Australas Phys Eng Sci Med (2015) 38:83–91
DOI 10.1007/s13246-014-0326-1

SCIENTIFIC PAPER

Preliminary results of an attempt to predict over apron occupational exposure of cardiologists from cardiac fluoroscopy procedures based on DAP (dose area product) values

Mohammad Taghi Bahreyni Toossi ·
Mohammad Mehrpouyan · Hossein Nademi ·
Reza Fardid

Received: 7 December 2013 / Accepted: 22 December 2014 / Published online: 28 December 2014

Abstract This study is an effort to propose a mathematical relation between the occupational exposure measured by a dosimeter worn on a lead apron in the chest region of a cardiologist and the dose area product (DAP) recorded by a meter attached to the X-ray tube. We aimed to determine factors by which DAP values attributed to patient exposure could be converted to the over-apron entrance surface air kerma incurred by cardiologists during an angiographic procedure. A Rando phantom representing a patient was exposed by an X-ray tube from 77 pre-defined directions. DAP value for each exposure angle was recorded. Cardiologist exposure was measured by a Radcal ionization chamber 10X5-180 positioned on a second phantom representing the physician. The exposure conversion factor was determined as the quotient of over apron exposure by DAP value. To verify the validity of this method, the over-apron exposure of a cardiologist was measured using the ionization chamber while performing coronary angiography procedures on 45 patients weighing on average 75 ± 5 kg. DAP values for the corresponding procedures were also obtained. Conversion factors obtained from phantom exposure were applied to the patient DAP values to calculate physician exposure. Mathematical analysis of our results leads us to conclude that a linear relationship exists between two sets of data: (a) cardiologist exposure measured directly by Radcal & DAP values recorded by the X-ray machine system ($R^2 = 0.88$), (b) specialist measured and estimated exposure derived from DAP values ($R^2 = 0.91$). The results demonstrate that cardiologist occupational exposure can be derived from patient data accurately.

Keywords Interventional cardiology · Entrance surface air kerma (ESAK) · Over apron exposure · Cardiologist · DAP

Introduction

Interventional cardiology includes a number of procedures such as coronary angiography (CA), percutaneous transluminal coronary angioplasty (PTCA) and electrophysiology procedures that are widely used in routine clinical practice. CA is used for detection of cardiovascular diseases. This procedure consists of injection of a contrast medium into the blood vessels of the patient through a catheter and highlighting the anatomical region of interest using fluoroscopy with X-rays [1–3].

During these procedures patients are exposed to significant doses due to the long duration of fluoroscopy and the large numbers of cine frames which are taken in each examination. Furthermore, the nature of interventional fluoroscopy examinations requires the presence of

---

M. T. B. Toossi
Medical Physics Department, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran

M. Mehrpouyan
Nutrition and Biochemistry Department, Faculty of Medicine, Sabzevar University of Medical Sciences, Sabzevar, Iran

M. Mehrpouyan (✉)
Medical Physics Research Center, Medical Physics Department, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran
e-mail: mehrpouyan.mohammad@gmail.com

H. Nademi
Javad-Al-Aeme Heart Hospital, Mashhad, Iran

R. Fardid
Radiology Department School of Paramedical Sciences, Shiraz University of Medical Sciences, Shiraz, Iran

physicians (cardiologists) in the close vicinity of the patient for relatively long times. The result is much higher occupational dose compared to other diagnostic procedures [4, 5]. The ever increasing number of cardiovascular patients worldwide requires a careful programme for protection of patients as well as personnel of the related departments [4, 6].

Scattered radiation arising from the patient is the main contributor to the dose to medical staff. Leakage radiation from the X-ray tube and, in some cases, the primary beam itself are the other possible sources of exposure [3, 7, 8]. Therefore, occupational doses in catheterization laboratories (CATHLABs) may exceed limits recommended by the International Commission on Radiological Protection (ICRP), and may even induce deterministic radiation effects in cases where radiological protection tools are not used appropriately [8, 9]. Interventional cardiology is a clinical practice with a high radiation risk, therefore appropriate protection evaluations should be performed, occupational doses should be monitored carefully and special attention should be paid to radiation protection of the staff involved in these procedures [4, 10–12].

To reduce occupational dose various protection tools such as leaded aprons, goggles, bed side curtains and glass screens suspended from the ceiling over the patient's body are used [11]. It is also necessary to implement effective measures for accurate, fast and simple dosimetry appropriate for such environments.

