

Radiation safety assessment of patient and staff during intracranial aneurysm treatment: A phantom study

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ABSTRACT

Background: Endovascular treatment using coiling embolization for intracranial aneurysms is common in interventional neuroradiology (INR). However, it is associated with high radiation exposure to both patients and medical staff. The assessment and management of radiation risk have been a concern.

Objective: To evaluate patient and scatter radiation doses at INR staff working position during the coiling embolization procedure in a phantom study.

Materials and methods: An anthropometric phantom from head to pelvis was placed on an angiographic table. To determine the phantom's entrance skin dose (ESD), 19 NanoDot optically stimulated luminescence dosimeters (OSLDs) were placed on the surface of the head phantom. Moreover, 6 NanoDot OSLDs were also placed on the surface of the phantom at 3 critical organs (eyes, thyroid, ovaries). To determine the scatter radiation dose at staff working position, polyvinyl chloride pipes (150 cm height) were placed at the position of all staff, including interventional radiologist (IR), radiology resident (RR), scrubbed nurse (SN), radiologic technologist (RT), circulating nurse (CN), and nurse anesthetists (AN). The InLight® OSLDs were placed on each PVC pipe at 50, 100, and 150 cm height from the floor level. Coiling embolization was simulated following the standard procedure using a bi-plane digital subtraction angiography unit with standard radiation protective equipment. The patient doses from the radiation dose structured report (RDSR) were also recorded.

Results: The highest ESDs were observed in the occipital part ($1,631.56 \pm 36.97$ mGy). These ESD peaks were also observed within the safety limit and produced no skin reaction. The radiation dose at the left eye was observed to be the highest value among critical organs. The highest scatter radiation dose was observed at the position of IR at 100 cm level. Among CN, AN, and RT positions, the highest dose was recorded at the RT position at the level of 150 cm. The RDSR showed that most of the patient radiation dose was received from the 2-dimension angiography.

Conclusion: The distribution of radiation dose varied across different staff positions. As the key person conducting the coiling embolization procedure, the IR position received the highest radiation dose. Thus, close monitoring and development of additional radiation protection methods for this position are essential. Although the radiation dose at the back of the head was elevated, it remained within safety limits. Nevertheless, the monitoring of potential radiation effects should not be neglected.

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Introduction

Endovascular treatment using coiling embolization has become a treatment for intracranial aneurysms due to its minimal invasiveness, high success rates, reduced

risks, and recovery time.¹⁻³ This procedure usually requires prolonged fluoroscopy and multiple angiographic images, causing significant radiation exposure and increasing the risk of developing deterministic and stochastic effects.⁴ It has been reported that early skin reactions such as erythema can occur at doses above 2 Gy, and a severe skin burn might develop if the exposures exceed 5 Gy. Moreover, temporary hair loss, permanent hair loss, and radiation-induced cataracts can be observed at doses around 3, 7, and 0.5 Gy, respectively.⁵ Moreover, the risk of cancer development is estimated to increase by 5% per sievert of effective dose for the general population.⁶ For safety issues, several studies have evaluated patient radiation dose using the radiation dose structured report (RDSR), direct measurement using a dosimeter in clinical practice, and phantom study.⁷⁻¹¹ The report of patient radiation dose is usually presented in terms of dose area product (DAP), reference air kerma, peak skin dose, effective dose, and absorbed dose. Previous studies have revealed that some radiation effects are observed in patients with embolization procedures.^{12,13} Moreover, the eye lens dose has also been reported to exceed the threshold.¹⁰ Monitoring and assessing patient radiation dose during embolization is an essential topic.

In addition to patients, medical staff, including radiologists, radiology residents, scrub nurses, and radiological technologists, are also usually exposed to scattered radiation, which could contribute to their overall radiation burden. It has been reported that using appropriate radiation personal protective equipment and shield techniques such as ceiling-mounted lead shields and lead curtains has been shown to lower radiation dose at staff positions.¹⁴⁻¹⁶ Although several personal protective equipment safety measures were applied to clinical practice, the radiation dose was also detected with high value in a complicated procedure, particularly embolization.¹⁷⁻¹⁹ Due to the complexity and prolonged procedure of coiling embolization, the evaluation of scatter radiation doses received by all staff to ensure that they remain within safe occupational limits should be performed accordingly.

