Estimation of Occupational Radiation Dose Levels of Interventional Cardiologists at the Philippine Heart Center

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The highest doses recorded for radiation workers in the hospital setting are for those who are occupationally exposed during fluoroscopically guided procedures. The aim of this study is to estimate the effective dose, *E* to interventional cardiology (IC) operators at the cardiac catheterization laboratory of the Philippine Heart Center by the use of a digital electronic personal dosimeter (EPD). Clinical data and technical factors were gathered from 40 coroangiogram (CA), 14 percutaneous transluminal intervention (PCI), and 10 double set-up (DSU) procedures. Estimated *E* from these procedures is 1.42/2.27-4.54 mSv for CA, 0.172/0-0.804 mSv for PCI, and 1.94/0.582-5.85 mSv for DSU. These values were found to be similar to the values found in literature. This is the same for the *E*/DAP values of 0.108 μSv/Gy·cm^2 for CA, 0.010 μSv/Gy·cm^2 for PCI, and 0.136 μSv/Gy·cm^2 for DSU. The estimated weighted annual dose for a busy interventional cardiologist is 3.53/2.852-11.19 mSv, which is lower than the dose limit given by the BSS.

Keywords: interventional cardiology, fluoroscopy, electronic personal dosimeter, effective dose, dose-area product

1. Introduction

Invasive cardiovascular procedures are made possible by the use of both x-ray fluoroscopy and x-ray cinefluorography [1-5]. A combination of relatively low dose screening and relatively high dose rapid sequence of radiographic exposures recorded in a film [1] or in a digital storage system is used for image acquisition. Increasing complexity of procedures require longer fluoroscopic duration, leading to increased exposure time to ionizing radiation [2,6,7] for the patient and also for the operators since they need to remain close to the patient all throughout the procedure [3,8]. Health benefits of these procedures to patients are extensive and undisputable; however, recurrent exposure to significantly high radiation doses of operators is a growing concern [1,5,9,10].

Operator doses arise from secondary and multiply scattered radiation [3,6,11]. Many factors influence the quantity and quality of radiation reaching the operators such as the amount of radiation delivered to the patient, the proximity of operator to the x-ray tube, the use of shielding, the complexity of the procedure, the dose options available on the x-ray machine, the size of the patient, and the technique and skill of the operator [4,7,8,10-13]. For the duration of an operator's career, the accumulated dose can lead to increased incidence of biological effects of radiation [2,14]. Detrimental effects of exposure to ionizing radiation to operators may be deterministic (radiodermatitis, aged skin, cataracts, *telangiectasia* in the nasal region, vasocellular epitelioms, and hand depilation) and/or stochastic ones (cancer incidence) [15]. At present, deterministic effects have been documented in an increasing number of cases [16].

Ionizing radiation doses from fluoroscopically guided interventional procedures registered the highest among all other groups using x-rays in medicine, industrial radiography, and research [17,18]. The 10th International Congress of the International Radiation Protection Association (ICRP) emphasized the need for improved protection in interventional radiology (IR), with a focus on the development of techniques for optimization of received doses [19]. Among the sources of quantifiable data is the modified quantity in radiation protection that relates the risk of partial or non-uniform exposure to the risk from an equivalent body exposure. This is the effective dose, *E* [20], with the Système International (SI) unit of sievert (Sv).

Occupational radiation dose monitoring is essential to protect workers at the CCL from radiation risk [17,21]. Various technologies and methods have been developed for the estimation of the whole body dose [1,21,22]. Thermo-luminescent dosimetry (TLD) has been reported as the most widely used technology for measuring personal doses [4,23] however the process can be very cumbersome. The easiest way is the use of digital electronic personal dosimeter (EPD) [21] that provides a real-time dose reading. In the need to monitor personal doses to cardiologists for different types of procedures that they perform, the use of an EPD worn at the chest level under the lead apron is the more direct and easier way to do it. For the estimation of *E*, from the survey of literature, the preferred algorithm is the Niklason et al. (N) double-dosimetry method that does not factor in the lead apron's thickness [1].

