Journal of Associated Medical Sciences 2024; 57 (1): 29-37

JAMS
Journal of Associated Medical Sciences

Scopus Indexed & Thai-Journal Citation Index Centre (TCI)

Journal of Associated Medical Sciences

Journal homepage: https://www.tci-thaijo.org/index.php/bulletinAMS/index

Radiation dose in radiologist from cerebral angiography using optically stimulated luminescence dosimeter

Tanyawimol Somtom[1] Thanakorn Somboot[1] Panatsada Awikunprasert[1*] Sirikarn Kittichotwarat[2] Puttita Damchoo[2] Atithep Mongkolratnan[3] Tanapol Dachviriyakij[4]

[1]Department of Radiological Technology, Faculty of Medicine Vajira Hospital, Navamindradhiraj University, Bangkok, Thailand
[2]Office of The Director, Faculty of Medicine Vajira Hospital, Navamindradhiraj University, Bangkok, Thailand
[3]Department of Surgery, Faculty of Medicine Vajira Hospital, Navamindradhiraj University, Bangkok, Thailand
[4]Ionising Radiation Metrology Group, Office of Atoms for Peace, Bangkok, Thailand

ARTICLE INFO

Article history:
Received 11 August 2023
Accepted as revised 3 October 2023
Available online 9 October 2023

Keywords:
Cerebral angiography, radiologist, OSL, controlled area

ABSTRACT

Background: The number of cerebral angiography procedures is increasing, resulting in higher X-ray radiation doses received by radiologists. Consequently, understanding the radiation doses received by radiologists and the accumulation of radiation in control rooms is crucial for guiding prevention strategies against radiation hazards.

Objectives: This study aimed to measure and evaluate radiation doses to the hands, lenses of the eyes, and thyroids of radiologists performing cerebral angiography procedures, as well as to measure the accumulated radiation dose in the control room.

Materials and methods: OSL dosimeters were placed on the eyeglass frames, thyroids, hands, and legs of radiologists performing 20 cerebral angiography procedures, as well as on the wall and window of the control room.

Results: Radiologists' average radiation doses were measured at specific body parts as follows: left eye (49 µSv), right eye (15 µSv), left hands (34 µSv), right hands (16 µSv), left legs (27 µSv), right legs (7 µSv), and thyroid glands (14 µSv). Notably, the received doses remained well within the maximum radiation dose limit established by the International Commission on Radiological Protection (ICRP). When calculating the maximum number of procedures that can be performed annually, we based it on the limit of the radiation dose that the eyes' lenses should not exceed. Our findings revealed that the permissible number of procedures determined by the lens radiation dose limit, should not surpass 405 cases annually (equivalent to 34 cases per month). The radiation dose from therapeutic angiography procedures was discovered to be up to 5 times higher than that from diagnostic angiography procedures. The maximum accumulated radiation dose in the control room was 1.18 µSv/hr, which remained below the limit of the Department of Medical Sciences (< 3 µSv/hr).

Conclusion: Radiologists receive less radiation from cerebral diagnostic angiography than therapeutic angiography. Organs on the left side were exposed to greater radiation levels than those on the right side. Wearing radiation protection devices during each procedure can reduce radiation exposure and mitigate long-term effects on radiologists. It is recommended to monitor and calculate the accumulated radiation dose of workers to ensure their exposure remains within safety limits.

* **Corresponding contributor.**
Author's Address: *Department of Radiological Technology, Faculty of Medicine Vajira Hospital, Navamindradhiraj University, Bangkok, Thailand*
E-mail address: panatsada@nmu.ac.th
doi: 10.12982/JAMS.2024.004
E-ISSN: 2539-6056

Introduction

Currently, a significant number of patients are facing issues related to cerebral vascular diseases. According to the World Stroke Organization (WSO), the global incidence of cerebral vascular diseases is approximately 15 million annually, with at least one death occurring every 6 seconds.[1] Cerebral vascular disease refers to a condition where the brain lacks blood supply due to cerebral artery stenosis, cerebral artery occlusion, or cerebral artery rupture, obstructing blood flow to the brain cells and leading to functional impairment or even death. Cerebral vascular disease stands among the noncommunicable diseases (NCDs), presenting a significant health concern in the Thai population. In 2018, it exhibited the highest mortality rate before the expected age, ranking second to cancer.[2] Therefore, diagnosing and treating cerebral vascular disease is crucial in reducing mortality rates. The treatment options for cerebral vascular disease vary depending on the severity of the disease, including medication, surgery, and endovascular interventions.