Recently, the number of intracranial aneurysms treated with endovascular techniques has significantly increased,²⁰ which might raise the risk of radiation exposure to medical staff. Furthermore, some staff may still surpass

this threshold due to the inconsistently worn lead glasses for lowering eye lens radiation exposure and the reduction of occupational eye lens dose limit to 20 mSv per year.^{21,22} Although personal dosimeters are regularly used in clinical practice, they cannot sufficiently represent the level of scatter dose distribution in the other important organs. In addition, the variation of equipment, protocol, and complexity of cases in each institute were noted. The assessment of radiation risk for patients and staff at each institute is essential for effective management and minimizing radiation-related hazards. The findings could be utilized to improve safety protocols for medical staff and establish follow-up procedures for patients exposed to high radiation doses.

Therefore, this study aimed to evaluate patient radiation dose and scatter radiation dose in INR staff working positions during the coiling embolization procedure in a phantom study.

Materials and methods

Digital subtraction angiography machine setting

All angiographic procedures were conducted using a digital subtraction angiography (DSA) machine, Artis Zee biplane (Siemens Medical Solutions, Munich, Germany). The DSA system underwent quarterly maintenance by the engineer of Siemens Healthineers Limited (Bangkok, Thailand). In addition, the Department of Medical Sciences and the Ministry of Public Health of Thailand conduct annual quality control checks using the national standard guidelines. During the experiment, the DSA machine was inspected and confirmed to function normally, while annual quality control results met the national standard. The DSA unit consists of two x-ray tubes and two flat-panel detectors. Tube A is located under the couch, while Tube B and Detector B are located laterally, as illustrated in Figure 1A. The system's radiation protection features include a lead curtain with 0.5 mm lead (Pb) equivalent (137x57 cm) positioned alongside the angiographic table and a ceiling-mounted lead glass shield with 0.5 mm Pb equivalent (61 cm x 76 cm). Additionally, lead shield partitions consisting of lead plate thickness of 1.5 mm (120 cm x 100 cm) and lead glass shield with 2.0 mmPb equivalent were provided to enhance radiation protection for nursing staff, as shown in Figure 1B.

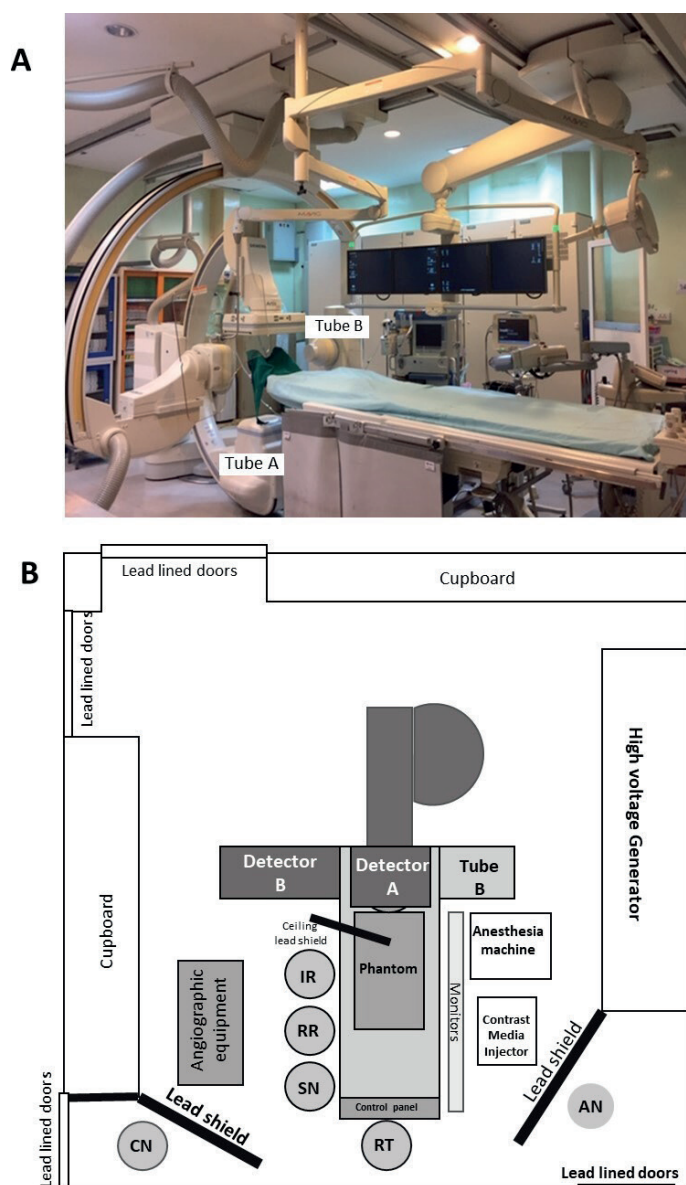


Figure 1. Angiographic suite with bi-plane systems (A) and the top-view perspective illustration demonstrates the position of staff and radiation protective equipment during coiling embolization (B).

