Journal of Engineering Technology and Applied Sciences, 2023 | *e-ISSN:* 2548-0391
Received 23 July 2022, Accepted 2 April 2023 | *Vol. 8, No. 1, 49-58*
Published online 29 April 2023, Research Article | *doi: 10.30931/jetas.1147340*

Citation: Hisiroglu Ayar, K., Kam, E., Dogan, Y., "Occupational Radition Dose of Personal in Pediatric Interventional Cardiology". Journal of Engineering Technology and Applied Sciences 8 (1) 2023 : 49-58.

OCCUPATIONAL RADIATION DOSE OF PERSONAL IN PEDIATRIC INTERVENTIONAL CARDIOLOGY

Kevser Hışıroğlu Ayar[a*], Erol Kam[b], Doğan Yaşar[c]

[a] *Department of Physics, Faculty of Arts and Sciences, Yildiz Technical University, Istanbul, Turkey*
*k.hisiroglu@gmail.com (*corresponding author)*

[b] *Department of Environmental Engineering, Faculty of Civil Engineering, Istanbul Technical University, Istanbul, Turkey*
erolkam@hotmail.com

[c] *Department of Physics, Faculty of Arts and Sciences, Ahi Evran University, Kırşehir, Turkey*
dogan.yasar@ahievran.edu.tr

Abstract

This study aimed to determine the effective doses of the cardiologist, nurses, and technical staff in the pediatric angiography laboratory during their diagnostic and therapeutic applications. This study also compares the radiation dose in the applications performed in the country with the effective doses exposed on a world scale. A total of 39 coronary angiography (CA) + percutaneous transluminal angioplasty (PTCA) methods were performed in the pediatric angiography laboratory during the study. The radiation dose received for each person in a single application was determined, and the total dose values were measured in sequential applications. If the annual workload is taken into consideration, it is calculated that the person with a high workload may be exposed to a dose of 1384.7 μSv per year. Furthermore, from the total effective dose values, the doses per procedure were calculated to be in the range of 6.5 to 11.1 μSv. These results are consistent with the literature.

Keywords: Personal dose, interventional radiology, pediatric cardiology, TLD

1.Introduction

Interventional imaging applications are preferred in the diagnosis and therapy of many diseases and their use is becoming widespread in the world [1]. In the UNSCEAR 2017 report, it was stated that people exposed to ionizing radiation worldwide were exposed to radiation from artificial radiation sources, and therefore a continuous upward trend in population dose [2]. Diagnostic radiology, image-guided interventional radiology, nuclear medicine and radiation therapy are the main medical applications of population doses especially for radiology workers [3].

Fluoroscopy is also an important imaging application in pediatric patients. Fluoroscopy is being increasingly used to guide pediatric interventional applications in the field of cardiology and gastroenterology, as well as for neurovascular, orthopedic, and surgical image-guided applications. To image the changes in arteries, cardiac catheterization with coronary angiography (CA) is used. As the arteries are damaged or blocked, the percutaneous transluminal angioplasty (PTCA) method can be used to re-establish blood flow to the heart. Fluoroscopy-guided interventional applications may result in greater radiation exposure to patients and staff than associated with typical diagnostic imaging [4].

In fluoroscopy examinations, many factors determine the dose rate of radiation emitted from the X-ray system. Depending on the physical structure of the patient's physical structure, the number of radiographs, area size, and fluoroscopy duration are important [5]. Fluoroscopic systems can produce very high radiation dose rates and at the same time, the application time can normally last for several minutes. As a result, interventional applications can produce significantly high radiation doses [3]. In terms of collective doses, medical radiation exposure in interventional applications contributes from 0.001 to 0.34 mSv per year, corresponding to 0.4 - 28.7 % of total radiation collective doses [6].

The main reasons for exposure to radiation in staff-directed interventional radiology are X-rays, which are scattered from the patient's body and leaking from the X-ray tube. Besides, personal can also be exposed to X-rays scattered from walls and ceilings [7].

Depending on the applications in X-ray imaging laboratories, protective apron for protection chest and the critical organs (gonad/ovary), goggles and thyroid protective collars are used by personal to minimize the harmful effects of ionizing radiation [8,9].