Cerebral angiography is a diagnostic and therapeutic procedure used to visualize blood vessels and identify the location of lesions during medical interventions. It involves using a Biplane Digital Subtraction Angiography (DSA) machine, which utilizes X-ray technology. During the procedure, a small catheter or tube is inserted into the artery to access the blood vessels supplying the brain and neck. Then, a contrast agent is injected to enhance visibility in radiographic images. These images help visualize the blood vessels and the lesion area with greater clarity. The procedure of cerebral angiography requires extensive radiographic imaging during the procedure. This includes real-time fluoroscopy, which provides live images of the moving blood vessels, a series of static images, mask images obtained before contrast injection, and image subtraction techniques applied to optimize the visualization of blood vessels. Subsequently, the physician plans the treatment of the affected cerebral blood vessels, which may involve various therapeutic techniques. These may include the application of balloon angioplasty to treat ischemic stroke, stent placement, or coil embolization to treat aneurysms. In cases of vascular blockages, an embolization technique using substances like glue may be employed to occlude the affected blood vessels. Conversely, for cases of arterial stenosis, treatments such as mechanical thrombectomy may be employed to address the condition and restore proper blood flow.[3]

The use of X-ray, known as ionizing radiation, leads to the ionization of atoms within the body, thereby exposing both patients and medical professionals to direct radiation as well as scattered radiation from various angles during diagnostic and therapeutic procedures.[4,5] The amount of radiation received by patients and medical professionals during cerebral angiography procedures depends on several factors. These factors include the distance from the X-ray tube, the duration of exposure during fluoroscopy, the number of radiographic images taken, and the radiation exposure technique used (kV, mAs). Additionally, the complexity of the underlying medical condition and the level of expertise demonstrated by the physician performing the procedure also contribute to the overall radiation dose received.[6] These combined factors may result in radiation doses that fall within permissible ranges[6] or potentially exceed the established safety thresholds for physicians and patients.[7] The effects of radiation include both stochastic and deterministic effects. Stochastic effects occur to a varying degree depending on the accumulated radiation dose received. Prolonged accumulation of radiation in the body over time may have long-term effects, such as the development of leukemia, genetic changes, and cataract formation.[8] Deterministic effects, on the other hand, depend on the amount of radiation received and may result in symptoms such as nausea and erythema. The International Commission on Radiological Protection (ICRP) has set a threshold dose for cataract formation at 0.5 Gy and established annual equivalent radiation dose limits for the lens of the eye for radiation workers not exceeding 20 millisieverts (mSv/y), and for the skin, hands, and feet not exceeding 500 mSv/y.[9] Monitoring and measuring the radiation doses physicians receive can help analyze and assess their radiation exposure for future risk prevention. Radiation measuring devices such as thermoluminescence dosimeters (TLD),[6,7] optically stimulated luminescence dosimeters (OSL)[10], photoluminescence glass dosimeters (PGD)[11] are positioned on the bodies of physicians, medical professionals, patients, or simulated phantoms. These dosimeters, along with personal radiation monitoring devices capable of offering real-time data,[12] serve to record and evaluate the levels of radiation exposure experienced by individuals involved in the procedure. By employing these measurement tools, healthcare providers can effectively monitor and assess radiation doses, thus promoting a safer environment for medical personnel and patients. Moreover, the control room of the cerebral angiography X-ray machine, regularly occupied by radiologic technologists, nurses, and physicians, is categorized as a controlled area with an elevated likelihood of radiation exposure compared to uncontrolled areas. Therefore, it is necessary to assess the effectiveness of the walls and doors in preventing radiation leakage. The Department of Medical Sciences specifies that the radiation dose in controlled areas should not exceed 5 microsieverts per hour (μSv/h), and regular measurements should be conducted every two years.[13] For instance, radiation survey meters or optically stimulated luminescence dosimeters are used to measure radiation levels in radiology work areas[14] or patient accommodation areas where iodine-131 therapy is administered.[15]

This research aims to measure radiation doses from radiologists' hands, feet, eye lenses, and thyroid during cerebral angiography procedures. Additionally, it aims to assess the accumulation of radiation doses in the control room of the X-ray machine used for cerebral angiography.

Materials and methods

Instruments and equipment

The C-Arm fluoroscopy machine used in this study was the Allura Xper FD20/20 Biplane model, manufactured by

Philips in the Netherlands. Radiation measurement devices included the nanoDot™ dosimeter (from Landauer® in the United States) for measuring accumulated radiation doses in various organs of the physicians. The InLight® dosimeter (also from Landauer® in the United States) was used to measure accumulated radiation doses in the environment. The nanoDot™ dosimeter readings were obtained using the microStar® Dosimetry Reader (manufactured by Landauer® in the United States). A radiation dose eraser (provided by the Office of Atoms for Peace, Thailand) removed the signal from OSL nanoDot™ dosimeter. An InLight® reader and annealer device (lnLight Auto 200 Dosimetry Reader, manufactured by Landauer® in the United States) were used.

Methods

This research study was approved by the Research Ethics Committee of the Faculty of Medicine Vajira Hospital, Navamindradhiraj University, with the reference number COA 087/2565. The aim was to measure radiation levels and assess the radiation doses received by radiologists during the cerebral angiography procedures.

