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Original article

Radiation doses to patients in coronary interventions in a hospital in Thailand

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Background: Radiation dose is best estimated by the Dose Area Product (DAP), the absorbed dose to air, multiplied by the X-ray beam cross-sectional area at the point of measurement. Interventional cardiologists should be made aware of the exposures to patients and how they compare to established norms.
Objective: We assessed patient doses during coronary diagnostic and interventions then compared doses between two angiocardiographic systems in our center and through these actions.
Methods and Results: In total, 308 (44.4%) diagnostic CAs, 229 (33.0%) one-vessel PCIs, 53 (7.6%) two or three-vessel PCIs, and 15 (2.2%) PCIs to CTO were carried out. The mean DAP value for diagnostic CAs in room No. 1 (Siemens Axiom Artis dBC) was 45.2±28.7 $Gy.cm^2$, compared with room No. 2 (Philips Allura Xper biplane FD 20/10) where mean DAP value was 78.6±58.4 $Gy.cm^2$ ($p < 0.001$). The mean DAP value for one-vessel PCIs in room No. 1 was 97.8±67.5 $Gy.cm^2$, compared with room No. 2, mean DAP value of 159.4±82.4 $Gy.cm^2$ ($p = 0.030$). The mean DAP value for two or three-vessel PCIs in room No. 1 was 153.1±65.6 $Gy.cm^2$, compared with room No. 2, mean DAP value of 168.0±94.7 $Gy.cm^2$ ($p = 0.070$). DAP values per procedure in diagnostic CAs, one-vessel PCIs, and two or three-vessel PCIs in room No. 2 were higher than in room No. 1 after multivariable correction for weight and fluoroscopy time.
Conclusions: Regular measurement of patient doses is an essential step to optimize exposure. It makes operators aware their own performance and allows comparisons with generally accepted practice.

Keywords: Coronary interventions, radiation dose

Interventional cardiology procedures are increasing in Thailand with about 44 catheterization laboratories currently in operation for a population of about 66 million. There is almost a 19% increase in coronary angiography (CA) from 2003 to 2006. Apart from diagnostic examinations, a remarkable increase is also observed in the therapeutic procedures such as percutaneous coronary intervention with about a 5% increase in period noted above. Many patients undergo repeated interventional procedures, some of them within a week or two. Some procedures do last up to an hour or more as far as radiation "ON" time is concerned, particularly where a combination of interventions are carried out on the same patient during a single session. This can result in high radiation doses to the patient and to staff in the catheterization laboratory. Coronary interventional procedures can generate highly localized dose to the skin of patients, which may be above the threshold of deterministic injuries and carry an increased risk of cancer induction. Thus, multiple procedures could lead to serious injury [1].

In interventional cardiology, radiation dose for patient is best estimated by the Dose Area Product (DAP), which is the absorbed dose to air, multiplied by the X-ray beam cross-sectional area at the point of measurement and it is express in $Gy.cm^2$ [2]. According to a recent statement of the ACC/AHA, "the DAP delivered to a patient during a procedure is both a measure of stochastic risk and a potential quality indicator. Physicians should be aware of the exposures

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they deliver to their patients and how they compare to established norms”. Unfortunately, radiological awareness is largely suboptimal, particularly in cardiology centers [3, 4].

The aims of this study were to 1) assess patient doses during coronary diagnostic and interventions; 2) compare doses between two angiocardiographic systems in our center and through these actions; 3) create the awareness of radiation safety among staff working in interventional cardiology. There is gross lack of information on radiation doses to patients in most Asian countries and absence of reports from Thailand on this issue. To our knowledge, our report represents the first analysis of patient doses during coronary interventions in Thailand and it is hoped that this will stimulate interest in the region for the benefit of patients and staff.