It is mandatory to monitor the exposure to occupational radiation personal during interventional radiological applications. However, monitoring of the individual radiation dose plays an important role in the concept of protection against occupational exposure by external radiation, provides a warning against unexpected exposure, and aims to limit individual exposure to a level acceptable to the occupational risk.

Following national and international regulations, it is necessary to monitor the radiation dose that the personal is exposed to in facilities used ionizing radiation. Passive (TLD, OSL, Film) and active (Electronic Personal Dosimeter) dosimeters are preferred to monitor the radiation dose. Personal dosimeters indicate the staff dose equivalent, Hp(d), at a certain depth below the position of the personal dosimetry used on the body surface [10].

In this study, we aimed to determine the radiation doses exposed to the cardiologists, nurses, technicians, and anesthesiologists who work in the pediatric angiography laboratory by the TLD dose measurement technique.

2.Material and method

This study was performed in the catheter angiography laboratories of Mehmet Akif Ersoy Thoracic and Cardiovascular Surgery Training and Research Hospital. In the hospital, angiography applications are performed in a total of 6 laboratories with 3 adults, 2 pediatrics, and 1 arrhythmia. The annual patient potential is increasing day by day, with 612 in 2016, 675 in 2017, and more than 725 patients in 2018. Towards the end of 2020, an average of 2000 procedures per month and 18.000 procedures per year can be performed in the heart catheterization and angiography laboratory. In our study, we aimed to determine with the TLD 51per measurement technique the radiation doses exposed by cardiologists, nurses, technicians, and anesthesiologists who work in pediatric angiography laboratories.

In pediatric angiography laboratories, Philips bi-plane, Allura Xper FD10/10, and monoplane system, Allura Xper FD20 (Philips Medical Systems) X-ray systems are used [11]. The 51per-area product meter is located on the head of the X-ray system. Medical staff consisting of cardiologist, nurse, anesthesia nurse, and technician perform stent placement, balloon angioplasty, atrial septal defect (ASD) closure, patent ductus arteriosus (PDA) closure, ventricular septal defect (VSD) closure, heart valve examinations of pediatric patients. Personal wears protective aprons, thyroid collars, and protective glasses in the range of 0.25 to 0.50 mmPb equivalent.

2.1 TLD measurement system

Thermoluminescence dosimeters (TLDs) were used in the personal dose measurements. Calibration of TLDs and post-irradiation evaluation were performed in the Secondary Standard Dosimetry Laboratory (SSDL). SSDL has a Harshaw 4500 model reader that connects a computer with WinREMS software, which can read the TLD card and chip. The TLD reader heating process is carried out by hot nitrogen gas. The TLD chips are designed specially doped lithium fluoride (LiF:Mg,Ti) crystals by Harshaw and their dose range are from 0.01 mGy to 10 Gy.The reader calibration factor (RCF) for the TLD reader and the element correction coefficients (ECCs) of the TLD chips were determined using the standard Cs-137 gamma source in the SSDL according to the WinREMS software manual [12].

In interventional cardiology applications, fluoroscopy and radiography imaging are used extensively during the examination and application period. Depending on the patient's physical condition, fluoroscopy and radiographic imaging, the voltage may vary in the range of 40 kVp to 125 kVp [11].

For the TLD system calibration, the Cs-137 radioactive source, the Yxlon International MGC 41 model X-ray system and the reference standard dosimeter for dose rate measurements were used [10]. The standard of reference, the PTW Unidos Webline electrometer and the PTW TM32002 model 1000 cc balloon ion chamber, provide the traceability of the Physikalisch-Technische Bundesanstalt (PTB).

TLD dosimeters are passive dosimeters with energy dependence. Especially in low energies their energy dependence is very high. To eliminate energy dependence, the TLD calibration chips were irradiated with N100 radiation quality in the narrow series given in ISO 4037-3: 1999 [10,12]. Calibration chips were read in the TLD reading system, the calibration correction coefficient was obtained and the TLD system calibration was updated.

Under the protective apron of each person, 3 TLD chips were placed in the abdomen. TLDs were used during the practices of the personal during the day. In some times, after a single application, TLDs were read and in some times readings were made after many applications. Dosimeter evaluations were made by considering the weekly application numbers of the personal. Therefore, some personal participated in a single application, while others participated in many applications.