Over the past 20 years, there has been a huge increase in the number of fluoroscopically guided cardiology procedures performed worldwide [5]. Given the rise in the quality of medical devices technology and the complexity of the now available medical procedures, there is also a growing concern on the need for guidelines in minimizing occupational radiation exposure [24-27,29,30]. To date, standardized protocols on radiation physics, radiation biology, and radiation protection are not yet well-established because extensive training of CCL workers is still ongoing [31].

Prolonged exposure to ionizing radiation throughout a person's professional career may lead to detrimental health effects. Due to the radiation exposure of the CCL operator arising from inadequate knowledge and training on radiation management [19], there is a need for determination of effective doses for efficient radiation management.

2. Materials and Methods

Occupational radiation dose measurements were performed at the cardiac catheterization laboratories of the Philippine Heart Center (PHC), which is the primary provider of comprehensive cardiovascular care enhanced by education and research in the Philippines. The equipment used was a digital electronic personal dosimeter (Thermo EPD Mk2) with a calibration traceable to the UK National Standard (which is a Primary Standard) by the use of transfer standard EPDs. The EPD is small, lightweight, and does not interfere with the work of the operator. The low detection limit of the EPD is 1 μSv, which is lower by 19 μSv compared to a TLD badge [21].

The X-ray systems used in the study were the Philips bi-plane system, Allura Xper FD10/10 and the monoplane system, Allura Xper FD 20. The built-in dose-area product meters (DAP) at the x-ray head of each machine were calibrated following the *in situ* DAP calibration protocol of the IAEA TRS-457 manual [41].

Clinical data and technical factors were gathered from 40 coroangiogram (CA), 14 percutaneous transluminal intervention (PCI), and 10 double set-up (CA/PCI) procedures; all performed using the femoral approach. The data was gathered using a stratified random sampling method. All pediatric cases were discarded and all adult cases were retained. All other procedures which are not CA, PCI or CA/PCI (combination of CA/PCI or CA/TCT) were also not included. The absence of any radiation protection devices (radiation glasses, thyroid shield, or lead gown) was noted but was not used as a stratification criterion. The number of years in practice of the operator was also not part of the sampling criteria.

The following data were recorded for each procedure: date, procedure, name of 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).

The EPD was worn at the chest level, under the lead apron of the primary operator, returning an $H_p(10)$ reading after each procedure.

The ICRP recommended the use of two dosimeters per operator for highly exposed operators at the cardiac catheterization laboratory. One dosimeter would normally be worn at chest height under the apron and another dosimeter at the level of the neck over the apron. The goal of this study was to compute for E using a single electronic personal dosimeter with the Niklason et. al (1994) algorithm:

$$E = H_u + 0.06(H_{os} - H_u) \qquad 2.1$$

Where: H_u is $H_p(10)$, which is the dose equivalent in soft tissue, 10 mm below the surface of the body

H_{os} *is* $H_p(0.07)$, which is the dose equivalent in soft tissue, 0.07 mm below the surface of the body

Per ICRP, $$H_u = 0.01 H_{os} \quad 2.2$$

Therefore, to compute for *E* using the $H_p(10)$ reading from a singe dosimeter, we used the equation,

$$E = H_p(10) + 0.06\left\{\left[\frac{H_p(10)}{0.01}\right] - H_p(10)\right\} \quad 2.3$$

The estimation of *E* for each procedure using the EPD, which was used to assess the staff's radiobiological risk, was divided by the DAP reading to produce the *E*/DAP index for a better definition and comparison of the doses received by an operator from a procedure.

The mean *E* from each procedure was further summarized for the estimation of weighted annual dose. The result was compared to the recommended occupational dose limits by the BSS, applied in the Philippines.