Limits for occupational exposure are expressed in effective dose [8]. Effective dose is intended for estimation of the overall stochastic risk from exposure to ionizing radiation. This quantity is calculated as the weighted sum of organ doses [8, 13]. For monitoring of the dose received by radiation workers the personal dose equivalent ($H_p(10)$) is measured. $H_p(10)$ is an estimator of the absorbed dose at 10 mm depth in human tissue. When a worker's body is uniformly exposed by radiation, the effective dose (E) can be estimated simply from $H_p(10)$ [14–16]. However, exposures in cardiology and interventional suites are typically non-uniform.

Presently, various methods are used to estimate effective dose arising from different fluoroscopic techniques [3, 7, 17]. Different methods have been proposed to derive effective dose for radiation workers from doses measured at one or two points on their body surface [16, 18, 19]. For example, in Britain, based on ICRP 85 recommendations, it is recommended to place one dosimeter under the lead apron to measure $H_p(10)$. By contrast, in the United States of America, according to NCRP 122, it is advised that if only one dosimeter is used, it must be placed over the shield at the neck region and if two dosimeters are worn, one should be placed under the apron at the lumbar region and the other over the apron at the neck region [11]. Recently, one radiation protection center in Holland (NCR) has proposed an alternative protocol. In their report, they recommended the use of only one dosimeter over the lead apron to increase the measurement's accuracy and to lower the costs. This technique will typically result in higher reported dose compared with the actual dose value. This method may be preferred to the models which underestimate the dose and consequently the radiation risks [11, 20]. In summary it should be noticed that there are costs involved in application of these practically used methods and the obtained results are typically retrospective.

To estimate the exposure of the patient, dose area product (DAP) can be utilized. ICRP has reported that the exposure of the medical practitioner correlates with that of the patient [4, 21, 22]. In recent years, several research teams have tried to find what relationship may exist between the patient's recorded DAP values and cardiologists' dose received during cardiac fluoroscopy. The main goal of these studies were to utilize DAP values to estimate physician dose arising from interventional fluoroscopy. Bor et al. 2009 have investigated the accuracy of two dosimetry techniques to estimate the doses to cardiologists. The first method included establishment of a database to relate the cardiologist extremity doses to the DAPs of patients. In the second one, an equation was suggested from which the cardiologist doses were calculated. Finally, they concluded that, as a useful method, DAP values may be used to estimate the cardiologists' doses [5]. Kuipers et al. 2010 demonstrated the relationship between absorbed dose measured over the lead apron in the chest region of the cardiologists and the patient exposure (DAP). They found a linear relationship (correlation coefficient of $R^2 = 0.55$) between these two variables [21] though this correlation is not very strong. In another study carried out by the European DIAMOND cardiology research group in 2006, the relationship between cardiologists' dose and their patients' exposure (DAP) was also investigated [23]. These previous studies examined correlations between total DAP and measures of occupational dose, however they took no account of the different imaging projections used. Better correlations may be expected when the amount of radiation delivered by each of the contributing imaging projections is considered.

Materials and methods

DAP to Exposure conversion coefficients arising from exposing a Rando phantom

The main goal of this study was to obtain the factors that may be used to estimate a cardiologist entrance surface air kerma (ESAK) arising from a CA or PTCA procedure.

Measured exposure and recorded DAP value for a specific view

In this study, a Siemens AXIOM Artis X-ray system was used. This system is equipped with a table-mounted leaded drape (Pb equivalent 0.50 mm) and a leaded glass shield (Pb equivalent 0.5 mm) suspended from the ceiling over the patient table. The Artis system is also equipped with a DAP meter, consisting of an ionization chamber placed in front of the tube collimator. This system makes a record of DAP value for each imaging projection and saves all DAP values acquired throughout a complete procedure. A Rando Alderson reference man phantom resembling an average male patient 75 kg in weight was placed on the patient table to produce scattered radiation. The phantom was exposed from 77 separate imaging angles, see "Definition of imaging views to produce converting factors" section. A plastic phantom representing a cardiologist 180 cm in height was placed in the position a physician would normally stand for a CA procedure. The positioning of the cardiologist phantom was guided by the work of other researchers [16, 24, 25]. Similar to a real procedure, a lead apron of 0.25 mm lead equivalent was placed on the cardiologist phantom. A Radcal ionization chamber, model 10X5-180, was placed on the lead apron in the chest region of the cardiologist phantom. The ionization chamber was placed 150 cm above the floor level and at a lateral distance of 15 cm from the edge of the patient phantom [10, 26] (Fig. 1). Schematic diagrams illustrating the positions of the cardiologist and patient phantoms in a real cardiac fluoroscopy procedure are shown in Fig. 2. For each imaging projection, the ESAK at the cardiologist phantom was measured by the ionization chamber. The dosimeter used in this study was calibrated by the secondary standards dosimeter laboratory (SSDL) of the Iranian atomic energy organization. Moreover, the DAP meter located on the X-ray tube was also calibrated and checked by the Siemens company's official representative. In all measurements the table-mounted drape and the ceiling-suspended shield were used to reduce the dose to the cardiologist phantom.