Materials and methods

Between August 2008 and January 2009, a total of 694 patients underwent invasive cardiovascular procedures in the catheterization laboratory at King Chulalongkorn Memorial Hospital. The laboratory is equipped with two biplane angiocardiographic systems. Room No. 1 has a Siemens Axiom Artis dBC, (Forchheim, Germany) and room No. 2 has a Philips Allura Xper biplane FD 20/10, (Eindhoven, the Netherlands). Image acquisition by the Siemens unit is performed through a biplane flat detector followed by digital image processing and documentation. The system is equipped with flat detectors with a 10 inch input field. Normal fluoroscopy mode and digital cine acquisition operate at 15 frames/second. The system uses a sophisticated automatic dose control system for automatic spectral beam filter selection in fluoroscopy. The maximum power of X-ray tube is 125 kW with a maximum kVp of 125. In the Philips unit, the normal fluoroscopy setting has pulse frequency of 15 frames/second and digital cine acquisition defaults to a 15 frames/second. The system has a 100 kW X-ray tube (maximum kVp of 125) with automatic dose control and programmable spectral beam prefilter.

Radiation dose was quantified with DAP meters incorporated in both unit and cumulative air kerma. The DAP meters use an air ionization chamber mounted in the X-ray assembly and integrate exposure over the entire image field. Further data collection included fluoroscopy time, cine runs, and total number of images. Both systems also provided cumulative air kerma values in mGy that is based on dose at the interventional reference point. The total dose of the biplane was recorded in terms of DAP (Gy.cm^2) and cumulative air kerma (mGy) for selected interventional procedures. Initially, data collection was started for a large number of procedures such as coronary angiography (CA) with or without left ventriculography or aortography, right or left cardiac catheterization, one-vessel percutaneous coronary intervention (PCI), two or three-vessel PCI, PCI to chronic total occlusion (CTO), peripheral angiography or intervention, percutaneous transvalvular mitral commissurotomy (PTMC), ASD closure, and PDA closure. In view of the smaller number of patients for many procedures, data collection was then mainly confined to CA with or without left ventriculography or aortography, one-vessel PCI, two or three-vessel PCI, and PCI to CTO. Mostly, we used a field size of 20 cm for coronary interventions in both systems. Results are expressed as mean±SD or median with interquartile range (IQR). Comparison of radiation dose between the two systems was made using Student’s *t* test. A multivariate regression analysis was performed to adjust for patient weight and fluoroscopy time that affected radiation dose. In order to investigate the distribution of DAP and cumulative air kerma in CA and PCI, data were presented in ranges (number of patients receiving DAP d”100 Gy.cm^2, 101 to 200 Gy.cm^2, 201 to 300 Gy.cm^2, 301 to 400 Gy.cm^2, e”400 Gy.cm^2, and cumulative air kerma <1Gy, 1 to 1.999 Gy, 2 to 3.999 Gy, 4 to 5.999 Gy, 6 to 9.999 Gy, e”10 Gy) (**Figures 1** and **2**).

Results

Of the 694 patients (426 were males), aged 63.1±13.3 years (mean±SD), with weight 63.6±13.3 kg. Five hundred and fifty-seven (80.3%) procedures were performed in room No. 1. In total, 308 (44.4%) were diagnostic CAs (CA with or without left ventriculography or aortography), 229 (33.0%) one-vessel PCIs, 53 (7.6%) two or three-vessel PCIs, and 15 (2.2%) PCIs to CTO.

A moderately high correlation was found between fluoroscopy time and DAP ($r = 0.71$, $p < 0.001$). The correlation between weight and DAP was weak ($r = 0.25$, $p < 0.001$). There was no correlation between weight and fluoroscopy time. Comparison of radiation doses between two angiocardiographic systems is shown in **Table 1**.

DAP values per procedure in diagnostic CA, one-vessel PCIs, and two or three-vessel PCIs in room

No. 2 were higher than room No. 1 after multivariable correction for patient weight and fluoroscopy time. Multivariate analysis performed using a stepwise forward multiple linear-regression model (**Table 2**) revealed patient weight, fluoroscopy time, and angiocardiographic systems were independent predictors of the radiation dose (DAP) during diagnostic CAs, one-vessel PCIs, and two or three-vessel PCIs. In cases of PCI to CTO, the mean DAP value per procedure was 397.3±221.8 Gy.cm^2, average fluoroscopy time was 39.2±20.1 minutes (**Table 3**).