Measurement of radiation doses received by radiologists.

Before attaching the nanoDot™ radiation dosimeter to the radiologist, baseline values of all nanoDot™ dosimeter badges were read using the microStar® Dosimetry Reader to establish background readings. The nanoDot™ dosimeter badges were individually wrapped in thin plastic sheets to prevent contamination and divided into two sets. One set was kept in a radiation-free area for the radiation background measurement. The other set, consisting of eight nanoDot™ dosimeter badges, was attached at various positions on the radiologist, including both sides of the eyeglass frames to represent the radiation doses at the lenses, the center of the outer and inner sides of the thyroid shield to measure the thyroid dose, both wrists, and both legs. After the completion of the procedure, the eight nanoDot™ dosimeter badges were placed in a light-tight box to prepare them for reading using the dosimetry reader. Once the readings were acquired, the badges underwent processing in the dosimeter reader to erase the residual signal from the nanoDot™ dosimeters. For subsequent procedures, a new set of nanoDot™ dosimeter badges was employed to measure the radiation doses during each procedure (Figure 1).

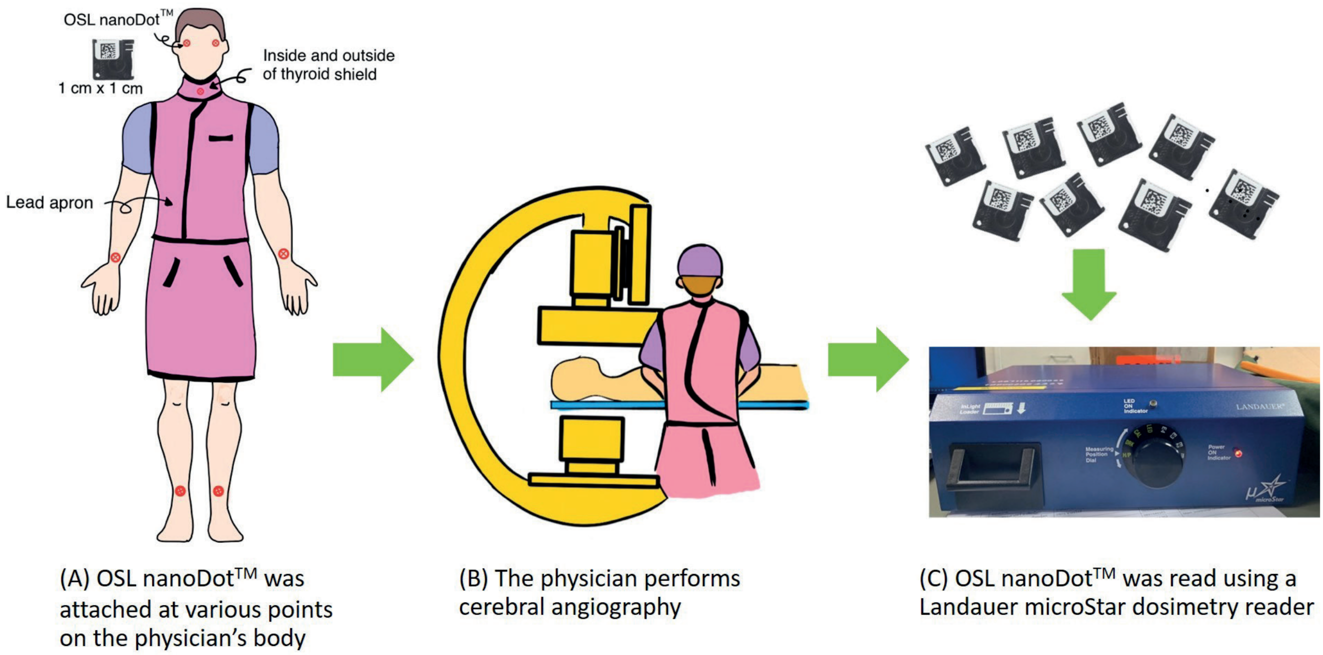


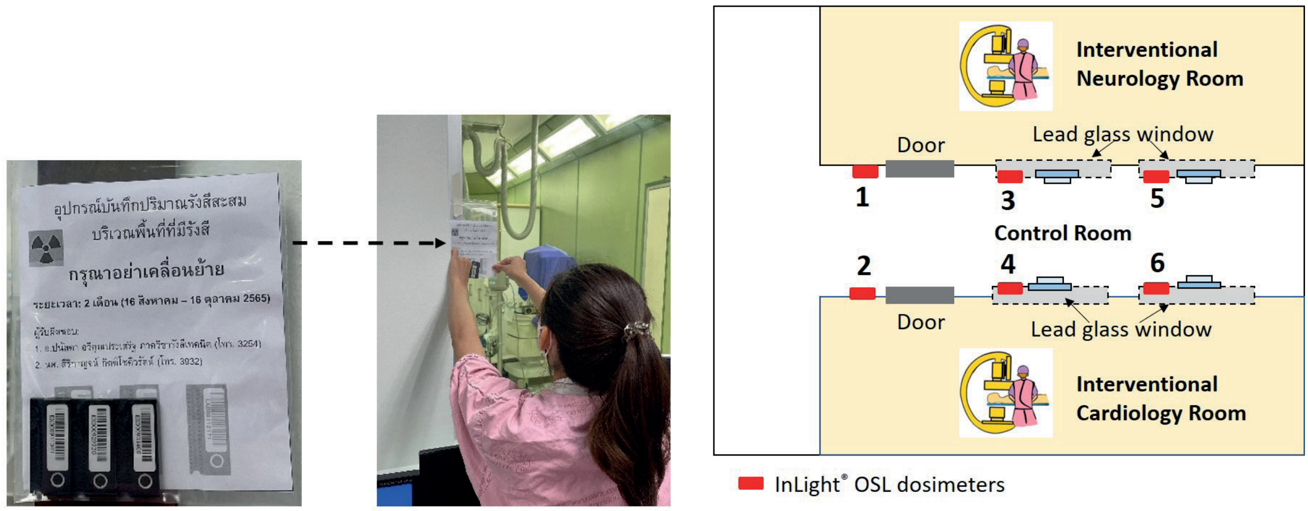
Figure 1. *Illustrates (A) The attachment of OSL nanoDot™ dosimeters to the physician's body. (B) The physician is performing cerebral angiography procedures. (C) The reading of OSL nanoDot™ dosimeters using a Landauer microStar dosimetry reader.*

In addition, this study collected both qualitative and quantitative data. Qualitative data included the type of procedure, pathological conditions, and vascular positions. Quantitative data consisted of fluoroscopic time, patient radiation doses, dose area product (DAP), and relevant parameters for each cerebral angiography procedure. The purpose of collecting this data was to analyze the relationships between radiation doses received and to calculate the maximum number of procedures that could be performed per month or per year. This analysis involved comparing the average radiation doses received by various organs with the established dose limits.

The Measurement of cumulative radiation in the controlled area

To assess the cumulative radiation dose in the controlled area, InLight® radiation dosimeters were placed in designated locations. Before placing the InLight®

