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ORIGINAL RESEARCH

Title Impact of Patient Head Posture on Lens Radiation Exposure During Cerebral Angiography

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ABSTRACT

BACKGROUND AND PURPOSE: Cerebral angiography remains crucial for detailed characterization and preoperative assessments for intracranial aneurysm. Despite its diagnostic importance, cerebral angiography poses challenges due to its invasiveness, the risk of neurological complications, and radiation exposure. To investigate the impact of head posture on lens radiation exposure during cerebral angiography, this study focused on the correlation between radiation doses to the eye lens, head flexion angles, and head size.

MATERIALS AND METHODS: A retrospective analysis was performed on 20 patients who underwent cerebral angiography for unruptured intracranial aneurysms between October and November 2022. Radiation doses to the lens, which were measured in a prior prospective study using photoluminescent glass dosimeters, were analyzed alongside head flexion angles, anteroposterior (AP) head diameters, and kerma-area product (KAP) to evaluate their correlation with lens radiation exposure. The lateral radiation source is located on the left side of the patients.

RESULTS: The cohort consisted of 20 patients (60% female, mean age: 62.3 ± 9.9 years). The radiation dose to the left eye (the eye closer to the x-ray source) was 2.8 times higher than that to the right eye (9.18 ± 3.31 mGy vs. 3.3 ± 0.60 mGy, $P < 0.001$). A strong positive correlation was observed between the left eye lens dose and head flexion angle ($R = 0.815$, $P < 0.001$). While the AP head diameter significantly correlated with the flexion angle, it showed no significant correlation with lens dose. The KAP was inversely correlated with both the left lens dose ($R = -0.597$, $P = 0.005$) and the flexion angle ($R = -0.689$, $P < 0.001$).

CONCLUSIONS: Our findings underscore the significant impact of head posture on lens radiation exposure during cerebral angiography. Adjusting head positioning may provide a practical approach to reduce radiation exposure to the lens. Furthermore, it is worth noting that the left lens received more radiation than the right, likely due to the X-ray source being on the left side of the patient.

ABBREVIATIONS: AP = anteroposterior; KAP = kerma-area product, PLD = photoluminescent glass dosimeter.

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SUMMARY SECTION

PREVIOUS LITERATURE: The eye lens is the most radiosensitive organ in the head and neck region, and radiation exposure to the lens is inevitable during cerebral angiography due to its anatomical proximity. It is known that the radiation dose to the lens significantly varies among individuals during cerebral angiography. However, the factors contributing to this variability are not yet known.

KEY FINDINGS: The flexion angle of the patient's head during the examination showed a strong correlation with the radiation dose to the lens, especially the left eye lens. On average, the radiation dose to the left eye was 2.8 times higher than that to the right eye.

KNOWLEDGE ADVANCEMENT: The varying head flexion angles among patients are the main contributors to the variability in lens dose. Adjusting the headrest height to a neutral or slightly extended position may effectively reduce lens exposure.

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INTRODUCTION

Intracranial aneurysm is a critical condition that can be life-threatening, resulting in subarachnoid hemorrhage in case of a rupture[1]. Intracranial aneurysms can be easily diagnosed via MR angiography or CT angiography with over 95% sensitivity[2]. Despite this, cerebral angiography is still widely used to characterize intracranial aneurysms and plays a critical role in the preoperative evaluation for clipping or coil embolization [2, 3]. However, choosing cerebral angiography as a diagnostic modality is not easy due to its invasiveness, associated risk of neurological complications, and potential for radiation exposure [3, 4]. This section may be divided into subsections if it facilitates reading the paper. The research design, patients/subjects, material used, means of confirming diagnoses, and statistical methods should be included. Do not include manufacturer's names unless the specific product is important to the procedures performed. When appropriate, indicate that approval was obtained from the institution's review board. Indicate that informed consent has been obtained from patients who participated in clinical investigations.

The lens of the eye is one of the most radiosensitive organs in the head region, with a nominal threshold of 500mGy for cataract formation [5]. Due to its close anatomical proximity, radiation exposure of the lens during cerebral angiography or head and neck CT is unavoidable. In our previous studies, we have focused on minimizing the radiation dose to the eye lens during these examinations [6, 7]. While doing so, we incidentally found that the radiation dose received by the lens varied significantly among patients. Therefore, in this study, we sought to investigate the mechanisms and anatomical factors associated with these variations in radiation exposure to the eye lens during cerebral angiography.

MATERIALS AND METHODS

Study design and patients

The study conducted a retrospective analysis of 20 patients who underwent cerebral angiography for the evaluation of unruptured intracranial aneurysms. These patients were part of a prospective study that took place between October 2022 and November 2022 at our center (Asan Medical Center, Seoul, South Korea). The analysis included patients aged between 18 and 80 years who underwent 4-vessel angiography, which covered both the internal carotid and vertebral arteries. Exclusion criteria included patients who had radio-opaque substances in the head from previous procedures, those who required additional angiography during the examination, and those who declined to participate in the study. The retrospective study protocol was approved by the Institutional Review Board of our institution (IRB No. 2024-0363), which waived the requirement for informed consent.