The angiographic procedures involved a multi-disciplinary team comprising an interventional radiologist (IR), a radiology resident (RR), a scrub nurse (SN), a radiologic technologist (RT), a circulating nurse (CN), and a nurse anesthetist (AN). The specific working positions of each

staff member are shown in Figure 1B. The angiographic protocol for coiling embolization during the experiments was configured to mirror the clinical settings outlined in Table 1.

Table 1. Coiling embolization protocol.

Setting parameters	Coiling embolization
Fluoroscopy	
Tube angulation of Tube A and B (°)	0°/0°
Pulse fluoroscopy (pulse/second, p/s)	10 p/s
Fluoroscopy time of Tube A and B (min)	23 min/ 12 min
2-Dimensional angiography (2DA)	
Tube angulation of Tube A and B (°)	11°/0°
Frame rate (frame/second, f/s), time (second)*	
Mask image	4 f/s, 1 sec
Arterial phase	4 f/s, 4 sec
Capillary phase	2 f/s, 4 sec
Venous phase*	1 f/s
Number of images	610
3-Dimensional rotational angiography (3DRA)	
Tube rotational angulation (°)	200°
Frame rate and acquisition time	133 f/s, 5 sec
Number of images	532
Digital radiography (DR)	
Tube angulation of Tube A and B (°)	11°/0°
Number of images	2
Source to image distance (cm)	
Fluoroscopy, 2DA and DR (Tube A/ B)	102/94
3DRA (Tube A)	120
Table level (from isocenter point)	
	-15 cm
Field of view (Diagonal length)	
Fluoroscopy and 2DA (detector A/B)	35 cm/25 cm
3DRA (A)	42 cm
DR	42 cm

*Time in the venous phase is not identified, as it depends on the requirement of the radiologist.

Coiling embolization experiments

The coiling embolization procedures were simulated using the parameters detailed in Table 1. The imaging techniques employed in this experiment included fluoroscopy, 2-dimensional angiography (2DA), 3-dimensional rotational angiography (3DRA), and digital radiography (DR). The imaging technique and protocol used in this study were designed specifically for this experiment by the product specialist to ensure the consistency and reproducibility of each experiment. To experiment, fluoroscopy techniques (10 pulses/second) from both planes were performed with fluoroscopy time of 23 minutes (tube A) and 12 minutes (tube B). Then, 2DA was performed using the acquisition as follows: 13 seconds (plane A and B) for 1 acquisition, 8 seconds (plane A and B) for 10 acquisitions, and 8 seconds (plane A) for 1 acquisition. A total of 610 images were

obtained. The 3DRA was performed twice with 4 acquisitions (mask and contrast acquisition) with 532 images. At the end of the experiment, DR images from both planes were obtained. At the same time, reference air kerma, dose area product (DAP) of each radiographic technique, and peak skin dose were recorded from the radiation dose structured report (RDSR). The effective dose was determined by multiplying the DAP value with the conversion coefficient of 0.087 mSv/Gy·cm²,^{9,23} and data was expressed as mSv.

Radiation dose measurement

To determine the scatter radiation dose at staff working positions, 6 polyvinyl chloride (PVC) pipes (150 cm height) were placed at the position of all staff, as shown in Figure 1B. The PVC pipes at IR, RR, and SN locations were placed 15 cm apart from the edge of the angiographic table with

a 50 cm interval between each pipe, while RT, CN, and AN were placed at their respective positions. The InLight® OSLDs (environment type, Ex) were placed on each PVC pipe at three different levels to represent the level of staff organs, including eyes lens (150 cm), hands or arms (100 cm), and legs (50 cm) as displayed in Figure 2. All InLight®

OSLDs Ex were placed facing the radiation source from the X-ray tube. To ensure the experiment's reliability and reproducibility, the locations of PVC pipes for each staff position were marked on the floor with additional marking of the PVC pipes at 50, 100, and 150 cm.