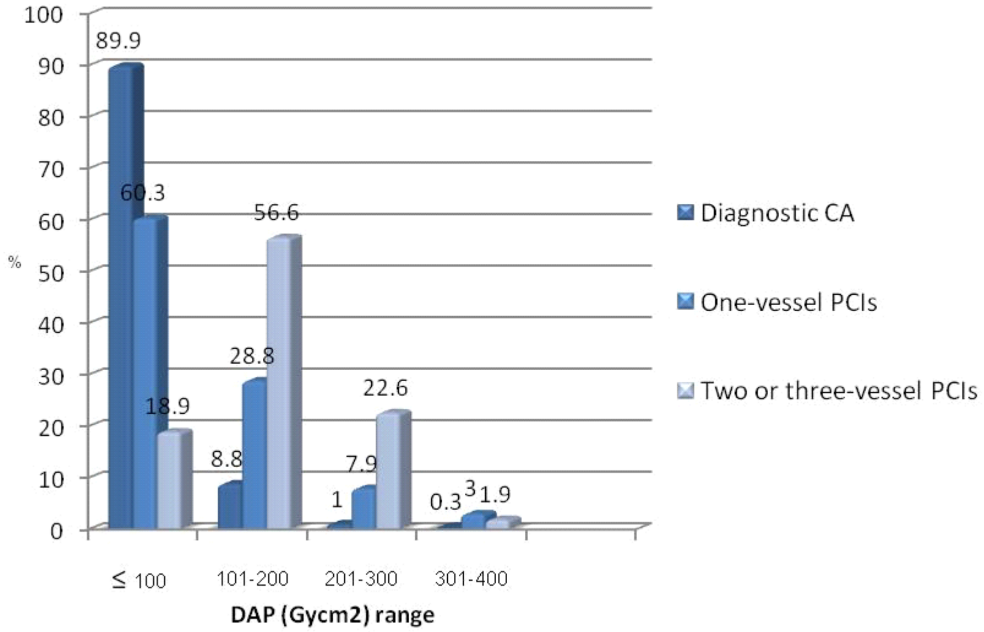

Figure 1. The distributions of DAP in diagnostic CAs, one-vessel PCI, two or three-vessel PCIs are presented in ranges (percent of patients receiving DAP ≤100 Gy.cm^2, 101 to 200 Gy.cm^2, 201 to 300 Gy.cm^2, and 301 to 400 Gy.cm^2).