Angiography and imaging equipment

Angiography in this study was performed using a 5-French catheter through the femoral artery. The catheter was positioned either in the proximal cervical internal carotid artery (ICA) or in the foraminal segment of the vertebral artery (VA), guided by roadmap and fluoroscopy. Routine DSA involved biplane imaging for both ICAs and the dominant VA, and single-plane (anteroposterior plane) imaging for the non-dominant VA. When DSA suggested an aneurysm or vascular anomaly, a 3D rotational angiography was performed. A radiolucent headrest of universal size was used for all patients in this study.

A biplane angiography machine (Artis zee biplane; Siemens Healthineers, Forchheim, Germany) was used for image and data acquisition. The lateral radiation source is located on the left side of the patients. The detector entrance dose was 1.82 μGy/frame. Copper filters were automatically applied within the range of 0.1 and 0.3 mm. The angiographic system automatically determined the kVp, milliampere (mA), pulse width, and copper filter in the optimized routine protocol of our angiography suite [7].

Lens radiation measurement and dosimetry system

The lens dose, defined as the radiation exposure to the eye lens, was estimated by measuring the entrance surface air kerma using a photoluminescent glass dosimeter (PLD). Specifically, three PLDs (GD-352M, AGC Techno Glass Co., LTD), each with a diameter of 4.33 mm and a length of 14.52 mm, were applied to the lateral canthus of each eye. For secure placement and stability during the examination, a specially designed pouch and goggles were used7. This setup was consistently maintained throughout the entire examination process, except during the 3D rotational angiography phase when the PLDs were removed.

For the assessment of radiation dose metrics in this study, we utilized the onboard meters to measure reference air kerma (AK, mGy) and the kerma-area product (KAP, Gy·cm²). The values are displayed in the equipment's dose report.

Head size and position measurements

In this study, the anteroposterior (AP) diameter of the head in all patients was measured using previously obtained diagnostic imaging, including sagittal T1-weighted images (T1-WI), time-of-flight (TOF) magnetic resonance angiography (MRA), and computed tomography angiography (CTA), which were conducted for the diagnosis of intracerebral aneurysms. The AP diameter was determined as the maximum distance between the outer cortex of the skull, parallel to the line connecting the petrous apex to the lens.

The flexion angle of the head during cerebral angiography is measured in the lateral plane as the angle between the line from the petrous apex to the lens and the horizontal line of the field of view (FOV) (**Fig. 1**). A zero angle signifies a neutral head position; positive angles indicate head flexion and negative angles suggest head extension.

Statistical analysis

Continuous variables are reported as mean ± standard deviation, while categorical variables are expressed as frequencies and percentages. A paired t-test was used to compare the lens doses in both eyes. Pearson's correlation coefficient was used to assess the relationships between lens dose and head flexion angle, head AP diameter, and KAP. Due to the significant differences in dose observed between the two eyes, lens doses were analyzed individually. Additionally, the relationships among KAP, flexion angle, and AP diameter were evaluated. All statistical analyses were conducted using R Studio (version 4.3.2, The R Project for Statistical Computing, Vienna, Austria). The confidence interval was set at 95%, and a P-value of less than 0.05 was considered statistically significant.

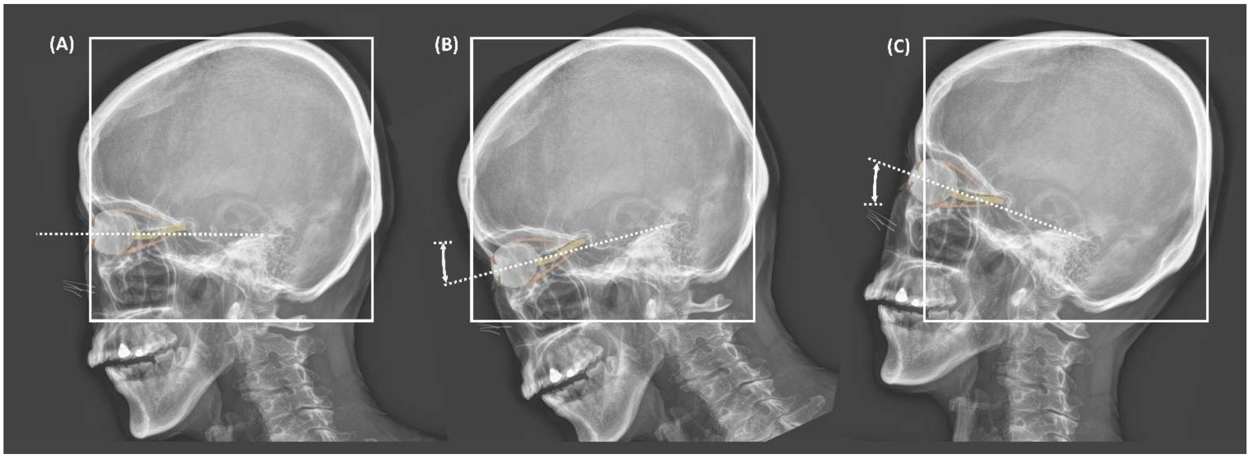


FIG 1. Illustration of field-of-view (FOV) change according to the head flexion angle: (A) neutral position, (B) flexion position, (C) extension position. The dotted line represents the line from the petrous apex to the lens, while the curved arrow indicates the flexion angle, defined as the angle between the line from the petrous apex to the lens and the horizontal line of the FOV, presented as a white box. In the neutral position (A), the lens was located at the border of the FOV. In the flexion position (B), the lens shifted into the FOV. However, the lens was outside of the FOV and significantly further from the FOV in the extended position (C).

