on the CC view. The mean radiation dose (AK) decreased by 47.8% (1.10 vs. 2.12 mGy) in the PA view compared to the CC view in four patients, although the mean kVP and mA did not differ between the patient groups. The AK/frame (1.49 vs. 1.55 mGy, P = 0.002) and the DAP/frame (22.7 vs. 23.6, P = 0.003) still resulted significant dose reduction in the PA view group even after excluding of the four patients with filter change.

Diagnostic performance analysis

The qualitative comparison between the angles were performed in total 55 patients with 62 aneurysms. The PA view was applied to the 31 aneurysms, and the CC view to the other 31 aneurysms. The location and the size of the aneurysms were not significant different between the groups and summarized in Table 2. The overlap between the aneurysm and the skull base was noticed higher in the PA view group (74.2 vs. 35.5%, P = 0.002). In the other hand, the degree of the overlap with the vessel did not show significant difference. Although the PA view group had a trend of higher visibility (clearly visible and visible) compared to the CC view group (90.3 vs. 64.6%, P = 0.096), there was no significant difference in the degree of the aneurysm visibility at both views.

Discussion

The major findings of this study were:

- the phantom study showed that the radiation dose level was significantly influenced by the craniocaudal angle on cerebral DSA and that applying the PA view (smaller craniocaudal angle) could reduce the radiation dose compared to use of the CC view;
- the patient study results corresponded to those of the phantom study in that the radiation dose decreased by 11% in the PA view group compared to the CC view group;
- the copper filter was automatically pulled out in 12.9% (4/31) of the patients with the CC view and which made the radiation dose much higher.

The relationship between the radiation dose and the tube angulation have already been studied in the cardiac catheterization field [2]. We confirmed our hypothesis that angulation may also increase the radiation dose in the cerebral DSA. The basic mechanism could

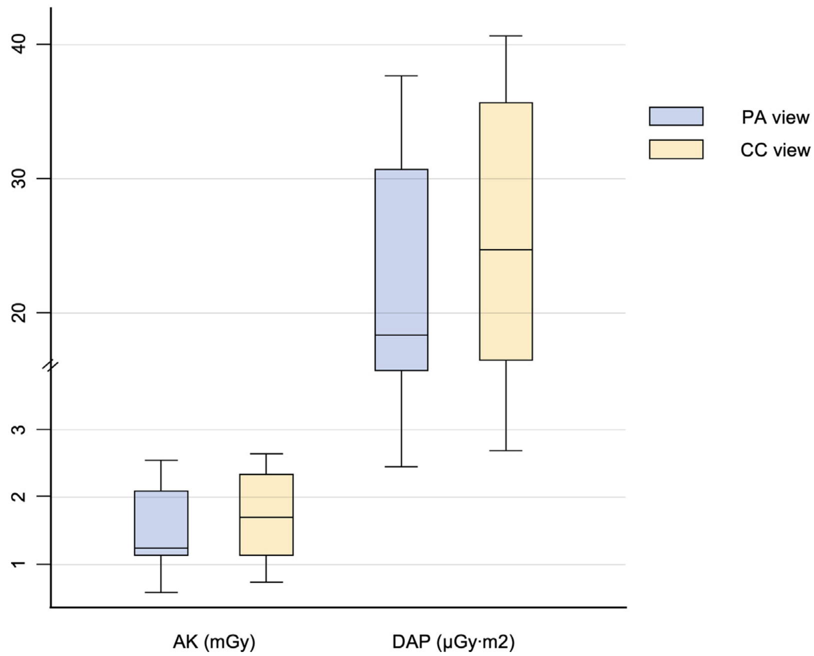

Fig. 4. Box plots showing the distribution of the reference air-kerma (mGy) and the dose-area product (µGy·m^2) for the PA view (left) and the CC view (right).

Table 2
Qualitative analysis of diagnostic performance between the PA angles.