The following data were recorded for each application: date, examination, name of the operator, position of the operator in reference to the x-ray tube, presence of radiation protection equipment, patient's demographic profile, voltage potential difference(kVp), exposure time(ms), anode current(mA), beam on time(s), air kerma (mGy) and DAP ($mGy.cm^2$).DAP meter is typically measured with a transmission chamber fitted in the angiographic system or temporarily added externally to the collimator assembly. Cumulative DAP values for each examination are recorded [13].The operation parameters for four applications are given in Table 1.

Table 1. Operation parameters of X-ray system the for each procedure

Application # 1				**Application # 2**			
Potential (kVp)	Current (mAs/mA)	Flouro time (ms)	DAP ($mGycm^2$)	Potential (kVp)	Current (mAs/mA)	Flouro time (ms)	DAP ($mGycm^2$)
67	433	5	1995	65	321	4	2801
63	242	4		64	301	4	
68	481	5		68	473	5	
74*	4	0		73*	4	0	
62	178	4		74*	4	0	

Application # 3				**Application # 4**			
Potential (kVp)	Current (mAs/mA)	Flouro time (ms)	DAP ($mGycm^2$)	Potential (kVp)	Current (mAs/mA)	Flouro time (ms)	DAP ($mGycm^2$)
66	390	4	4582	64	298	4	1348
69	516	5		64	290	4	
66	368	4		72*	3	0	
72*	3	0		62	221	4	
66	416	5		64	309	4	
68	508	5					
68	478	5					
69	524	5					
67	443	5					

*Radiography shots

The working position of the personal during the interventional cardiology procedure is shown schematically in Figure 1. In addition, the laboratory image of the x-ray imaging systems is given in Figure 2.

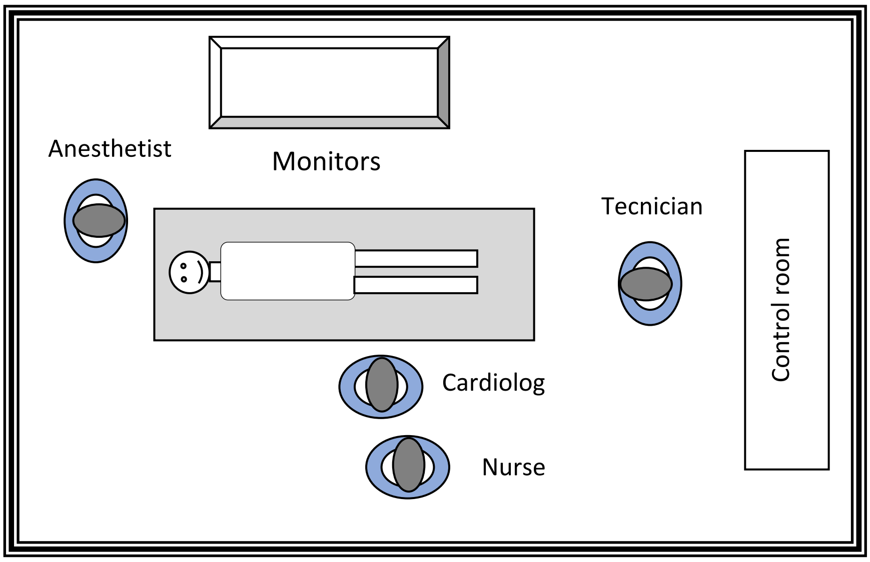

Figure 1. Schematic representation of the working position of personal in invasive cardiological applications

Figure 2. Interventional pediatric angiographic imaging laboratory.

3. Results and discussion

A total of 39 CA and PTCA applications were performed in the pediatric angiography laboratory during the study. The radiation doses to which the personal was exposed were determined by TLD. Due to the rotational work of cardiologists performing angiography applications, the number of their applications remained low compared to another technical health personal (Nurse, anesthesia nurse, technician).

Technical health personal is participating in practices carried out by many cardiologists and increasing their number of applications. In angiography application, 3 different TLD chips were placed under a protective apron and the measurements were taken. In many cases, TLDs have remained in use for multiple applications. In table 2, personal category and application numbers, average dose values measured by TLD in each application are given respectively.