RESULTS

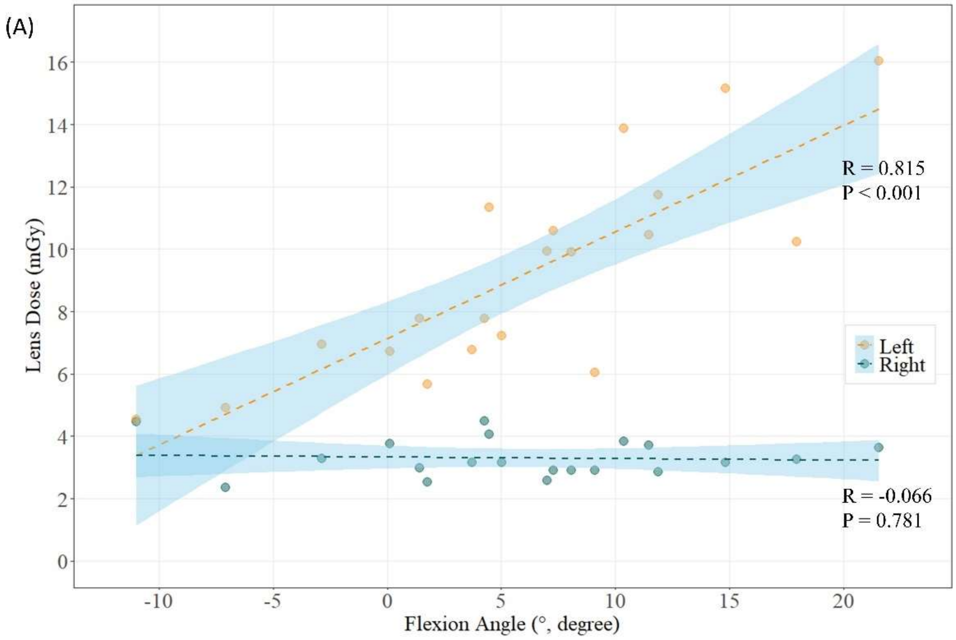
Patient characteristics

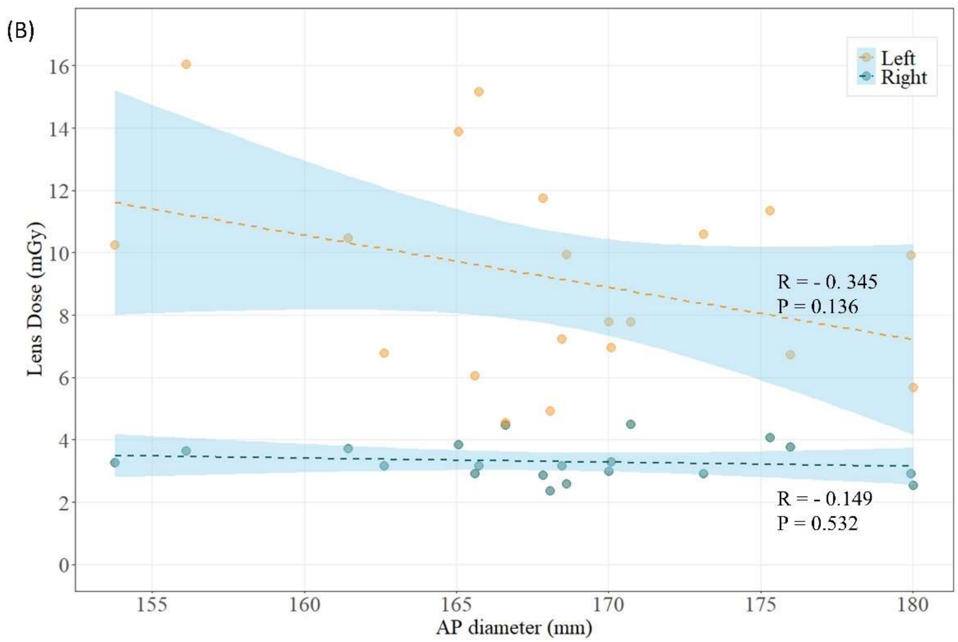
A total of 20 patients (60% female) with a mean age of 62.3 ± 9.9 years were included in the study (**Table 1**). The average head flexion angle was 6.0 ± 7.8 degrees. The mean AP head diameter was 168.3 ± 6.8 mm. The radiation dose to the left eye was 2.8 times higher than that to the right eye (9.18 ± 3.31 mGy vs. 3.3 ± 0.60 mGy, $P < 0.001$). The mean KAP was 21.67 ± 6.0 Gy·cm², and the average AK was 134.0 ± 32.1 mGy.