	PA view (*n* = 31)	CC view (*n* = 31)	*P*-value[a,b]
Location			0.68[a]
Paraclinoid	15 (48.3)	12 (38.7)	
P-COM	5 (16.1)	7 (22.5)	
AchA	4 (12.9)	3 (9.6)	
A-COM	0 (0)	2 (6.4)	
MCA	7 (22.5)	7 (22.5)	
Size	3.5 ± 1.0	3.7 ± 0.9	0.38[b]
Vessel overlap			0.48[a]
100%	2 (6.4)	5 (16.1)	
> 50%	4 (12.9)	6 (19.3)	
50%	3 (9.6)	4 (12.9)	
< 50%	4 (12.9)	5 (16.1)	
0%	18 (58)	11 (35.4)	
Bone overlap	23 (74.1)	11 (35.4)	0.005[a]
Visibility			0.09[a]
Clearly visible	20 (64.5)	14 (45.1)	
Visible	8 (25.8)	6 (19.3)	
Barely visible	3 (9.6)	9 (29)	
Invisible	0 (0)	2 (6.4)	

Data presented as mean ± SD or *n* (%). PA: postero-anterior; CC: craniocaudal angled.
[a] Fisher's exact test for categorical variable.
[b] Wilcoxon rank-sum test for continuous measures.

be the same in that an oblique angle causes the radiation beam to penetrate more tissue due to the inevitably increased object thickness, and which leads to enhancing the radiation dose by the machine in order to maintain the image quality. One interesting finding we noticed in the phantom study was that introducing caudal angles made the radiation dose much higher than in the cranial angles (Fig. 3) This could be explained in that additionally included areas of the beam penetration on caudal angles were facial bony structures, i.e. mandible, alveolar bones, and teeth, which are relatively hyperdense structures in DSA, while on the other hand, the posterior neck soft tissues are additionally included on cranial angles (Fig. 1).

There was a small yet significant dose reduction (mean 11%) in the PA view in the patient study and which corresponded to the phantom study. This is noteworthy in that it has not been previously studied and is easy to apply on routine diagnostic cerebral angiography. This principle also applies to neurointerventional procedures in which extreme angles can often be used. This is especially true when using working angles (Waters' angle) in the treatment of anterior communicating artery origin aneurysms because these angled, magnified images can greatly increase the radiation dose. Even though it would not be always possible to apply the optimal angle to minimize the radiation dose, operators should always keep it in mind while doing procedures.

The finding regarding additional filtration could be another interesting and important issue. In our patient study we found that the thickness of the copper filter automatically changed between two different angles and which caused higher radiation exposure in four patients on the CC view. This phenomenon was caused by a protocol responsible for automatic selection of the optimal copper filtration thickness. This protocol (CARE Filter (Siemens; Artis Q ceiling), EPX (Philips; Azurion), Auto CU (GE; Innova IGS 540 Assist), RITE Beam Filter (Cannon; Infinix-I Sky+) was designed to balance the radiation dose, the load on equipment, and the quality of the image. Occasionally, as in the above cases, the radiation dose may increase while considering the load on the X-ray tube and maintenance of image quality. In recent years, as the heat capacity of the equipment has improved and the tube output has increased, the ability to cope with the increase in the object thickness has improved. The proper image quality can be obtained while using the certain filter thickness. In such a situation, it is preferable to use the fixed filter thickness. However, it should be considered that there may be a limit depending on the equipment. A selective use of the PA view when the automatic removal of the copper filter was anticipated may be one of the solutions to optimize the radiation dose.

When applying the PA view in a clinical setting, one important issue we had to address was a potential diagnostic problem. We assessed the diagnostic ability of both angles with small aneurysms which might be missed on a 2D DSA. The overlap of the skull base with the aneurysm was predictably observed more when using the PA view, but there was no significant difference in the visibility of the aneurysms. This fact may suggest that bone subtraction artifact has a negligible effect in the diagnosis of the small aneurysms.