dosimeters, their baseline values were obtained by reading them with the InLight® Dosimetry Reader. A set of three InLight® dosimeters was packed in individual plastic bags. One set was stored in an area without radiation to serve as the background radiation value. The remaining sets of InLight® dosimeters were placed in the control room of the angiography room, where the staff regularly performs their duties. These dosimeters were left in place for two months to measure the cumulative radiation dose. After the designated period, the radiation dose accumulated in the InLight® dosimeters was read using the InLight® Dosimetry Reader (Figure 2). At the end of the two months, all the InLight® dosimeters were sealed in light-protected boxes and sent to read using the InLight® Dosimetry Reader. Three readings were conducted to determine the average radiation dose per hour at various positions within the control room. These calculated values were then compared against the established radiation dose limits for the controlled area.



(A) Three InLight® OSL dosimeters were packed in a plastic bag with a label to inform everyone

(B) OSL dosimeters will be placed at various locations in the control room.

(C) Six sets of OSL dosimeters were attached to the red marks in the image.

Figure 2. *Illustrates (A) The preparation of InLight® OSL dosimeters. (B) The attachment of OSL dosimeters in the control room. (C) OSL dosimeters were attached at six positions in the control room.*

Results

The data obtained from 20 patients who underwent cerebral angiography revealed the following average values: the patients' average body mass index (BMI) was 26.11±3.96, the average fluoroscopy time was 19.91±20.81 minutes, and the average dose area product (DAP) was 119,751±99,175 mGy/cm^2. Additionally, the average number of acquired runs was 14±7, and the average number of acquired images was 762±438 (Table 1).

Table 1. Data on cerebral angiography procedures (N=20).

	Max	Min	Average	SD
Patient BMI	36.21	20	26.11	3.96
Fluoroscopy time (minutes)	90.12	3.36	19.91	20.81
DAP (mGy/cm^2)	452,435	33,684	119,751	99,175
Number of acquired runs	42	6	14	7
Number of acquired image	1690	294	762	438

Interventional radiologists' radiation dose during cerebral angiography was measured using nanoDot™ dosimeters at various organs. The dosimeters were attached to the outside and inside of the thyroid shield, both sides of the eyes, both hands, and both legs. Organs on the left side received higher radiation doses than the right side. The left eye received the highest dose at 49±65 µSv (max 289 µSv), followed by the left hand at 34±37 µSv (max 46 µSv). The maximum and minimum values of the measured radiation dose are very different. This may be due to staff height and experience, radiation shield used, OSL efficiency, and angular dependence. Using a thyroid shield reduced radiation dose by approximately three times (Table 2).

Table 2. Radiation dose received by organs during cerebral angiography procedures (N=20).