The next column gives the cumulative radiation dose from each staff member participating in the study. In the last column, the standard deviation of the values measured with 3 different TLD chips used by the personal is given.

As a result of the evaluation of the data obtained in the experimental study, it is seen that there are some variations in the radiation doses that the personal are exposed to.

In the example of Cardiologist # 2, large variations were found between doses exposed for the same number of applications; while 3.49 μSv in the first 4 applications, the average dose was 52.54 μSv in the other 4 applications.In the example of an anesthesia nurse, it was found that it was exposed to 27.99 μSv for 1 application, 9.15 μSv for 4 applications and 4.29 μSv for 3 applications.

The main reason for these variations is thought to be due to the variation in the number of graphic and fluoroscopy taken in each application and the difference in current densities with the applied X-ray energy potential. However, the distance and positions of the personal to the X-ray source, and patient during the examination also reveal another important reason for dose distribution.

Table 2.TLD measurement values of cardiologists and technical personal

Personal	Total application	Application number	Average dose (μSv)	Cumulated dose(μSv)	Standard deviation %
Cardiologist #1	15	1	28.30	144.44	15.7
		1	8.39		8.4
		3	10.72		9.5
		4	43.99		4.8
		6	53.04		12.5
Cardiologist #2	8	4	3.49	56.03	1.2
		4	52.54		0.6
Cardiologist #3	16	4	64.35	103.99	2.3
		4	52.67		6.9
		6	51.32		6.4
Nurse	31	1	5.69	343.37	7.1
		4	9.15		3.0
		3	4.29		0.9
		4	60.92		6.6
		6	51.95		1.1
		4	57.29		8.7
		6	54.55		3.2
		3	99.52		4.2
Anesthesia nurse	35	1	27.99	311.07	4.3
		4	7.29		2.3
		3	3.55		1.9
		4	47.99		4.0
		6	52.94		1.6
		6	70.47		7.1
		4	49.20		7.7
		4	51.64		3.2
		3	75.95		6.0
Technician	32	1	7.27	331.24	1.0
		4	18.72		3.2
		4	46.89		3.5
		6	50.65		2.6
		6	45.27		3.0
		4	51.75		0.8
		4	47.79		4.8
		3	62.89		10.6

There is a relationship between radiation dose and distance called the inverse square law. The dose rate of electromagnetic radiation emitted from a source (X-ray tube, radionuclide etc.) decreases inversely with the square of the distance. Since X-rays are electromagnetic radiation, they obey the inverse square law. The personal not staying in a fixed position during the application, the X-ray tube emitting radiation or the distance to the patient may also cause changes in the radiation dose.

It is possible to say that the dissimilarity in the standard deviation is effective on the position of the TLD chips used for each application. Due to the inability of the cardiologist and other personal to remain inactive, the geometric position of each TLD changes. In the event of a change of position of TLD, the degree of radiation exposure will vary depending on the angle of incidence of radiation and scatter source-TLD distance.
In Table 3, the total number of applications, total doses and dose values per application are given. Accordingly, it was found that the dose was between 6.5 - 11.07 μSv per application. According to these results, the doses are consistent with the effective dose E values obtained by many investigators and given below.

Table 3. Personnal doses per application

Personal	Total application	Cumulated dose (μSv)	Dose per application (μSv/app)
Cardiologist #1	15	144.44	9.63
Cardiologist #2	8	56.03	7.0
Cardiologist #3	16	103.99	6.50
Nurse	31	343.37	11.07
Anesthesia nurse	35	311.07	8.89
Technician	32	331.24	10.35

There are a large number of publications giving occupational doses per given procedure in X-ray imaging and estimating likely annual doses. In a study performed by Tsapaki et al. mean cardiologist effective dose (E) per procedure was found to be 0.2 μSv in coronary angiography (CA) and 0.3 μSv in percutaneous transluminal coronary angioplasty (PTCA) [14]. Depending on the type of procedure and the technique used, the operator dose, per procedure, ranges from 3 to 450 μSv at the neck over protective garments, and from <0.1 to 32 μSv at the waist or chest under protective garments [8].