Fig. 1 Locations of the dosimeter, physician phantom, patient phantom, X-ray tube, and the patient table

Definition of imaging views to produce converting factors

The movement of the C-arm X-ray tube around the patient is limited; however, heart vasculature can be completely visualized during CA or PTCA procedures when the tube is moved in the directions recommended by the relevant cardiologists' textbooks (Table 1) [1, 2]. In most cases cardiologists are not able to adjust the X-ray tube toward the pre-specified reference directions (Table 1) in CA or PTCA procedures; this is due to the natural or man-caused complexities involved in these procedures. In this study the pre-specified X-ray tube positions (angles) were selected so as to cover the whole 3D space above and around the patient's body. These views are similar to those previously used by other researchers [7, 27]. Seventy seven views representing various X-ray tube positions in left anterior oblique (LAO), right anterior oblique (RAO), cranial (CR) and caudal (CA) directions around the phantom are shown in Fig. 3. The 77 views are formed by the combination of eleven LAO and RAO views with each of the seven CR and CA views.

DAP to ESAK converting factors (CF); calculations and applications

The patient phantom was exposed for 3 s with the X-ray tube at each of the 77 imaging projections. AEC mode was selected to control exposure parameters. The ESAK at the cardiologist phantom was measured by the ionization chamber placed on the lead apron at the chest region. Corresponding DAP values were acquired from the informatics file of the Siemens Artis system. The conversion

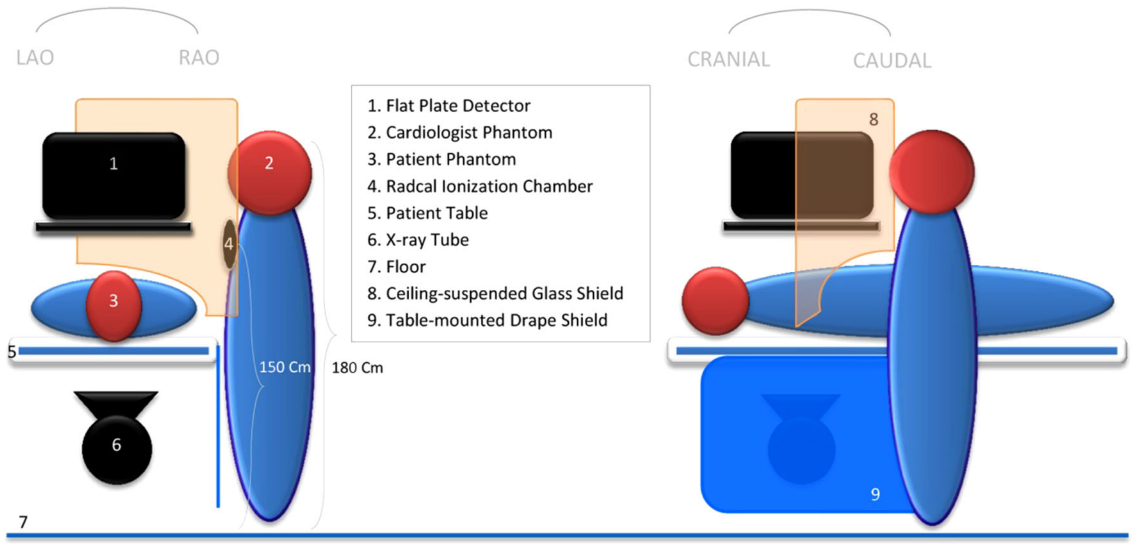


Fig. 2 Schematic diagrams illustrating the positions of the cardiologist and patient phantoms

Table 1 Different reference views in LAO and RAO directions of coronary fluoroscopy X-ray tube to image right coronary artery (RCA) and left coronary artery (LCA)