Organ	Max	Min	Average	SD
Left Eye (µSv)	289	2	49	65
Right Eye (µSv)	54	2	15	14
Inside Thyroid Shield (µSv)	64	0*	5	14
Outside Thyroid Shield (µSv)	73	2	14	16
Left Hand (µSv)	174	2	34	38
Right Hand (µSv)	47	0*	16	15
Left Leg (µSv)	236	0*	27	52
Right Leg (µSv)	21	0*	7	5

*Note: *organs with readings below the background during cerebral angiography are reported as receiving 0 Gy of radiation dose.*

Comparing radiation exposure in various organs during diagnostic and therapeutic cerebral angiography, it was found that therapeutic procedures resulted in higher doses than diagnostic ones (Figure 3). The radiologist's left eye received up to 5 times more radiation during therapeutic procedures, and the left hand received up to 2 times more (Table 3). Moreover, therapeutic procedures require longer fluoroscopy time, leading to higher radiation doses for patients than diagnostic procedures.

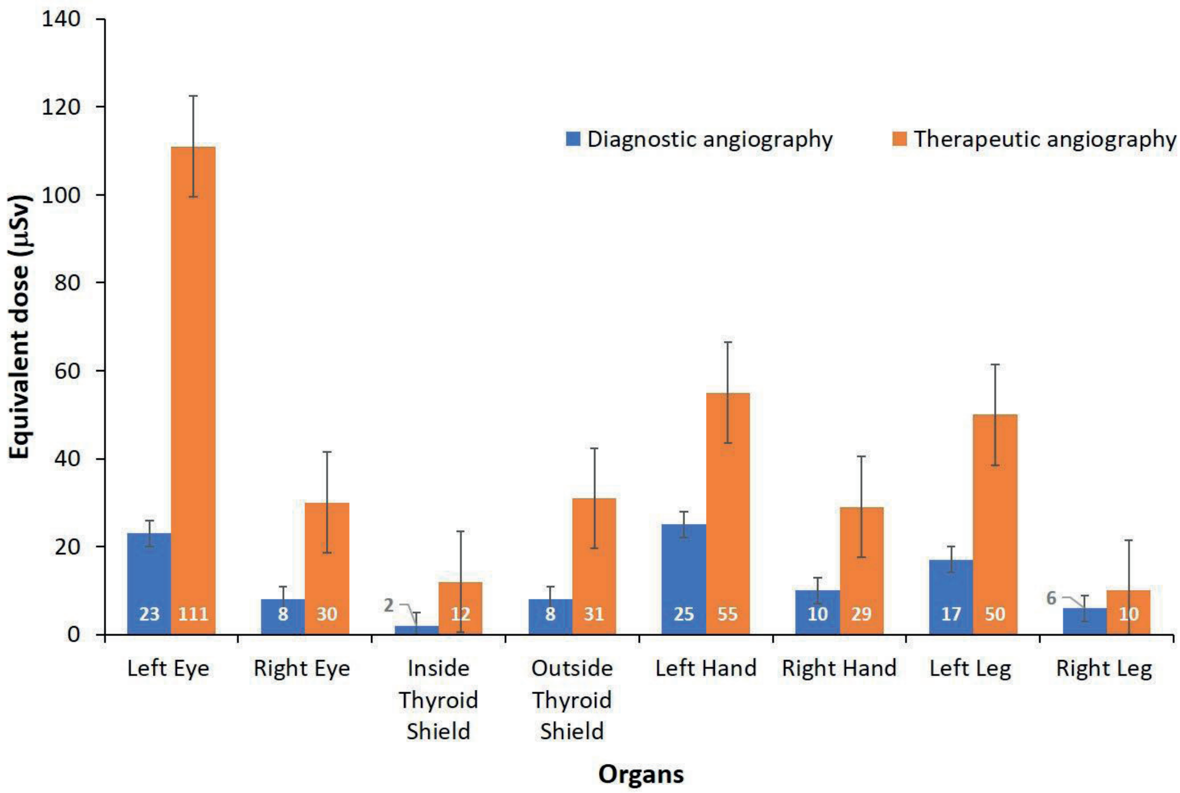


Figure 3. *Compares the radiation equivalent doses between the two procedure types for each organ.*

Table 3. Radiation equivalent doses for radiologists in different organs during diagnostic (N=14) and therapeutic (N=6) cerebral angiography procedures.