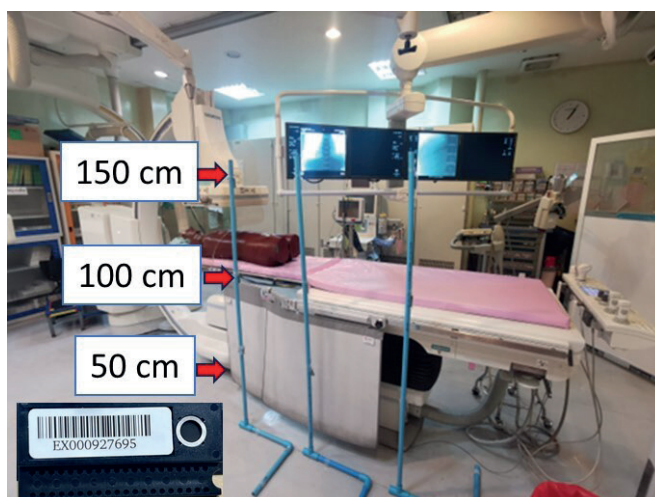


Figure 2. The setting of PVC pipes and level of InLight® OSLDs placement.

The sequence of radiation dose exposure at all staff positions was conducted following the institution's operating procedure. IR, RR, and SN were exposed to radiation during the experiment only during the fluoroscopy procedure and removed from the angiographic suit. In contrast, CN and AN were exposed to radiation during the procedure. Moreover, RT was exposed to radiation during the fluoroscopy at its position and moved to the position of CN during 2DA, 3DRA, and DR procedures.

Since almost all the patients who underwent coiling embolization were critical patients with endotracheal tubes, the direct measurement of entrance skin dose (ESD) in these patients is neither safe nor practical. Therefore, an anthropometric phantom was used instead of patients to replicate radiation dose measurement. To determine the ESD of the phantom, head-to-pelvis anthropometric

phantoms were placed on an angiographic table, as depicted in Figure 3A. NanoDot OSLDs were placed on the surface of the head phantom at 19 points, as displayed in Figure 3B. Moreover, 6 nanoDot OSLDs were also placed on the surface of the phantom at critical organ positions, including left and right eyes (LE, RE), thyroid (LT, RT), and female gonadal organs (LO, RO). To ensure the accuracy of the OSLDs placement in every experiment, these points were marked on the phantom with a permanent marker. The experiment and radiation dose measurements were performed in triplicate. Of these, unexposed OSLDs were used as controls and kept under the same conditions as the exposed OSLDs. The data from these OSLDs were then used for radiation dose calculations. After radiation exposure, all OSLDs were sent to the Personal Dosimetry Laboratory at the Office of Atoms for Peace (OAP) for radiation dose evaluation.