Interestingly, the overlap of vessels with the aneurysm tended to be less in the PA view even though the results were not statistically significant and highly variable according to the location and the projecting direction of the aneurysms. The other issue we concerned about was that we may need to adapt to the PA view, instead of the CC view that we have been used to.

There are some limitations in the study. First, the degree of average dose reduction may not be clinically significant, even though statistically significant. In some patients, however, the dose was markedly increased when applying the CC view, which was caused by the automatic filter control. This phenomenon may carry an important clinical meaning. Second, since the anatomy of the skull and the neutral head position on the table may differ in all patients, a zero-degree angle on gantry does not always indicate the true PA angle. We manually adjusted the angles as close as possible to the true PA angle while viewing the fluoroscopic image. Third, the effect of the angle on the radiation dose could not be the same among patients as well as the phantom we used. This is probably because the anatomy of the skull differs in each patient. Fourth, the number of the aneurysms in the diagnostic analysis may be rather small to eliminate any diagnostic concern over the PA view. However, the analysis showed that the PA view had a trend of better aneurysm visibility compared to the CC view even though it was not statistically significant.

In the present study comprising a phantom and a sample of aneurysm patients, we addressed the way to lower the radiation dose in an angiographic examination. The patient study showed that applying the true PA angle could reduce the radiation dose, albeit small. More importantly, we found that the radiation dose considerably increased by removal of the copper filter as a part of the automatic exposure control when the tube angulation exceeds a certain critical point. It is advisable to recognize these phenomenon for minimizing the radiation dose in a daily routine cerebral angiography. The results of this study will also serve as a reminder of the relationship between the angle and radiation dose for other studies intending to reduce the radiation dose.

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Disclosure of interest

The authors declare that they have no competing interest.

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References

[1] Harrigan MR, Deveikis JP. Diagnostic cerebral angiography. Totowa, NJ: Humana Press; 2012. p. 99–131.
[2] van Asch CJJ, Velthuis BK, Rinkel GJE, et al. Diagnostic yield and accuracy of CT angiography, MR angiography, and digital subtraction angiography for detection of macrovascular causes of intracerebral haemorrhage: prospective, multicentre cohort study. BMJ 2015;351:h5762-h.
[3] Piazza M, Nayak N, Ali Z, et al. Trends in resident operative teaching opportunities for treatment of intracranial aneurysms. World Neurosurg 2017;103:194–200.
[4] Yi HJ, Sung JH, Lee DH, et al. Analysis of radiation doses and dose reduction strategies during cerebral digital subtraction angiography. World Neurosurg 2017;100:216–23.
[5] Schneider T, Wyse E, Pearl MS. Analysis of radiation doses incurred during diagnostic cerebral angiography after the implementation of dose reduction strategies. J Neurointerv Surg 2017;9:384–8.
[6] Kim DJ, Park MK, Jung DE, et al. Radiation dose reduction without compromise to image quality by alterations of filtration and focal spot size in cerebral angiography. Korean J Radiol 2017;18:722–8.
[7] Honarmand AR, Shaibani A, Pashaee T, et al. Subjective and objective evaluation of image quality in biplane cerebral digital subtraction angiography following significant acquisition dose reduction in a clinical setting. J Neurointerv Surg 2017;9:297–301.
[8] Implications of Commission recommendations that doses be kept as low as readily achievable. 1st ed. Oxford: Published for the International Commission on Radiological Protection by Pergamon Press; 1973.
[9] Ihn YK, Kim B-S, Byun JS, et al. Patient radiation exposure during diagnostic and therapeutic procedures for intracranial aneurysms: a multicenter study. Neurointervention 2016;11:78–85.
[10] Kuon E, Dahm JB, Empen K, et al. Identification of less-irradiating tube angulations in invasive cardiology. J Am Coll Cardiol 2004;44:1420–8.
[11] MPH SAM, MD AP, MD NSB, et al. Relationship of beam angulation and radiation exposure in the cardiac catheterization laboratory. JACC Cardiovasc Interv 2014;7:558–66.