Organ	Diagnostic Angiography (N=14)				Therapeutic Angiography (N=6)			
	Max	Min	Average	SD	Max	Min	Average	SD
Left Eye (µSv)	47	2	23	13	289	35	111	96
Right Eye (µSv)	17	2	8	5	54	13	30	18
Inside Thyroid Shield (µSv)	4	0*	2	1	64	0	12	25
Outside Thyroid Shield (µSv)	16	2	8	4	73	9	31	23
Left Hand (µSv)	74	2	25	20	174	12	55	60
Right Hand (µSv)	34	0	10	8	47	9	29	19
Left Leg (µSv)	60	0	17	19	236	4	50	91
Right Leg (µSv)	18	0	6	5	21	2	10	6

*Note: *organs with readings below the background during cerebral angiography are reported as receiving 0 Gy of radiation dose.*

The evaluation of the maximum number of cerebral angiography procedures that radiologists can perform is based on the average radiation quantities received by various organs, measured in millisieverts (mSv). By dividing this average by the organ-specific radiation dose limit per year, we can determine the maximum number of procedures performed annually. Similarly, dividing it by 12 months gives the maximum number of procedures that can be performed per month. Using the radiation quantity received by the left eye, radiologists can perform a maximum of 405 procedures per year or 34 per month during cerebral angiography (Table 4).

Table 4. Displays the maximum number of cerebral angiography procedures that radiologists can perform per year and per month.

Organ	Cerebral Angiography Procedures (N=20)	
	Maximum number of procedures per year	Maximum number of procedures per month
Left Eye	405	34
Right Eye	1,370	114
Inside Thyroid Shield	63,291	5,274
Outside Thyroid Shield	20,711	1,726
Left Hand	14,594	1,216
Right Hand	31,143	2,595
Left Leg	18,625	1,552
Right Leg	67,159	5,597

Comparing diagnostic and therapeutic cerebral angiography procedures, it was found that if physicians performed only diagnostic procedures, the maximum number of procedures per year would be 865 (72 procedures per month). However, if physicians performed only therapeutic procedures, the maximum number of procedures per year would be 181 (15 procedures per month). The radiation doses received by the thyroid, eyes, hands, and legs did not exceed the prescribed limits (Table 5).

Radiation levels in controlled areas

We measured the accumulated radiation levels at various positions in the controlled area. Notably, the position in front of the interventional neurological angiography room door exhibited the highest radiation level, measuring 1.18 µSv/hr. Comparatively, the position in front of the cardiac angiography room door had a radiation level of 0.93 µSv/hr. However, the position between the two angiography rooms and the control room, near the leaded glass window, had a relatively lower radiation level, measuring below 0.68 µSv/hr. Importantly, this value remains below the radiation dose limit specified by the Department of Medical Sciences, Ministry of Public Health (Figure 4).

Table 5. The maximum number of procedures that radiologists can perform per year and month for diagnostic cerebral angiography procedures (N=14) and therapeutic cerebral angiography procedures (N=6).

Organ	Diagnostic procedures (N=14)		Therapeutic procedures (N=6)	
	maximum number of procedures per year	maximum number of procedures per month	maximum number of procedures per year	maximum number of procedures per month
Left Eye	865	72	181	15
Right Eye	2,458	205	674	56
Inside Thyroid Shield	198,113	16,509	24,457	2,038
Outside Thyroid Shield	39,810	3,318	9,772	814
Left Hand	19,836	1,653	9,028	752
Right Hand	47,814	3,985	17,172	1,431
Left Leg	29,313	2,443	10,064	839
Right Leg	79,909	6,659	48,940	4,078

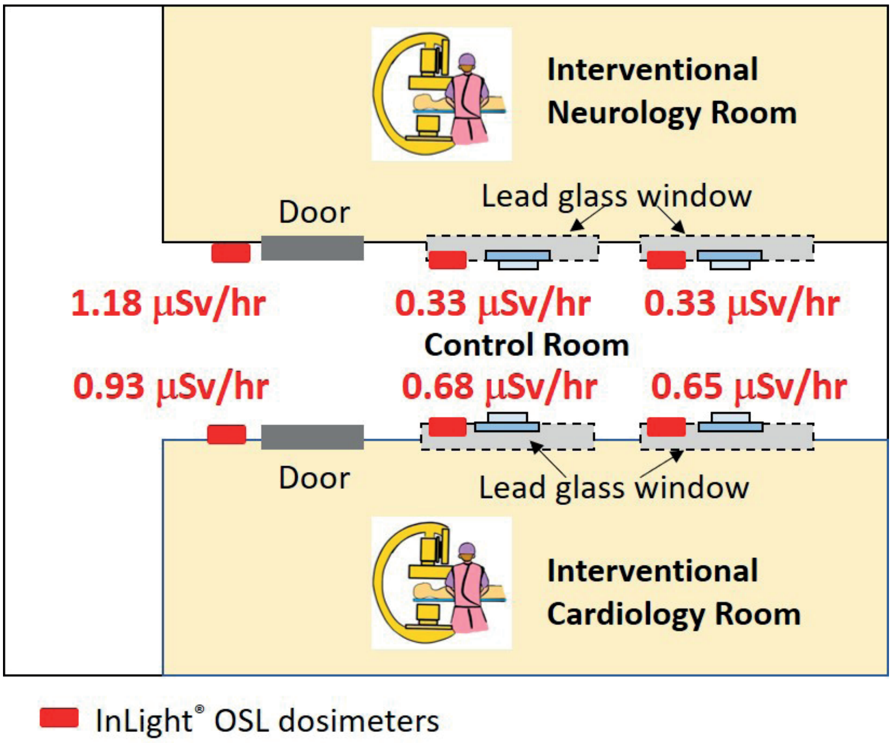


Figure 4. *Illustrates the accumulated background radiation levels at various points in the controlled area.*