Factors affecting the lens dose

A significant correlation was observed between the lens dose of the left eye and the head flexion angle ($R = 0.815$, $P < 0.001$; **Fig. 2A**). Conversely, the lens dose of the right eye did not significantly correlate with the flexion angle ($R = -0.066$, $P = 0.781$). The AP diameter of the head did not show a significant correlation with the radiation exposure of the lenses in either eye; in contrast, a trend was observed for the radiation dose to the left lens to decrease with increasing AP diameter ($R = -0.345$, $P = 0.136$; **Fig. 2B**). An increasing flexion angle was associated with a decreasing AP diameter ($R = -0.496$, $P = 0.026$), indicating that patients with smaller head AP diameters may flex their heads more (**Fig. 2C**).

There was a significant negative correlation between the KAP and lens dose in the left eye ($R = -0.597$, $P = 0.005$), but not in the right eye ($R = 0.051$, $P = 0.830$, **Supplementary Fig. 1A**). Furthermore, a significant negative correlation was observed between the KAP and the flexion angle ($R = -0.689$, $P < 0.001$, **Supplementary Fig. 1B**), indicating that as the flexion angle decreased, KAP tended to increase. However, a significant correlation was also identified between KAP and the AP diameter of the head ($R = 0.401$, $P = 0.079$, **Supplementary Fig. 1C**). As the AP diameter increased, KAP tended to increase.


(A)
Lens Dose (mGy)
Flexion Angle (°, degree)
R = 0.815
P < 0.001
R = -0.066
P = 0.781
Left
Right


(B)
Lens Dose (mGy)
AP diameter (mm)
R = - 0. 345
P = 0.136
R = - 0.149
P = 0.532
Left
Right

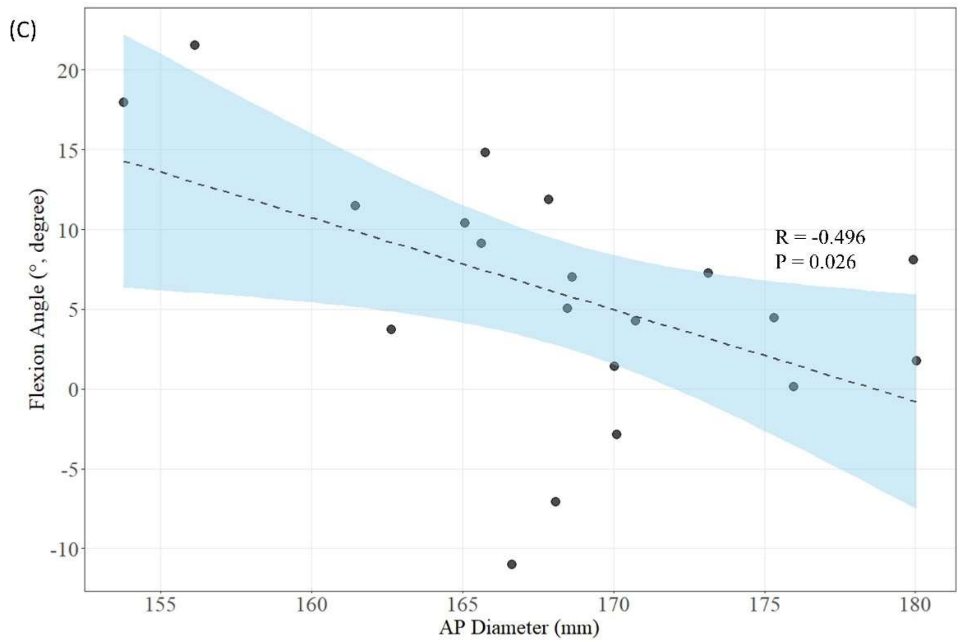


FIG 2. Scatter plots illustrating the relationships between (A) head flexion angle and lens dose, (B) AP diameter of the head and lens dose, and (C) head flexion angle and AP diameter of the head.

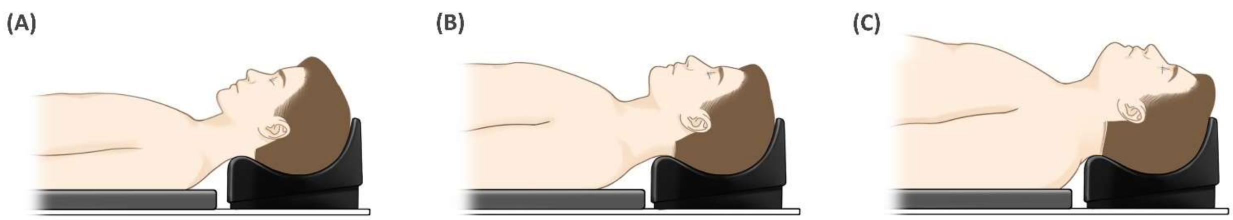


FIG 3. Illustration of head position changes relative to the anteroposterior (AP) diameter of the head and the corresponding body shape: (A) a flexion position for an individual with a small head and body size, (B) a neutral position for an individual with an average-sized head and body, and (C) an extension position for an individual with a large head and body.