In a study performed by Entesar Z. et al., the mean doses over the 5-month period for TLDs placed on the chest level under the 0.35 mm Pb equivalent apron for cardiologists were given as 0.74 ± 0.04 mSv/month, 0.83 ± 0.06 mSv/month and 1.78 ± 0.14 mSv/3 months, yielding a dose of 3.35 mSv/5 months [15].

UNSCEAR states in its 2010 report that several countries are able to provide distinction between traditional techniques and interventional techniques in diagnostic radiology. The approximate effective dose reported for conventional diagnostic radiology was about 0.5 mSv for monitored personal, while it was about 1.6 mSv for interventional procedures. Lately data from 23 countries, gave an average median effective dose of 0.7 mSv for interventional cardiologists in a short time [15,16].

Abhisekhet et al.reported adjusting for protective lead aprons by the Webster methodology, the average operator received an effective dose of 38 μSv [17]. The average effective cardiologist dose per procedure was 2.7 μSv (range 0.3–14.3 μSv) for CA and 6.4 μSv (range: 1.3–27.5 μSv) for PTCA procedures. For cardiologists, the mean effective dose was equal to 158.3 μSv (range: 8.3–1050 μSv) [18].

With the EPD dosimeter, the radiation doses of 3 operators were measured by Maja et al. for the body, neck and hand for 14 weeks in 281 patients with 284 procedures. Per procedure, the operators were exposed to a mean effective dose (E) of 2.2 ± 5.9 μSv [19].

In the study conducted by Santos et al. with electronic personal dosimetry, the cumulative dose of the personal in digital subtraction angiography (DSA) was measured as 30.92 mGy.

4.Conclusion

The highest risk area in terms of radiation dose for personal in the medical field is interventional applications. The most important reason is that due to the application on the patient, the personal is working almost in a close position to the source of radiation. As it is seen in Table 1, it is obvious that the number of radiation doses received in each application will increase in proportion to the number of applications. Therefore, it is emphasized by international authorities that work behind protective clothing and screens to protect against the harmful effects of radiation. It is important to use protective materials to reduce exposure to radiation. In addition, many studies have demonstrated the importance of protective materials in radiation protection.

For radiation workers, the effective dose cannot exceed 20 mSv for an average of five consecutive years and 50 mSv at any year [20,23]. Considering the 750 applications per year, each of the three laboratories will perform an average of 250 applications. Considering the personal who are exposed to the highest radiation dose, it can be predicted that they will be exposed to a dose of 1384.6 μSv per year. Regardless of the type of application, examinations were made by applying X-ray energy qualities that are more or less close to each other, as given in Table 1. After all, this is an experimental study and the measurement results are reflected in the study. Furthermore, from the total dose values, the doses per exposure were calculated to be in the range of 6.5 to 11.1 μSv.

According to the data obtained in this study the effective dose estimated for all personel was lower than the limits recommended by International Commission on Radiological Protection (ICRP). These results are consistent with the literature.

Acknowledgments

The authors would like to thank to Prof. Dr. Alper Guzeltas and the health personnel of catheter angiography laboratories in Mehmet Akif Ersoy Thoracic and Cardiovascular Surgery, Training and Research Hospital for their valuable cooperation.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

[1] Miller, D. L., "Overview of Contemporary Interventional Fluoroscopy Procedures", Health Physics 95 (2008) : 638-644

[2] United Nations Scientific Committee on the Effects of Atomic Radiation, Sources, Effects and Risks of Ionizing Radiation, UNSCEAR 2017 Report, United Nations (2018).

[3] International Atomic Energy Agency. Dosimetry in Diagnostic Radiology. An International Code of Practice, Technical Reports Series No. 457, IAEA, Vienna (2007).

[4] European Guidlines on Diagnostic Reference Levels for Pediatric Imaging Medical Radiation Exposure of the European Population. Radiation Protection No. 185, European Union, Luxembourg. EC (2018)

[5] IAEA Human Health Series. Dosimetry in diagnostic radiology for paediatric patients. No. 24 (2013), (ISSN 2075-3772).

[6] Medical Radiation Exposure of the European Population. Radiation Protection No.180, (2014), European Union, Luxembourg. EC.