Discussion

This study aimed to assess the radiation exposure from interventional radiologists during cerebral angiography procedures using the optical stimulated luminescence (OSL) nanoDot™ dosimeter. The radiation dosimeters were attached to the arms of the glasses to represent the radiation dose to the eye's lens and to the inside and outside of the thyroid shield to represent the radiation dose to the thyroid gland. The dosimeters were also placed on the hands and legs of the physicians performing the procedures. The study included 20 cases, revealing that the left-sided organs, including the left eye, left hand, and left leg, received a notably higher average radiation dose in comparison to their corresponding right-sided counterparts. This observation can be attributed to the fact that during cerebral angiography procedures, interventional radiologists consistently stand on the right side of the patient, bringing their left side closer to the X-ray tube. The radiologist's left eye received a higher radiation dose than other organs, potentially posing a risk of radiation to the eye lens and cataract formation.[16, 17] To prevent exceeding the maximum permissible dose of radiation defined by the International Commission on Radiological Protection (ICRP), it is crucial to utilize lead glasses for lens protection and wear radiation shielding devices during therapeutic cerebral angiography procedures. These measures can reduce the radiation dose the interventional radiologist receives up to three times, consistent with studies in orthopedic surgical procedures[18] and transcatheter arterial chemoembolization for hepatocellular carcinoma treatment.[19] Furthermore, organizations working with radiation should establish monitoring programs to evaluate personnel's annual cumulative radiation exposure and calculate the cumulative dose over five years.

The main limitation of this study was the inability to attach the nanoDotTM dosimeter to the lens position directly. Instead, it was fixed to the arms of the interventional radiologist's eyeglasses during cerebral angiography. Although this approach may not precisely represent the scattered radiation dose at the lens position, it is a reference point used in other radiation dose studies involving radiologists' lenses,[7,20] where measurement devices were attached near the left and right eye lenses.

Although the radiation dose may not exceed the level that causes deterministic radiation effects, it may pose a risk of stochastic effects, which include a small probability or risk of developing fatal cancer and genetic defects in the future. However, this is a very low-risk probability, ranging from one in a hundred million to one in ten million patients. Radiation oncologists and staff performing interventional radiology procedures must take necessary precautions.[21]

Radiation dose measurement devices such as the nanoDotTM enable the assessment of cumulative radiation dose in controlled areas by calculating dose values per hour. The calculated cumulative radiation dose values represent the actual radiation dose values experienced in real-world applications. Moreover, these devices are valuable for measuring cumulative radiation doses in patient ward areas undergoing treatment with iodine-131 radiation therapy and for measuring radiation in drainage pipes.[15] The Department of Medical Sciences, Ministry of Public Health, recommends conducting regular inspections of controlled areas and verifying the proper functioning of radiation protection equipment at least once a year to ensure adequate radiation protection in accordance with established standards.[13]

Conclusion

During cerebral angiography, the left eye of the radiologist receives the highest radiation doses. Radiation protection devices such as thyroid shields and lead aprons can effectively reduce radiation exposure, and it is advisable to wear them during every cerebral angiography procedure. Organizations working with radiation should establish a monitoring system to track personnel's annual cumulative and cumulative doses over five years, ensuring compliance with prescribed limits for occupational exposure. Controlled areas' cumulative radiation dose should not exceed the limits set by the Department of Medical Science

References

[1] Saposnik G, Galanos LC, Guerrero R, Casagrande F, Adhamidhis E, Gao MMY, *et al*. The World Stroke Academy: A World Stroke Organization global pathway to improve knowledge in stroke care. Int J Stroke. 2022; 17(8): 829-34. doi: 10.1177/174749 30221085895.

[2] Department of Medical Sciences, Ministry of Public Health. Report on the Situation of NCDs: Diabetes, hypertension and related risk factors in 2019. 1st Ed. Bangkok: Aksorn Graphic and Design Publishing; 2020. (in Thai)

[3] Haussen DC, Nogueira RG. Primer on cerebrovascular diseases: conventional cerebral arteriograph. 2nd Ed. San Diego: Academic Press; 2017: 707-12.

[4] Chida K, Kato M, Kagaya Y, Zuguchi M, Saito H, Ishibashi T, *et al*. Radiation dose and radiation protection for patients and physicians during interventional procedure. J Radiat Res. 2010; 51(2): 97-105. doi: 10.1269/jrr.09112.

[5] Feygelman VM, Huda W, Peters KR. Effective dose equivalents to patients undergoing cerebral angiography. Am J Neuroradiol. 1992; 13(3): 845-9.