Table 1: Baseline characteristics of the patients (n = 20).

Characteristics	Values
Age, years	62.3 ± 9.9
Female sex	12 (60.0)
Anteroposterior diameter of the head, mm	168.3 ± 6.8
Flexion angle of the head, degrees	6.0 ± 7.8
Radiation dose to the lens, mGy* ※	
Right eye	3.30 ± 0.60
Left eye	9.18 ± 3.31
Kerma area product, Gy·cm²	21.6 ± 6.0
Air kerma, mGy	134.0 ± 32.1

* The radiation dose was measured during digital subtraction angiography (DSA) and fluoroscopy.

※ P-value was <0.001. Paired t-test was used to compare the lens doses between the eyes.

Data are presented as mean ± standard deviation or number (%).

DISCUSSION

The study revealed that radiation exposure to the lens is significantly affected by the head's flexion angle during cerebral angiography, with greater flexion leading to a higher dose. Additionally, there was a noticeable difference in radiation exposure between the eyes; the left eye received higher doses and was more sensitive to changes in the flexion angle. Although the head's flexion angle tended to decrease as the AP diameter of the head increased, there was no direct correlation between the head size and the lens dose in either eye.

The influence of the head's flexion angle on lens dose is likely due to the positioning of the eye lens. This can be explained by the shift in the eye lens's location relative to the FOV with different head positions (**Fig. 1**). As supported by Ryu JC et al., positioning the head off-center can reduce lens dose by moving the lens outside the FOV during 3D rotational angiography [6]. In a neutral head position, the lens is outside the FOV; however, when the head is flexed, the lens moves into the FOV, resulting in increased radiation exposure. In contrast, an extended head keeps the lens outside the FOV. **Figure 1** illustrates the relationship between the flexion angle, lens location, and FOV.

The left eye is subject to significantly higher lens doses than the right eye and displays greater sensitivity to the flexion angle of the head. This discrepancy likely results from the left eye being closer to the radiation source on the lateral plane, which increases its exposure to both indirect scattered radiation and direct rays. This observation is consistent with prior studies that have reported increased radiation exposure to the left eye lens [7-9]. Considering that the positioning of both eyes relative to the radiation source in the AP plane is identical, it can be inferred that radiation from the AP plane plays a minor role in the observed difference. Another intriguing observation is the negative correlation between KAP and the lens dose of the left eye. Typically, KAP serves as a measure of patient exposure to radiation; paradoxically, a higher KAP during cerebral angiography may suggest a larger head size, which often corresponds to an extended positioning (**Fig. 3**). This extended positioning, in turn, leads to a reduction in the lens dose.

There have been few studies focused on the relationship between head positions and radiation dose during cerebral angiography. Previous studies have shown the amount and difference in lens dose for both eyes during interventions; however, they have not proven which factor influences the lens dose [8, 9]. Other studies have shown that tilting of the CT gantry or neck extension can impact the lens dose during head and neck CT scans [10, 11]. Similar to this study, tilting the gantry or extending the neck moves the lenses to a location where they are exposed to relatively less radiation.

The flexion angle of the head, which can affect the lens dose during cerebral angiography, can be adjusted by changing the headrest height. Individuals with smaller heads and bodies may require a lower headrest, while those with larger heads and bodies might need a higher headrest to maintain a neutral head position. Although a more extended head position further reduces the lens dose, it can lead to patient discomfort. Therefore, finding a balance with a neutral or slightly extended head position could effectively optimize both the lens dose and patient comfort. Furthermore, if supported by angiomachines, adjusting the detector's orientation based on the flexion angle may serve as an effective strategy to minimize radiation exposure to the lens.

There are several limitations in this study. Firstly, it was a retrospective study with a limited number of participants. However, the data was derived from a well-controlled previous prospective study and seemed adequate to establish a relationship between the factors and lens doses. Secondly, the impact of the height of the headrest on the head flexion angle and lens dose could not be assessed. Future prospective studies should be conducted to optimize headrest height for minimizing dose and enhancing patient comfort. Thirdly, radiation doses from AP and lateral planes were not distinguished, as separating these measurements would require increased contrast use and extended procedure time, which could potentially compromise patient safety. Lastly, the study only measured AP head diameters, which might not fully reflect all structural information of the heads.

CONCLUSIONS

In conclusion, our study revealed that the flexion angle of the head significantly influences the variation in lens dose among patients. Notably, the lens dose in the left eye was significantly higher than in the right eye, and it increased significantly when the patient's head was flexed during examination. Adjusting the headrest height to maintain a neutral or slightly extended position could be a simple yet useful strategy to minimize lens exposure.