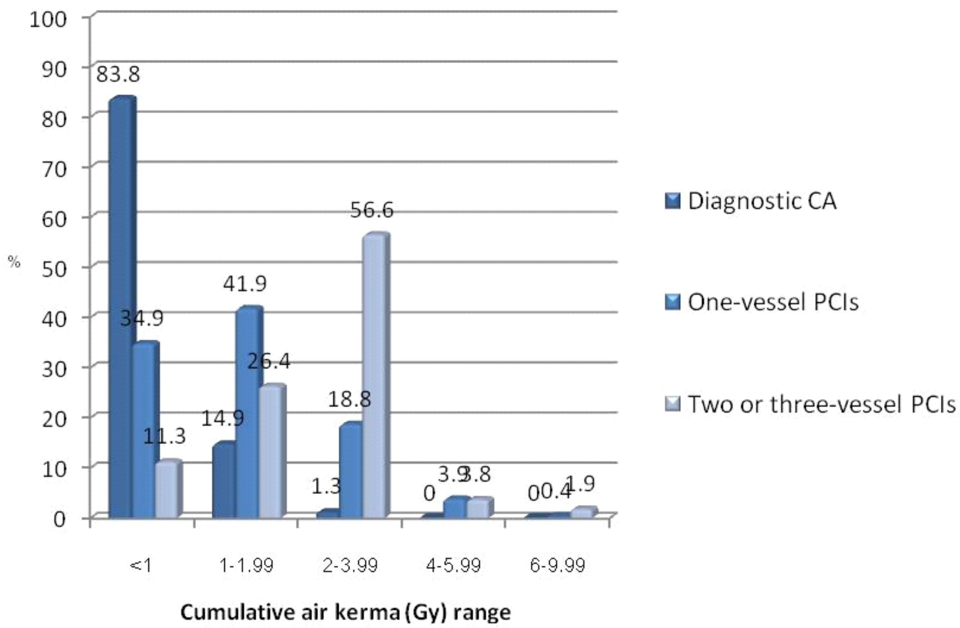

Figure 2. The distributions of cumulative air kerma in diagnostic CAs, one-vessel PCI, two or three-vessel PCIs are presented in ranges (percent of patients receiving <1Gy, 1-1.999 Gy, 2-3.999 Gy, 4-5.999 Gy, 6-9.999 Gy).

Table 1. Comparisons of radiation doses between two angiocardiographic systems

Procedures	Parameters	Room No. 1 Siemens Axiom Artis dBC	Room No. 2 Philips Allura Xper biplane FD 20/10	*p* value
Diagnostic CAs	**Weight (kg)**			
Room No. 1, n = 241	Mean	64.1±13.6	60.6±13.5	0.860
Room No. 2, n = 67	Median (IQR)	62.6 (55.0-72.3)	59.0 (51.9-67.9)	
	Flu time (min)			
	Mean	5.7±5.2	6.2±5.1	0.896
	Median (IQR)	4.1 (2.5-6.9)	5.0 (3.0-8.0)	
	DAP (Gy.cm^2)			
	Mean	45.2±28.7	78.6±58.4	<0.001
	Median (IQR)	37.4 (26.8-55.3)	64.0 (37.6-101.8)	
	Cumulative air kerma (mGy)			
	Mean	612.1±373.4	881.7±506.4	
	Median (IQR)	510.3 (350.8-774.8)	780.0 (492.3-1112.0)	0.006
One-vessel PCIs	**Weight (kg)**			
Room no. 1, n = 198	Mean	65.0±12.4	64.9±12.0	0.939
Room no. 2, n = 31	Median (IQR)	64.6 (55.6-72.3)	62.3 (56.3-70.8)	
	Flu time (min)			
	Mean	13.3±12.3	14.7±9.4	0.673
	Median (IQR)	9.3 (5.9-16.4)	12.3 (7.6-20.2)	
	DAP (Gy.cm^2)			
	Mean	97.8±67.5	159.4±82.4	0.030
	Median (IQR)	80.5 (53.8-118.0)	136.0 (88.0-208.8)	
	Cumulative air kerma (mGy)			
	Mean	1481.3±1078.5	2149.8±1143.4	
	Median (IQR)	1205.5 (781.0-1771.0)	1849.0 (1148.5-2733.0)	0.197
Two or three-vessel PCIs	**Weight (kg)**			
	Mean	64.4±11.2	58.6±13.7	0.485
Room No. 1, n = 42	Median (IQR)	64.0 (56.0-69.0)	60.0 (46.0-65.0)	
Room No. 2, n = 11	**Flu time (min)**			
	Mean	19.9±10.6	18.7±13.1	0.351
	Median (IQR)	17.5 (12.0-25.3)	18.0 (8.0-27.0)	
	DAP (Gy.cm^2)			
	Mean	153.1±65.6	168.0±94.7	0.007
	Median (IQR)	139.5 (107.8-190.3)	167.0 (67.0-233.0)	
	Cumulative air kerma (mGy)			
	Mean	2361.8±1048.1	2380.1±1290.0	
	Median (IQR)	2241.5 (1546.8-2855.0)	2244.0 (926.0-3557.0)	0.173

Table 2. Multiple linear regression analysis relating patient weight, fluoroscopy time, room No. (angiocardiographic system) to DAP