[6] Berthelsen B, Cederblad A. Radiation doses to patients and personnel involved in embolization of intracerebral arteriovenous malformations. Acta Radiol. 1991; 32(6): 492-7. doi: 10.1177/0284185 1910320061.

[7] Lunelli NA, Khoury HJ, Andrade GHV de, Borrás C. Evaluation of occupational and patient dose in cerebral angiography procedures. Radiologia Brasileira. 2013; 46(6): 351–7. doi: 10.1590/S0100-39842013000600007.

[8] Seals KF, Lee EW, Cagnon CH, Al-Hakim RA, Kee ST. Radiation-induced cataractogenesis: A critical literature review for the interventional radiologist. Cardiovasc Intervent Radiol. 2016; 39(2): 151-60. doi: 10.1007/s00270-015-1207-z.

[9] Authors on behalf of ICRP, Stewart FA, Akleyev AV, Hauer-Jensen M, Hendry JH, Kleiman NJ, *et al*. ICRP publication 118: ICRP statement on tissue reactions and early and late effects of radiation in normal tissues and organs--threshold doses for tissue reactions in a radiation protection context. Ann ICRP. 2012; 41(1-2): 1-322. doi:10.1016/j.icrp.2012.02.001.

[10] Gonzales CAB, Morales AA. Assessment of patient and staff doses in interventional cerebral angiography using OSL. Proceedings of World Congress on Medical Physics and Biomedical Engineering; 2015 Jun 7-12; Toronto, Canada, 2015. doi: 10.1007/978-3-319-19387-8_192.

[11] Moritake T, Matsumaru Y, Takigawa T, Nishizawa K, Matsumura A, Tsuboi K. Dose measurement on both patients and operators during neurointerventional procedures using photoluminescence glass dosimeters. Am J Neuroradiol. 2008; 29(10): 1910-7. doi: 10.3174 /ajnr.A1235.

[12] Castilho AVB, Szjenfeld D, Nalli D, Fornazari V, Moreira AC, Medeiros RB. A study of radiation doses to the patient and medical team at embolization procedures. J Radiat Prot Res. 2019; 44(3): 110-7. doi: 10.14407/jrpr.2019.44.3.110.

[13] Department of Medical Sciences, Ministry of Public Health. Laboratory Radiation Safety Handbook. Bangkok: Beyond Publishing Company Limited; 2020. (in Thai)

[14] Phaorod J, Wongsanon W, Hanpanich P, Dornsrichan P, Awikunprasert P, Sriwicha J, *et al*. The measurement radiation doses to the lens of eye and thyroid gland

from computed tomography brain scans and radiation dose around in CT scan room: phantom study. Srinagarind Med J. 2020; 35(2): 153-60. (in Thai)

[15] Wisetnan C, Molee P, Awikunprasert P, Srichachet K, Pungkun V. A survey of radiation released from patients treated with radioiodine-131 therapy. J Assoc Med Sci. 2021; 54(2): 17-21.doi: 10.14456/jams.2021.12.

[16] Krisanachinda A, Srimahachota S, Matsubara K. The current status of eye lens dose measurement in interventional cardiology personnel in Thailand. Radiol Phys Technol. 2017; 10(2): 142-7. doi: 10.1007/s12194-017-0403-8.

[17] Principi S, Delgado Soler C, Ginjaume M, Beltran Vilagrasa M, Rovira Escutia JJ, Duch MA. Eye lens dose in interventional cardiology. Radiat Prot Dosimetry. 2015; 165(1-4): 289-93. doi: 10.1093/rpd/ncv051.

[18] Palácio EP, Ribeiro AA, Gavassi BM, Di Stasi GG, Galbiatti JA, Junior AD, et al. Exposure of the surgical team to ionizing radiation during orthopedic surgical procedures. Rev Bras Ortop. 2014; 49(3): 227-32. doi: 10.1016/j.rboe.2014.04.008.

[19] Kaewmarong K, Teebumrung N, Awikunprasert P, Kittichotwarat S, Claimon T, Dachviriyakij T. Measurement of radiation dose by a radiologist from Transarterial Chemoembolization (TACE) intervention with optically stimulated luminescence. J Med Health Sci. 2023; 30(1): 44-52. (in Thai)

[20] Kato M, Chida K, Ishida T, Toyoshima H, Yoshida Y, Yoshioka S, et al. Occupational radiation exposure of the eye in neurovascular interventional physician. Radia Prot Dosim. 2019; 185(2): 151-6. doi: 10.1093/rpd/ncy285.

[21] Hidajat N, Wust P, Felix R, Schröder RJ. Radiation exposure to patient and staff in hepatic chemoembolization: risk estimation of cancer and deterministic effects. Cardiovasc Intervent Radiol. 2006; 29(5): 791-6. doi: 10.1007/s00270-005-0247-1.