ACKNOWLEDGMENTS

None

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SUPPLEMENTAL FILES

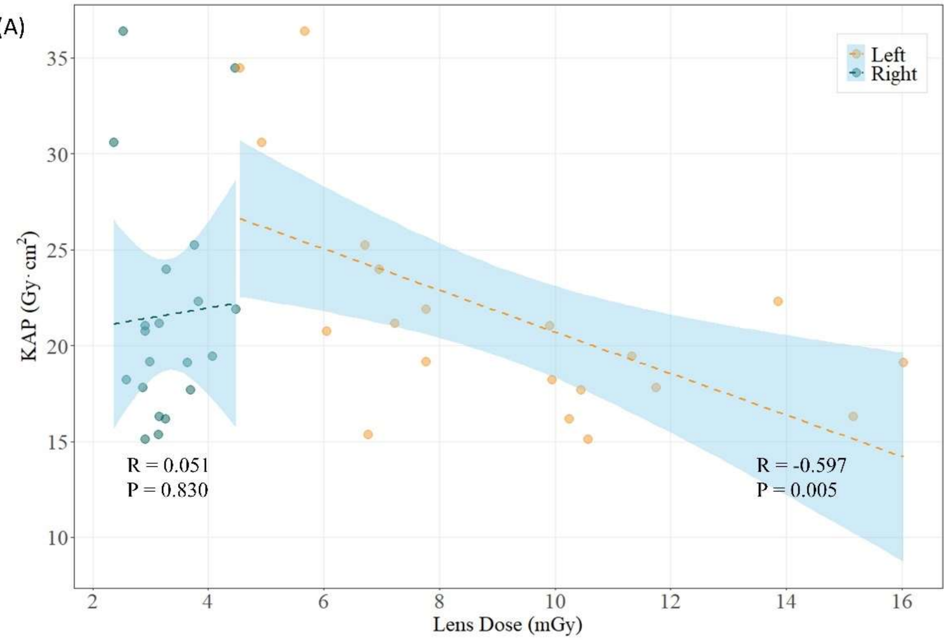
Supplementary Table 1. Differences in Kerma Area Product for anteroposterior and lateral views based on aneurysm location

Characteristic	Right (n=12)	Left (n=17)	P-value
Anteroposterior (Gy·cm2)	14.8 (12.7 – 16.8)	15.4 (14.4 – 17.8)	.40
Lateral (Gy·cm2)	5.5 (4.4 – 7.8)	6.9 (4.8 – 8.7)	.56

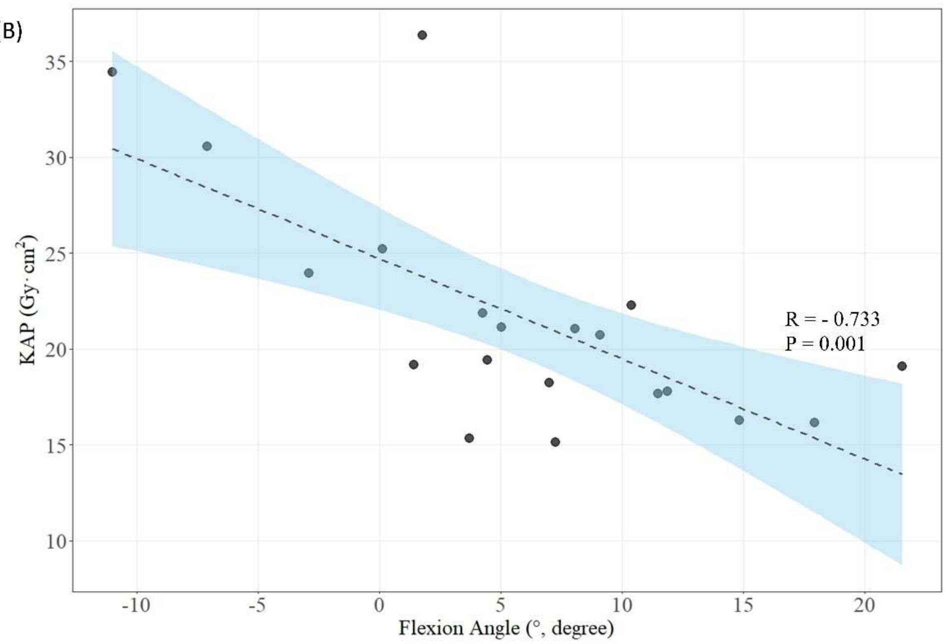
Data are presented as the median (interquartile range)