3. Results

3.1 Data by procedure type

Table 1. Statistics for CA, PCI, and CA/PCI

	CA			PCI			CA/PCI		
	Fluoro time/ beam-on time (min)	DAP (Gy×cm^2)	Estimated Effective Dose (μSv)	Fluoro time/ beam-on time (min)	DAP (Gy×cm^2)	Estimated Effective Dose (μSv)	Fluoro time/ beam-on time (min)	DAP (Gy×cm^2)	Estimated Effective Dose (μSv)
Mean	4.25	37.94	4.34	13.96	110.55	1.49	35.93	144.12	22.9
Standard deviation	4.72	31.57	8.42	9.41	116.43	2.95	19.73	72.1	22.67
Median	2.48	29.74	0	11.37	65.51	0	37.42	139.74	17.35
Mode	1.8	no mode	0.694	6.35	65.51	0.694	no mode	no mode	no mode
Range	27.17	175.66	48.58	28.9	425.03	6.94	67.92	233.88	69.4
Minimum	1	8.58	0	3.3	14.57	0	11.15	50.84	0
Maximum	28.17	184.24	48.58	32.2	439.6	6.94	31.77	284.73	69.4
3rd quartile	5.38	50.38	6.94	19.03	185.41	1.74	44.47	179.36	38.17

For 40 patients who underwent CA, 67.50% were male and 32.50% were female. The average age was 60 (±7) y, the average height was 164 (±10) cm, and the average weight was 71 (±16) kg. For 14 patients who underwent PCI, 57.14% were male and 42.86% were female. The average age was 66 (±12) y, the average height was 159 (±8) cm, and the average weight was 63 (±10) kg. For 10 patients who underwent CA/PCI, 90.00% were male and 10.00% were female. The average age was 59 (±13) y, the average height was 164 (±10) cm, and the average weight was 75 (±19) kg.

Table 1 presents the result of the fluoroscopy time or beam-on time in min, dose-area product (DAP) in Gy·cm^2, and estimated effective dose in μSv for CA, PCI, and CA/PCI procedures performed at PHC during the duration of this study.

3.2 Normalization of E to DAP

The *E*/DAP index in Table 2 shows the value of the operator's estimated effective dose, *E* normalized to the patient's dose-area product. The *E*/DAP value for each procedure is useful in evaluating the dependence of *E* to the technical parameters of the x-ray system, the use of protection devices and the operator's skill.

Table 2. The E/DAP Index for CA, PCI, and CA/PCI

	E/DAP value (mSv/Gy·cm^2)		
	CA	PCI	CA/PCI
Mean	0.12	0.011	0.15
Standard deviation	0.1982	0.0278	0.1273
Median	0	0	0.154
Mode	0	0	0
Range	0.9	0.1	0.4
Minimum	0	0	0
Maximum	0.9	0.1	0.4
3rd quartile	0.182	0.004	0.207

3.3 The Estimation of Weighted Annual Dose

The two cardiac catheterization laboratory at the Philippine Heart Center services patients 6 days a week. From a survey of the log book for each laboratory, it was found that the busiest interventional cardiologist performs 2 procedures a day. This data together with the estimated effective doses from each procedure were used to calculate the weighted annual dose for an interventional cardiologist, presented in Table 3.

Table 3. The Estimation of Weighted Annual Dose

Type of procedure	Number of cases from this study	Estimated effective dose (mSv)	%	Number of working days/year	Number of procedures /day	Estimated weighted annual dose (mSv)
CA	40	4.34/6.94	62%	288	2	1.55/2.48
PCI	14	1.49/6.94	22%	288	2	0.19/0.88
CA/PCI	10	2.29/6.94	16%	288	2	0.21/0.64
				Estimated weighted annual occupational dose		**1.95[a]/4.00[b]**

[a]based on the calculation of the mean effective doses/ [b]based on the mode

The estimated weighted annual occupational dose for a busy interventional cardiologist working at 288 days per year and performing 2 procedures per day is 1.94 mSv based from calculation of the mean estimated effective doses from CA, PCI, and CA/PCI and 4.00 mSv based from calculation of the most frequent value (mode) of effective doses from CA, PCI, and CA/PCI.