Equations	Cumulative R^2 value	*p* value
Diagnostic CAs		
DAP = –84.78 +1.08weight + 4.51flu time +34.98 room No.	0.64	<0.001
One-vessel PCIs		
DAP = –142.79 +1.98weight + 4.21flu time + 55.91 room No.	0.60	<0.001
Two or three-vessel PCIs		
DAP = –218.40 +3.54weight + 5.12flu time + 41.44 room No.	0.63	0.009

Table 3. Radiation doses in 15 patients who underwent PCI to CTO

	Weight (kg)	Flu time (min)	DAP(Gy.cm^2)	Cumulative air kerma (mGy)
Mean±SD	73.6±15.6	39.2±20.1	397.3±221.8	5801.5±3231.8
Median (IQR)	68.3 (62.7-78.5)	37.7 (23.8-48.0)	343 (234.8-557.5)	5060.0 (3541.0-7735.3)

Discussion

Our study is the first to report radiation doses during coronary interventions in Thailand. In a study of the International Atomic Energy Agency coordinated research program covering a total of 2265 CAs and 1844 PCIs in five countries and 14 angiographic units, DAP guidance levels of 50 and 125 Gy.cm^2 are suggested for CA and PCI procedures [5]. It was stated that these levels should be adjusted for the complexity of the procedures performed in a given institution. There have been number of other studies and reported values vary between 25 to 65 Gy.cm^2 for CA and 85 to 118 Gy.cm^2 for PCI [6-10]. Our study showed a mean value for CA of 45 Gy.cm^2 in room No. 1, which is well within the range reported by other investigators, but a mean value of 78.6 Gy.cm^2 in room No. 2, which is higher than other reported studies and is almost 80% higher than the value in room No. 1. Similarly, mean value for one-vessel PCI in room No. 1 of 97.8 is within the range as compared to other studies but in room No. 2, the value of 159.4 is outside the range reported by many others. It should be noted that in many earlier studies the values for PCI have been averaged for different levels of complexity whereas in our study we estimated values separately for one vessel, two, or three vessels.

The mean DAP value for two or three vessel PCIs in room No. 1 is 56% higher than the DAP value for one-vessel PCI, whereas they are only marginally different in room No. 2. The result may be because the sample size is relatively small (11 in room No. 2 for two or three vessels). However, DAP values per procedure in diagnostic CA, one-vessel PCIs, and two or three-vessel PCIs in room No.2 were higher than in room No.1 after multivariable correction for patient weight and fluoroscopy time. In spite of a need to add other factors that indicate complexity of the procedure [11, 12], it can be attributed to the detector elevation in the frontal plane of FD 20/10, Philips Allura Xper. Because coronary interventions require cranial or caudal angulations, therefore the large detector can cause more space between patient and detector.

Unlike DAP there are difficulties in comparing cumulative air kerma as earlier machines did not have this measure and in many papers the value of entrance skin dose or peak skin dose have been reported by dis-similar and inconsistent methodologies. While this paper was being finalized, it is noted that guidelines for patient dose and dose management have been published [13]. This will facilitate future work in patient dosimetry.

The maximum skin doses reported in a study [9] covering 322 patients (CA+PCI) were <1 Gy for 28% of the patients (90/322) and >2 Gy for 13.5% of the patients (42/322). This compares roughly well with our results in which about 15% of the patients received maximum dose (cumulative air kerma) >2.0 Gy. It needs to be kept in mind that cumulative air kerma may be about 40% higher than peak skin dose in cardiac interventions. Acute radiation doses may cause erythema and cataract at 2 Gy, permanent epilation at 7 Gy, and delayed skin necrosis at 12 Gy [14].