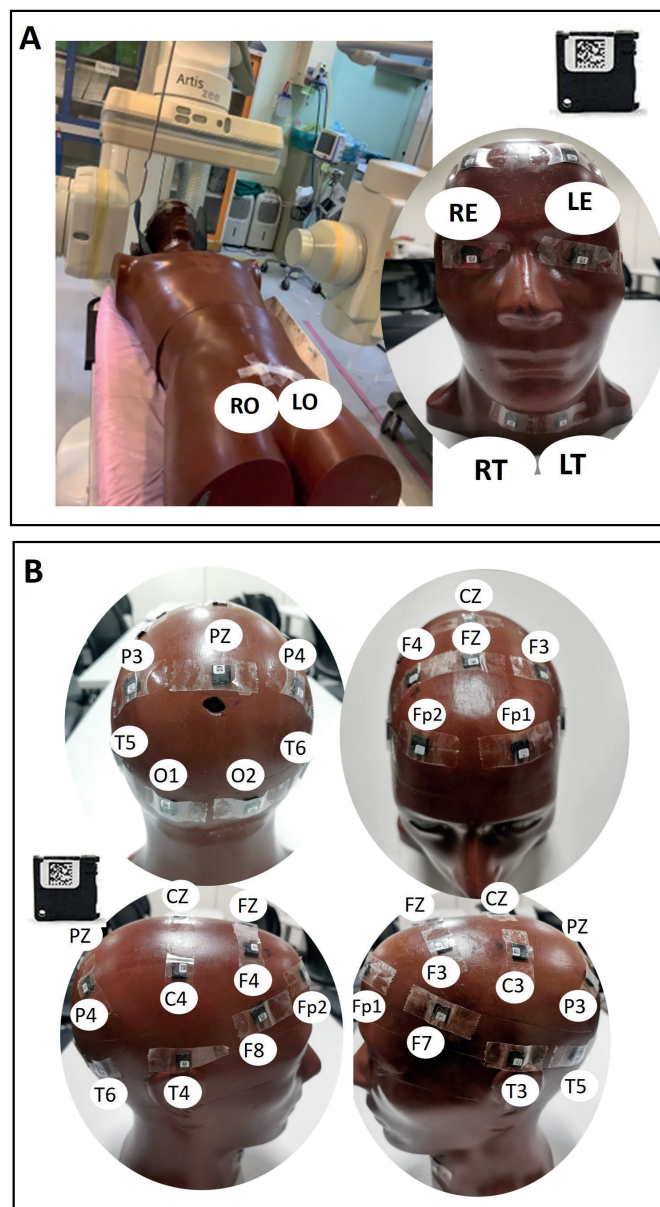


Figure 3. The setting of anthropometric phantom and the nanoDot OSLD placing on phantom skin at 3 critical organs (A). The location of nanoDot OSLD placed on head phantom surface (B).

Radiation dose evaluation

All OSLD radiation doses were evaluated using a MicroStar reader, and data readouts were performed using the MicroStar reader (Landauer Inc., Glenwood, Illinois, USA). The radiation doses were calculated by analyzing the emitted light from the stimulated dosimeters using the commercial software InLight Dose Calculation version 2.0.6.6, developed by Landauer, Inc. (Landauer Inc., Glenwood, Illinois, USA). The software was calibrated using a set of nanoDot dosimeters with known doses exposed to a Reference Quality Radiation 6 or RQR6 beam quality (80 kV) traceable to the National Institute of Standards and Technology (NIST). The most recent calibration was completed in May 2023. Additionally, routine quality control tests are conducted on the MicroStar reader using dosimeters irradiated with different known doses at the Primary Standard Dosimetry Laboratory, Office of Atoms for Peace (OAP) to assure measurement accuracy and reliability.

InLight® OSLDs Ex were read using a configuration that specified the dosimeter type as “environment” and the kind of case default as “Ex”. The dosimeter was placed in an InLight loader, and all elements were read. The results were reported as ambient dose equivalent ($H_p(10)$), which is relevant for whole-body radiation assessment, and directional dose equivalent ($H_p(3)$), which is applicable for skin, extremity, or eye lens.²⁴ Both doses were reported in mSv, the standard unit in radiation dose measurement.

Specific steps were followed during the configuration and reading process to read nanodot OSLDs. The dosimeter type was set to nanoDot, and the display unit was configured to show the dose in mGy. The nanoDot OSLD was fitted with an adapter and inserted into the InLight loader for reading. The results were presented in mGy units.

To ensure objectivity in the analysis, the researcher responsible for OSLDs reading and radiation dose calculation was blinded to the placement positions of each OSLD. To

calculate radiation dose, the residual signal of each OSLD was read after annealing and kept as a baseline. The exposed OSLD was then read twice, and the radiation dose was calculated by subtracting the basis and control values (unexposed OSLD). The radiation dose from all OSLDs of each position was averaged. A phantom skin dose and dose at critical organs were expressed as mGy, while radiation dose scatter radiation dose at staff working position was described as mSv.

Statistical analysis

All data was presented as mean±standard deviation (SD). Radiation dose calculation, the effective dose from

RDSR, mean, and SD were analyzed using the Microsoft Excel.

Results

Radiation dose structured report

The patient radiation dose from the dose report of the DSA modality is presented in Table 2. It was found that most of the radiation dose was received from the 2DA technique (2,665.7±26.2 mGy, 40,255.0±11.3 µGy·m²). The peak skin entrance dose was 2,372±2.8 mGy, and the effective dose from coiling embolization was 55.00±0.01 mSv.

Table 2. Radiation dose coiling embolization form dose report.

Dose report	Value
<i>Reference air kerma (mGy)</i>	
Fluoroscopy	1,130±4.2
2DA	2,665.7±26.2
3DRA	207.0±1.4
DR	3.8±0.1
Total reference air kerma	4,009.5±31.9
<i>DAP (Gy·cm²)</i>	
Fluoroscopy	171.01±0.16
2DA	402.55±0.11
3DRA	57.71±0.04
DR	1.02±0.01
Total DAP	632.28±0.08
<i>Effective dose (mSv)</i>	
Fluoroscopy	14.89±0.01
2DA	35.01±0.01
3DRA	5.02±0.00
DR	0.09±0.00
Total effective dose	55.00±0.01
Peak skin entrance dose (mGy)	2,372.0±2.80

Phantom skin dose

The ESD of the head phantom from coiling embolization is shown in Table 3. The ESD has a varied distribution across the head phantom. The peak ESD was found at O1 ($1,631.56 \pm 36.97$ mGy), followed by O2 ($1,513.49 \pm 88.75$

mGy), located at the back of the head phantom. The point that obtained the lowest radiation dose was Fp2 (40.01 ± 7.83 mGy), which was located at the front of the head phantom. The radiation dose at the left side of all points was higher than that of the right.