4. Discussion and Conclusion

4.1. Estimated dose, E

The mean estimated effective dose of 3.97 (±1.22) μSv for CA was found to be similar with the values reported in literature. The mode, which is almost 0, falls at the lower end of the range 0.00002 to 0.038 mSv (0.02 to 38 μSv) reported in literature [4].

For PCI, the mean estimated effective dose of 1.36 (±0.72) μSv was found to be lower than Lange with 3.4 μSv [32], Whitby with 1.8 μSv [33], and Goni with 1.6 μSv [3]. The mode, which is almost 0, is at the lower end of the range 0.00017 to 0.031 mSv (0.17 to 31 μSv) reported in literature [4].

For CA/PCI, the mean estimated effective dose of of 21.0 (±6.56) μSv was found to be similar with the values reported in literature. The mode is almost 0, falls at the lower end of the range 0.004 to 0.027 mSv (0.4 to 27.1 μSv) reported in literature [4].

4.2 The E/DAP Index

The mean estimated effective dose to operators normalized to the patient DAP (*E*/DAP) for CA is 0.1076 (±0.03) μSv/ Gy·cm^2. This value falls on the higher edge of the range 0.002 to 0.13 μSv/ Gy·cm^2 reported in literature [4]. The *E*/DAP range for this study is almost 0 to 0.79 μSv/ Gy·cm^2.

For PCI, the mean estimated effective dose to operators normalized to the patient DAP (*E*/DAP) is 0.009 (±0.04) μSv/ Gy·cm^2. This value falls on the lower edge of the range 0.002 to 0.17 μSv/ Gy·cm^2 reported in literature [4]. The *E*/DAP range for this study is almost 0 to 0.09 μSv/ Gy·cm^2.

For CA/PCI, the mean estimated effective dose to operators normalized to the patient DAP (*E*/DAP) is 0.136 (±0.04) μSv/ Gy·cm^2. This value falls on the lower edge of the range 0.9 to 0.74 μSv/ Gy·cm^2 reported in the literature [4]. The *E*/DAP range for this study is almost 0 to 0.4 μSv/ Gy·cm^2.

4.3 The Estimated Weighted Annual Dose

The estimated weighted annual occupational dose values for a busy interventional cardiologist at the Philippine Heart Center is lower than the 20 mSv/year, average over 5 consecutive years and 50 mSv in any single year recommended dose limits for occupational exposure by the IAEA and ICRP, as stated in the BSS. The table for recommended dose limits for occupational exposure can be found in Table 4.

Table 4. Recommended dose limits for occupational exposure

Dose Quantity	Occupational Dose Limit
Effective dose	20 mSv per year average over 5 consecutive years (100 mSv in 5 years), and 50 mSv in any single year
Equivalent dose in:	
Lens of the eye	150 mSv in a year
Skin	500 mSv in a year
Hands and feet	500 mSv in a year

4.4 Conclusion

Comparison of values for the same dosimetric quantity from different interventional cardiology procedures is not appropriate to the objectives of this study, given that each procedure has its own distinctive clinical indications. Hence, the values from this study were compared to the values for the same dosimetric quantity from a similar interventional cardiology procedure from published literature of studies conducted in other countries.

For *E*, the medians and the modes were found to be in between the values found in literature. This is similar for the medians and the modes for *E*/DAP computed values.

For the median and mode of the estimated weighted annual dose for a busy interventional cardiologist from this study, both were found to be lower than the recommended occupational dose limit of 20 mSv/year, average over 5 consecutive years and 50 mSv in any single year given by the BSS.

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