Reports of skin injuries in the 1990s had a common feature in that the operating staff did not know about the possibility of such injuries from the interventional procedure (**Figure 3**). The awareness started in 2004 with a training course organized by the IAEA especially for interventional cardiologists. Subsequently our group in the hospital has organized a number of training events for clinical and paramedical staff who work in the catheterization laboratory and there is good degree of awareness. We started recording of radiation doses in all PCI patients only in 2008 in our hospital. Periodic testing of angiography machines is done. Patient entrance surface air kerma using 2 mm copper placed at flat panel detector for room No. 2 machine (Philips Allura Xper biplane FD 20/10) using flu2 mode (normal default fluoroscopy mode setup by factory), field size 19 cm was 35.81 mGy/-min compared with room No. 1 machine (Siemens Axiom Artis dBC) using an automatic mode and field size of 20 cm was 17.9 mGy/minute. Thus the dose rate of room No. 2 machine was about 2 times higher as compared with the room No.1

machine. Based on this observation, we decided to shift from normal flu mode to low fluoroscopy mode for our routine use after verifying image quality. The dose rate has reduced to 11.38 mGy/minute (**Figure 4**).

Figure 3. Skin injury in a patient with chronic total occlusion, underwent repeated PCI **a**) 2 months, **b**) 6months, **c**) 8 months after last PCI, and **d**) after the flap surgery

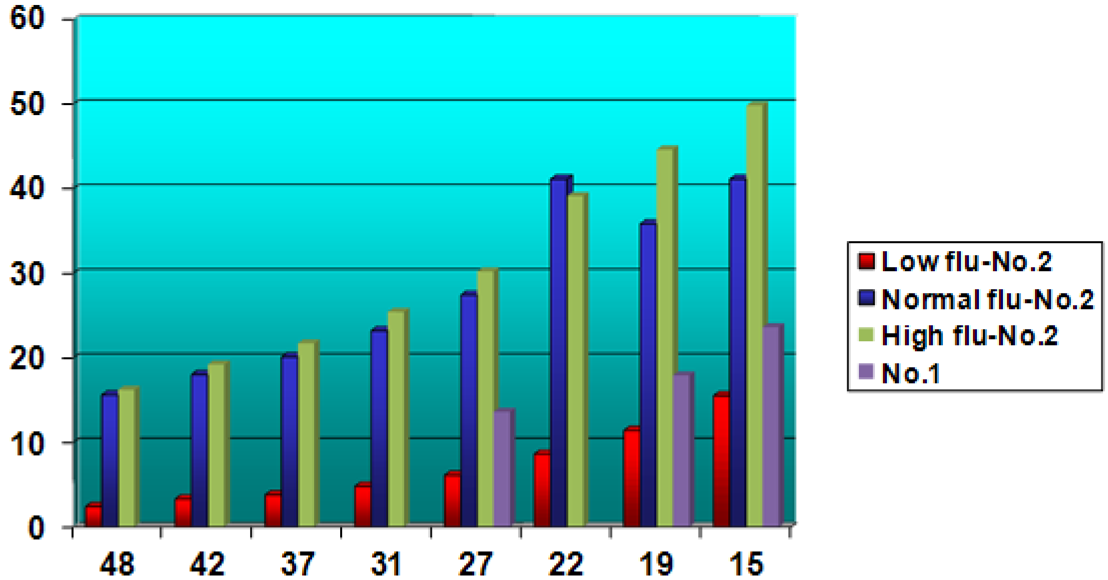

Figure 4. Patient entrance surface air kerma during low, normal, and high fluoroscopy mode in room No.2 (Philips Allura Xper biplane FD 20/10) compared with automatic fluoroscopy mode in room No.1 (Siemens Axiom Artis dBC)

The staff and patient doses have been compared and they are correlated [15]. Thus dose management actions on patient doses will also improve the staff protection. It has been emphasized that the patient and staff doses should be known by the interventional cardiologists [16]. Radiation doses in interventional procedures being high, regular measurement of patient doses is an essential step to optimize exposure. It makes operators aware of their own performance and allows comparisons with the generally accepted practice. If reductions in radiation dose to the patient are to be achieved, all catheterization laboratories must be capable of estimating patient dose. In this respect our study created awareness among all staff in the catheterization laboratory of patient dose assessment and dose management. It is hoped that such studies when conducted in other centers shall lead to a reduction in patient doses and bring a culture of radiation safety in cardiac interventions and among staff in catheterization laboratories.

All authors declare no conflict of interest.

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