Table 3. The skin radiation dose of head phantom from coiling embolization procedure.

Point of measurement		Skin radiation dose (mGy)
1	Fp1 (L)	47.70 ± 15.11
2	Fp2 (R)	40.01 ± 7.83
3	F3 (L)	268.74 ± 13.45
4	F4 (R)	67.12 ± 5.24
5	F7 (L)	346.61 ± 25.30
6	F8 (R)	74.12 ± 5.46
7	Fz (C)	84.01 ± 55.01
8	Cz (C)	121.97 ± 1.11
9	Pz (C)	$1,027.04 \pm 8.53$
10	C3 (L)	477.41 ± 22.59
11	C4 (R)	166.32 ± 9.54
12	P3 (L)	$1,089.60 \pm 143.33$
13	P4 (R)	970.57 ± 80.80
14	T3 (L)	423.07 ± 0.18
15	T4 (R)	277.93 ± 5.48
16	T5 (L)	$1,190.94 \pm 167.99$
17	T6 (R)	$1,082.87 \pm 102.99$
18	O1 (L)	$1,631.56 \pm 36.97$
19	O2 (R)	$1,513.49 \pm 88.75$

Radiation dose of phantom critical organs

Table 4 presents the radiation dose at phantom critical organs. The highest radiation dose at these critical organ points was found at LE (59.97 ± 7.99 mGy), followed by RE

(47.18 ± 3.14 , 9.72 ± 1.27 mGy). The radiation dose on the left side of these points was slightly higher than on the right.

Table 4 The radiation dose to the critical organs of phantom from the coiling embolization procedure.

Location of measurement	Radiation dose (mGy)
LE	59.97 ± 7.99
RE	47.18 ± 3.14
LT	12.38 ± 1.54
RT	9.72 ± 1.27
LO	0.13 ± 0.01
RO	0.13 ± 0.01

Scatter radiation dose at staff working position

The scatter radiation dose at the staff working positions during the coiling embolization procedure is presented in Figure 4. Among the three positions exposed to radiation during fluoroscopy (IR, RR, SN), the IR position at 100 cm received the highest dose (0.193 ± 0.093 mSv), followed by the IR position at 150 cm (0.173 ± 0.020 mSv). The lowest scatter radiation dose was observed at the SN position at 150 cm (0.042 ± 0.018 mSv). At the IR position, the radiation

dose at the level of 50 cm was detected, with the lowest among all three levels. The overall radiation dose at RR and SN was lower than IR's. Although CN, AN, and RT positions were protected by shielding and distance from the radiation source, measurable radiation doses were still detected. The highest dose was recorded at the RT position at 150 cm (0.085 ± 0.007 mSv), while the lowest dose was observed at the CN position at 50 cm (0.043 ± 0.018 mSv).