Wilcoxon signed rank Test was used to compare the KAP in aneurysm location

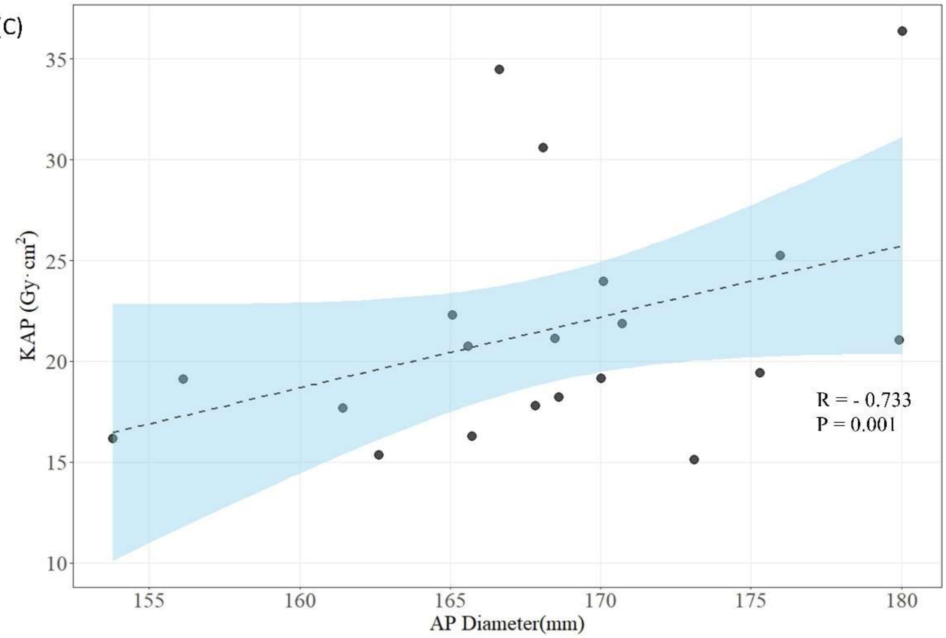
(A)


Left
Right
R = 0.051
P = 0.830
R = -0.597
P = 0.005
KAP (Gy·cm^2)
Lens Dose (mGy)

(B)

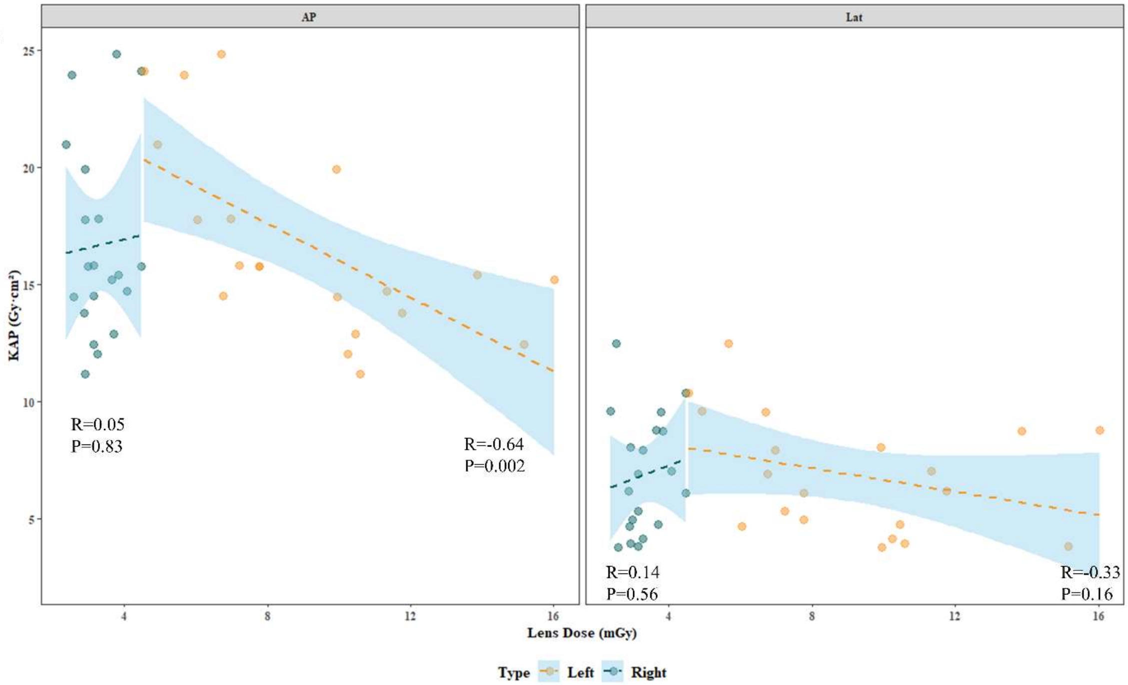

R = - 0.733
P = 0.001
KAP (Gy·cm^2)
Flexion Angle (°, degree)

(C)