[7] Stisova V. ;"Effective dose to patient during cardiac interventional procedures (prague workplaces)", Radiation Protection Dosimetry 111(3) (2004) : 271- 274.

[8] Miller, D. L ,Vañó, E., Bartal, G., Balter, S., Dixon, R., Padovani, R., Schueler, B., Cardella, J. F., Baère; T.D., "Occupational radiation protection in interventional radiology: A Joint Guideline of the Cardiovascular and Interventional Radiology Society of Europe and the Society of Interventional Radiology", Cardiovascular Interventional Radiology 33 (2010) :230- 239. DOI 10.1007/s00270-009-9756-7.

[9] Badawy M. K., Deb P., Chan R., Farouque O.; "A review of radiation protection solutions for the staff in the cardiac catheterisation laboratory". Heart, Lung and Circulation 25 (2016) : 961-967.

[10] International Atomic Energy Agency; Calibration of radiation protection monitoring instruments IAEA, Safety Reports Series No. 16 (2000).

[11] The International Commission on Radiological Protection(ICRP); Occupational radiological protection in interventional procedures. ICRP Publication 139. Annals ICRP 47(2) (2018)., ICRP.

[12] International Organization for Standardization. X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy-Part 3: Calibration of area and personal dosemeters and the measurement of their response as a function of energy and angle of incidence. ISO 4037-3. ISO (1999).

[13] International Atomic Energy Agency, IAEA-TECDOC-1641; Patient dose optimization in fluoroscopically guided ınterventional procedures, Final report of a coordinated research Project (2010).

[14] Tsapaki, V., Kottou, S., Patsilinakos, S., Voudris, V., Cokkinos, D.V.; "Radiation döşe measurements to the interventional cardiologist using an electronic personal dosemeter". Radiation Protection Dosimetry 112(2) (2004) : 245-249. doi:10.1093/rpd/nch394

[15] Dalah E. Z., Mahdi O., Elshami W., et al.; "Occupational doses to cardiologists performing fluoroscopically-guided procedures". Radiation Physics and Chemistry 153 (2019) : 21-26.

[16] Herona J. L., Padovani R., Smith I., Czarwinski R.; "Radiation protection of medical staff". European Journal of Radiology 76 (2010) : 20-23.

[17] Mohapatra, A., Greenberg, R.K., Mastracci, T.M., Eagleton, M.J., Thornsberry; B., "Radiation exposure to operating room personal and patients during endovascular procedures". J. Vasc Surg. 58(3) (2013) : 702-9. doi:10.1016/j.jvs.2013.02.032

[18] Fardid R., Toossi M. T. B., et al.; "Evaluation of occupational radiation exposure of cardiologists in interventional radiography in Mashhad CATHLABs". Int. J. Low Radiation 9(2) (2013) : 160-168.

[19] Ingwersen, M., Drabik, A., Kulka, U., Oestreicher, U., Fricke, S., Krankenberg, H., Schwencke, C., Mathey; D., "Physicians' radiation exposure in the catheterization lab: does the type of procedure matter?". JACC Cardiovasc Interv. 6(10) (2013) : 1095-102. doi: 10.1016/j.jcin.2013.05.012

[20] International Commission on Radiation Protection,ICRP. 1990, Recommendations of the ICRP Publication 60, Annals of the ICRP. Pergamon Press, Oxford, (1991).

[21] Papadakis, A. E., Damilakis; J., "Organ doses and normalized organ doses for various age groups in ultralow dose pediatric C-arm cone-beam CT". European Radiology 32 (2022) : 5790-5798.

[22] Coşkun, A. N., Demir, M,, Çetin, F., "Koroner anjiyografi uygulamalarında operatörün göz lensinin maruz kaldığı radyasyon dozunun belirlenmesi." Aydın Journal of Health 6(3) (2020) : 284- 297.

[23] Asgar, A., Mirmohammadi, S.J., Mehrparvar, A.H., Nekoofar, Z., Daneshian, E., Parach, A.A., "Evaluation of the protective effect of lead glasses on occupational eye dose in interventional cardiologic procedures; does it benefit the same for all groups of radiation workers?" International Conference on Radiation Safety: Improving Radiation Protection in Practice. Extended Abstracts (2021).