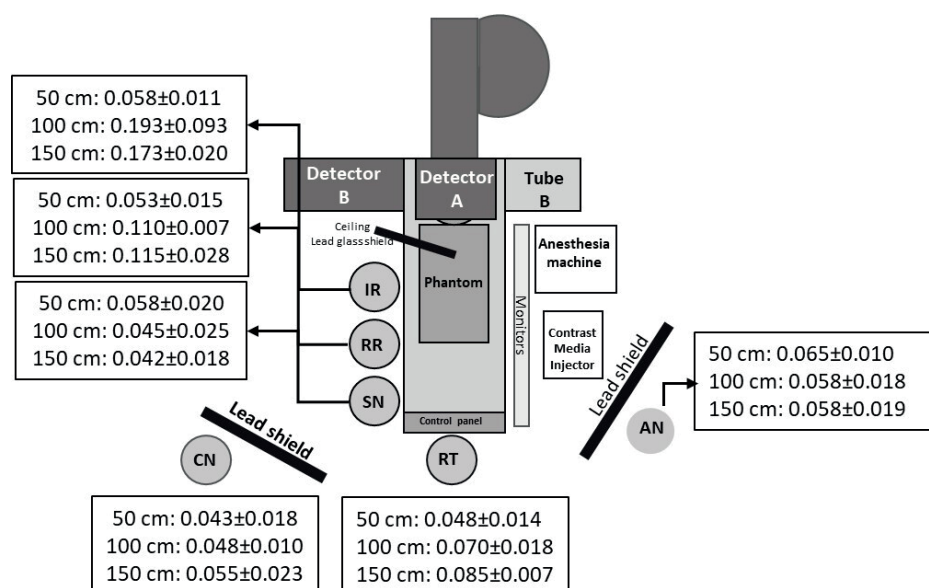


Figure 4. The scatter radiation dose distribution among 6 staffs positions and 3 levels on each position. The radiation dose is expressed as mSv.

Discussion

This study assesses radiation dose during coiling embolization in patients and medical staff using the OSLDs technology. These findings are relevant to our institute and can serve as important information in improving radiation protection strategies for patients and staff in clinical practice. A high dose was recorded at the back of the head (O1, O2 point), which aligned with the previous study's findings.^{8,25} It has been previously reported that the bi-plane DSA system produces a higher radiation dose for plane A DSA.²⁶ The angulation and the magnification of images of plane A DSA play a crucial role in the higher radiation dose of this plane.^{27,28} Since the radiation entered the head phantom from the back (plane A) and left side (plane B) while in a supine position, the left and back of the head phantom received higher radiation doses than the right and front, respectively.

The experimental data from the RDSR revealed that most of the patient's radiation dose exposure during the coiling embolization procedure originated from the 2DA technique, contributing to a significant skin radiation dose.^{25,29,30} The peak skin entrance dose observed ($>2,000$ mGy) suggests a need for optimizing the 2DA technique to minimize patient exposure and decrease the risk of radiation effects, particularly stochastic effects.⁵ This study's total DAP, reference air kerma, effective dose, and fluoroscopy time were similar to the previous report. Still, the peak

skin entrance dose was slightly higher than the reported study.⁹ Interestingly, the peak skin entrance dose from RDSR was higher than the information from nanoDot OSLD. The PSD from RDSR was obtained by multiplying reference air kerma with the conversion factor; hence, these data differed slightly. In addition, the angulation dependence of nanoDot OSLD has been reported,^{31,32} which might contribute an essential role in the difference in radiation dose between RDSR and nanoDot OSLD. When determining a patient's skin dose, an external dosimeter and radiation dose measurement from the RDSR should be considered.

Radiation exposures exceeding the threshold can result in tissue injury, leading to cell death. When the exposure surpasses the threshold, radiation-induced cell death may cause erythema, skin reactions, or hair loss.^{4,5} Several studies have reported that the back of patients' heads usually receives a higher radiation dose during fluoroscopic-guided procedures, leading to radiation effects such as hair loss.^{12,13,33}

A comparison of skin doses with previous reports is shown in Table 5. The skin doses at the back of the head of the phantom in this study were lower than that reported in other studies, where alopecia was observed following embolization of intracranial vascular abnormality. During coiling embolization, particularly in complex procedures, radiation exposure may exceed the threshold, leading to potential radiation consequences. Therefore, the INR unit

must establish a monitoring system to track and manage possible skin reactions in patients exposed to higher radiation levels. Additionally, efforts should focus on identifying and implementing optimization techniques to reduce patient radiation doses.

The critical organs, including eyes, thyroid, and ovaries, were also assessed to determine the safety of these organs. Since the eyes were in the radiation field, they received a higher radiation dose than the others. The threshold for radiation-induced cataracts has been reported as more than 1-2 Gy for acute exposure and 5-8 Gy for chronic exposures.³⁴ This study found that the maximum dose at eye level of the phantom was 59.97 ± 7.99 mGy, which was significantly lower than the threshold dose and remained within safety limits. The left eye and left thyroid received a higher radiation dose than the right side, which conformed with the study of Sánchez and colleagues.¹⁰ On the other hand, lower radiation doses were detected concerning the ovaries far from the radiation field. As reported previously, the angulation of nanoDot OSLD might affect low radiation dose detection.^{32,35}

Numerous studies have demonstrated the occupational dose of staff from interventional radiology units using different dosimeter types in clinical practice and phantom study.^{7,11,18,19,35,36} However, a few recent studies have focused on multidisciplinary staff exposure during neurointerventional procedures. Mussmann and colleagues have demonstrated radiation exposure to staff during INR procedures in clinical practice. Radiologists received the highest radiation dose, ranging from 0.5-218.6 μ Sv, while radiographers received lower doses, ranging from 0.1-51 μ Sv.³⁷ Other studies also reported that the radiologist received eye doses from therapeutic procedures of INR ranging from 13-289 μ Sv.³⁸

Although this was a phantom study, the findings on staff doses were consistent with those of previous research. In addition, this study extended its scope beyond radiologists and radiological technologists to include other staff members.