Hurst's the heart [2]	Braunwald's heart disease [1]
RAO 30°	LAO 60°, Cranial 20°
LAO 45°	LAO 60°, Caudal 25°
LAO 45°, Cranial 30°	R/LAO 0°, Caudal 20°
RAO 15°, Cranial 30°	R/LAO 0°, Cranial 20°
LAO 45°	RAO 30°, Cranial 20°
LAO 45°, Cranial 30°	RAO 30°, Caudal 25°
	LAO 60°
	LAO 60°, Cranial 25°
	RAO 30°

factors (nGy/μGym^2) for the 77 pre-defined views were obtained from the following equation.

$$\mathrm{CF}_i = \frac{(\text{Over apron ESAK})_i}{(\text{DAP value})_i} \qquad (1)$$

Angiography and angioplasty procedures consist of several simultaneous cinegraphy modes of the coronary artery in no specified angles and one fluoroscopy mode of the patient's chest region. DAP values for fluoroscopy and cine modes are reported separately. Therefore, the total DAP can be calculated as the sum of the DAPs of the fluoroscopy and cine modes [21]:

$$(\mathrm{DAP}_{\text{total}} = \text{fluoroscopic DAP} + \text{cine DAP}) \qquad (2)$$

Pantos et al. reported that fluoroscopy contributes a large component of the total DAP value (19 % in angiography and 41 % in angioplasty) [28]. In the current study, to achieve a better accuracy for estimated CF$_i$, a DAP value attributed to the fluoroscopy mode was obtained independently. Fluoroscopy was performed on the chest region of the patient phantom in 10 s time intervals during which the tube was being moved from the left to the right or from the head to the toes under the patient table. Corresponding DAP value and physician ESAK were recorded. These measurements were repeated six times and the exposure and DAP readings were averaged. Siemens AXIOM Artis systems generate an informatics file at the end of each procedure. This file includes: number of imaging views, time interval of the procedure, location of the X-ray tube, DAP value attributed to each imaging view, and the total DAP value attributed to the whole fluoroscopy procedure. DAP values extracted from the informatics file were combined with the conversion factors measured in this study to estimate the cardiologist's exposure on the chest region (ESAK in nGy). An example of the informatics file is presented in Fig. 4. The cardiologist's exposure on the chest region is computed by means of a simple worksheet in Microsoft Office Excel software, as presented by the following equation (*i* is the identification number specified to each cinegraphy view that varies from 1 to 77 (Fig. 3) as well as to the fluoroscopy views):

$$(\text{Over apron ESAK of cardiologist})_{\text{total}} = \sum_{i=1}^{n} \{(\mathrm{CF})_i \times (\mathrm{DAP})_i\} \qquad (3)$$

Cardiologist exposure measurement in the presence of a real patient

To provide a comparison with the estimation from the DAP; the ESAK at the chest region of the cardiologist was measured by the Radcal ionization chamber for 45 cases. Patient weight ranged from 70 to 80 kg. The cardiologist was recommended to avoid any unnecessary movement. A suspended leaded glass curtain was also used to reduce scattered photons impinging physician's body. For each procedure the informatics file of the Siemens AXIOM Artis system was extracted and the patient's DAP values were broken down into DAP values for various projections (Fig. 4). At the end of each procedure two ESAK values were made available: measured and estimated exposure. The measured exposure was obtained as explained earlier. The estimated exposure was reconstructed from potentially 77 different scenarios and one fluoroscopy mode; as described in "DAP to ESAK converting factors (CF); calculations and applications" section. Finally physician's measured and estimated exposures are compared. If the two set of ESAK values are not significantly different, it implies that the proposed method may be useful to estimate cardiologist's exposure indirectly, simply, but accurately.

Results

Exposure conversion coefficients attributed to the 77 imaging views as calculated by Eq. 1 are presented in Table 2. The corresponding conversion factor for the fluoroscopy section (based on the description presented in "DAP to ESAK converting factors (CF); calculations and applications" the section) is 3.23 nGy/μGym^2.

Mean, standard deviation, first, second (median) and third quartiles of four variables; measured and estimated ESAK of the cardiologist's in chest region on the lead apron, total DAP values and percentage variation of estimated exposures compared with the corresponding mea-