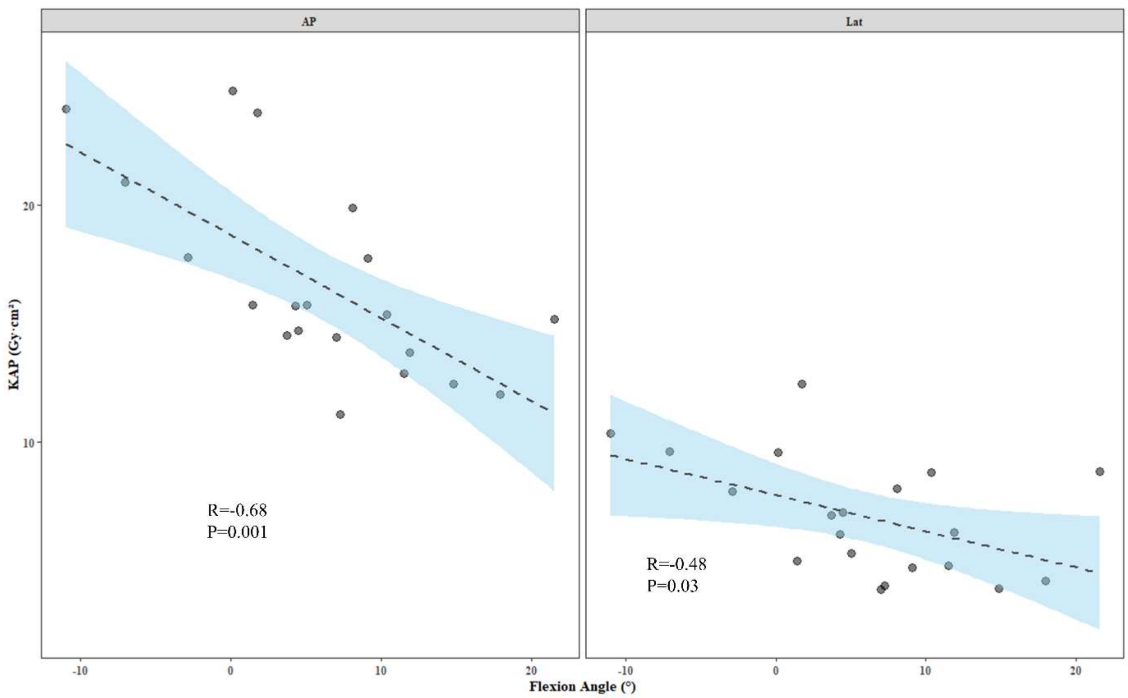


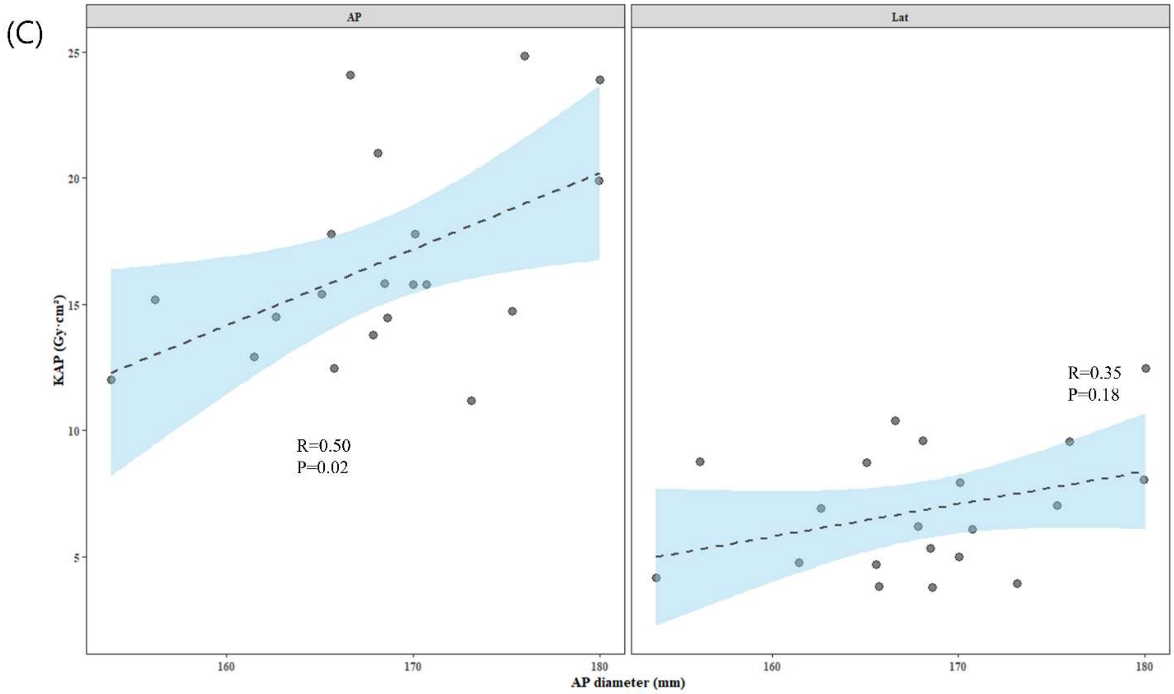
Supplementary Figure 1. Scatter plot illustrating the relationships between (A) lens dose of each eye and KAP, (B) head flexion angle and KAP, and (C) AP diameter of head and KAP.

(A)


AP
Lat
KAP (Gy·cm²)
R=0.05
P=0.83
R=-0.64
P=0.002
R=0.14
P=0.56
R=-0.33
P=0.16
Lens Dose (mGy)
Type Left Right

(B)


AP
Lat
KAP (Gy·cm²)
R=-0.68
P=0.001
R=-0.48
P=0.03
Flexion Angle (°)



Supplementary Figure 2. Scatter plot illustrating the relationships between (A) lens dose of each eye and KAP in each AP and lateral tube, (B) head flexion angle and KAP in each AP and lateral tube, and (C) AP diameter of head and KAP in each AP and lateral tube.