The difference in radiation dose among the three positions (IR, RR, and SN) across the three levels was attributed to two key radiation protection principles: distance from the radiation source and shielding system.³⁹ At 50 cm level, both IR and RR positions were shielded by a lead curtain placed at the side of the angiographic table. Although a ceiling lead glass shield was also used at the IR position, limitations such as its small size and the gap between the shield and the patient were noted. As a result, the radiation dose at 50 cm level was lower than at 100 and 150 cm levels. In this study, the radiation dose at 150 cm was used to estimate the eye lens exposure for radiologists. During the year of experimentation, coiling embolization was the most common procedure, with 72 cases. Although the calculated annual dose based on the number of cases per year (12.46 mSv/year) did not exceed the dose limit (20 mSv), further exposure from other endovascular treatment procedures may result in a higher eye lens dose than the limit. It has been reported that staff exposed to radiation have a higher risk of developing cataracts compared to those not exposed.^{40,41} Therefore, prioritizing using lead

glasses and improving radiation protection measures for radiologists are essential.

In contrast, at the SN position, the radiation dose was higher at 50 cm levels than at the other levels due to the absence of a lead curtain shield. Among RT, CN, and AN, the highest radiation dose was recorded at the RT position, which was closer to the radiation source. The radiation doses at 50 and 100 cm were used to estimate the skin dose at the leg and hand, respectively. The occupational dose limit for skin exposure is 500 mSv/year.⁴² The estimated annual skin dose at the IR position was 13.90 mSv/year (72 cases/year). Therefore, none of the staff received radiation doses that reached this limit. Nonetheless, developing efficient radiation protection strategies is essential to minimize radiation risk, particularly radiation-induced cancer, among all staff.

Moreover, certain limitations include the following. Although experimental parameters such as tube angulation, fluoroscopy time, number of images, and other conditions were held constant throughout the triplicate experiments, the standard deviation of radiation dose measurements in this study remained relatively high. This variability can be attributed to several factors. Firstly, scatter radiation consists of low-energy X-rays that are less energetic than the primary X-ray beam. Previous studies have demonstrated that low-energy radiation is associated with a higher percentage of measurement errors due to its increased sensitivity to environmental and equipment factors.⁴³ Furthermore, measurement variability is due to each OSLD's unique sensitivity, influenced by manufacturing batches and inherent material properties. To address these challenges, determining the precise energy of scatter radiation and calibrating OSLDs to match the specific radiation energy used could enhance the accuracy and reproducibility of dose measurements. Implementing such calibration techniques might mitigate the effects of sensitivity variability and reduce standard deviations in future investigations. Since the data for simulating coiling embolization were collected retrospectively from a dose report program, substantial details were missing, such as fluoroscopy magnification, tube angulation during coiling procedures, and the number of hand injections of contrast media by interventional radiology.

As a result, this experiment may not fully replicate clinical conditions. Factors influencing OSLDs measurements, such as using a phantom instead of real patients, may not accurately reflect the actual radiation doses patients receive. Additionally, the radiation dose at staff positions was measured using PVC pipes. Because a phantom equivalent was not used, only scatter radiation in the air was estimated, excluding backscatter radiation. Further research is required to address these limitations, such as a prospective study in a clinical setting using different types of dosimeters to monitor radiation doses or a phantom study that simulates the setting as closely as possible to an actual examination, as well as employing a tissue equivalent phantom as staff to include backscatter radiation.

Conclusion

The distribution of radiation dose varied across different staff positions. As the key person conducting the coiling embolization procedure, the IR position received the highest radiation dose. Hence, close monitoring and developing additional radiation protection methods for this position are essential. Although the radiation dose at the back of the head and eye was high, it remained within safety limits. Nevertheless, the monitoring of potential radiation effects should not be neglected. Lastly, the high radiation generated by the 2DA technique should be optimized to enhance its safety and efficiency.

Conflict of interest

The author declared no conflict of interest.

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