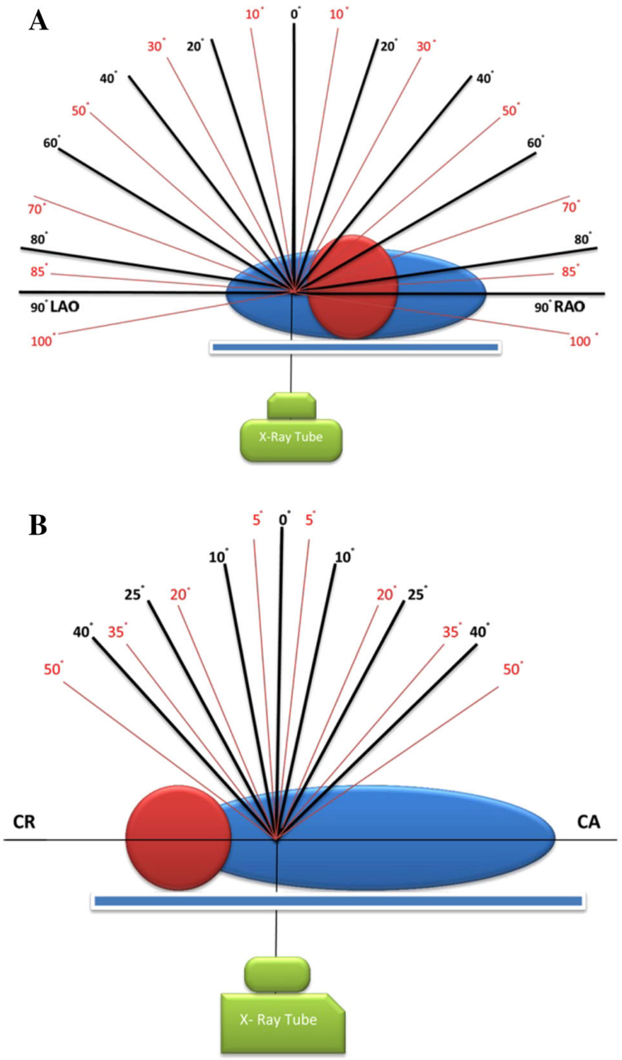
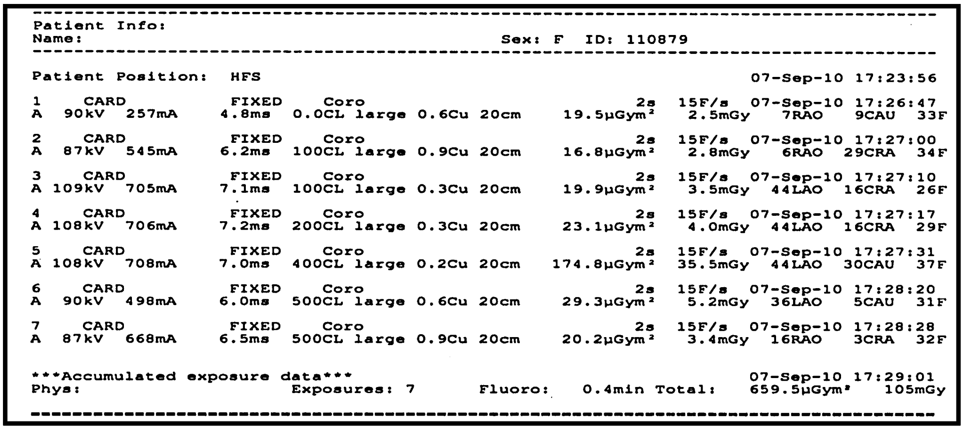


Fig. 3 X-ray tube positions in RAO, LAO directions (part A); cranial (CR), caudal (CA) (part B) directions are illustrated. Each view is shown in a specific range with light red lines



```
--------------------------------------------------------------------------------
Patient Info:
Name:                                           Sex: F  ID: 110879
--------------------------------------------------------------------------------

Patient Position:   HFS                                          07-Sep-10 17:23:56

1     CARD           FIXED    Coro                          2s   15F/s  07-Sep-10 17:26:47
A  90kV  257mA      4.8ms  0.0CL large 0.6Cu 20cm     19.5µGym²   2.5mGy    7RAO    9CAU   33F

2     CARD           FIXED    Coro                          2s   15F/s  07-Sep-10 17:27:00
A  87kV  545mA      6.2ms  100CL large 0.9Cu 20cm     16.8µGym²   2.8mGy    6RAO   29CRA   34F

3     CARD           FIXED    Coro                          2s   15F/s  07-Sep-10 17:27:10
A 109kV  705mA      7.1ms  100CL large 0.3Cu 20cm     19.9µGym²   3.5mGy  44LAO   16CRA   26F

4     CARD           FIXED    Coro                          2s   15F/s  07-Sep-10 17:27:17
A 108kV  706mA      7.2ms  200CL large 0.3Cu 20cm     23.1µGym²   4.0mGy  44LAO   16CRA   29F

5     CARD           FIXED    Coro                          2s   15F/s  07-Sep-10 17:27:31
A 108kV  708mA      7.0ms  400CL large 0.2Cu 20cm    174.8µGym²  35.5mGy  44LAO   30CAU   37F

6     CARD           FIXED    Coro                          2s   15F/s  07-Sep-10 17:28:20
A  90kV  498mA      6.0ms  500CL large 0.6Cu 20cm     29.3µGym²   5.2mGy  36LAO    5CAU   31F

7     CARD           FIXED    Coro                          2s   15F/s  07-Sep-10 17:28:28
A  87kV  668mA      6.5ms  500CL large 0.9Cu 20cm     20.2µGym²   3.4mGy  16RAO    3CRA   32F


***Accumulated exposure data***                                  07-Sep-10 17:29:01
Phys:                    Exposures: 7      Fluoro:   0.4min Total:   659.5µGym²   105mGy

--------------------------------------------------------------------------------
```

Fig. 4 An example of the informatics files generated by the AXIOM Artis system at the end of each cardiac fluoroscopy procedure

Table 2 Measured cinegraphy and conversion factors from DAP to physician ESAK (nGy/μGym^2) for 77 specified imaging views for an AXIOM Artis fluoroscopy system

Cinegraphy Views	RAO 90°	RAO 80°	RAO 60°	RAO 40°	RAO 20°	R/LAO 0°	LAO 20°	LAO 40°	LAO 60°	LAO 80°	LAO 90°
CR 40°	5.95	3.86	2.48	1.52	1.03	1.32	6.35	6.44	8.92	9.43	10.71
CR 25°	5.91	2.96	2.02	1.37	1.09	1.28	4.74	5.20	7.50	7.55	10.18
CR 10°	5.37	2.17	2.08	1.29	1.06	1.25	3.24	4.37	6.45	8.46	7.51
CR0°, CA0°	4.91	2.18	1.92	0.97	0.83	0.94	3.08	4.18	5.20	9.07	7.28
CA 10°	5.65	1.88	1.53	1.12	1.01	0.93	2.02	4.06	6.66	7.45	9.48
CA 25°	5.56	2.99	1.72	1.07	0.88	0.87	1.97	3.79	5.26	6.49	8.12
CA 40°	5.19	3.00	1.58	1.18	0.88	0.91	1.71	2.94	4.32	5.70	7.32

Table 3 Mean, standard deviation, first, second (median) and third quartiles of measured over-apron ESAK, corresponding estimated ESAK, recorded DAP values and percentage overestimation of ESAK arising from 45 angiographic procedures

Values	Mean	SD	25th	50th	75th	Minimum	Maximum	Normality (KS test)
Measured ESAK (nGy)	3,143	1,960	1,573	2,950	4,530	630	11,587	0.61
Estimated ESAK (nGy)	3,625	2,160	1,764	3,449	5,257	788	10,541	0.31
Total DAP (μGym^2)	1,216	736	576	1,078	1,747	269	3,392	0.09
Percentage overestimation of ESAK	14.5	17.2	5.0	18.0	26.5	−20.0	48.0	

sured exposures arising from 45 angiographic procedures are presented in Table 3 and Fig. 5. The Kolmogorov–Smirnov statistical test was applied to the four variables; the outcome is evident that these variables are normally distributed ($p > 0.05$). One-way ANOVA test applied to the values of measured and estimated ESAK; provides $p > 0.05$. Thus it can be concluded that the two sets of data are not significantly different. Mean Percentage overestimation of ESAK was 14.5 % with a standard deviation of 17.2 % and ranged from a maximum of +48 % to a minimum of −20 % (Table 3). Measured exposures, estimated exposures and the total recorded DAP values acquired from CA procedures of patients ranged from 0.630 to 11.578 μGy, 0.788 to 10.541 μGy, and 2.688 to 33.917 Gycm^2, respectively.

Figure 6 shows the relationships between the measured and estimated exposures to the total recorded DAP$_{\text{total}}$ (μGym^2) values in each CA procedure. The relation between the measured and estimated exposures to DAP$_{\text{total}}$ values are strong relations with $R^2 = 0.88$ ($p < 0.05$) and $R^2 = 0.95$ ($p < 0.05$) respectively. Figure 7 shows the relationship between the measured and estimated exposure values in each CA procedure. The relationship between these two parameters is very linear with $R^2 = 0.91$ ($p < 0.05$). The reported equation is presented for converting estimated exposures to measured exposures in each procedure.

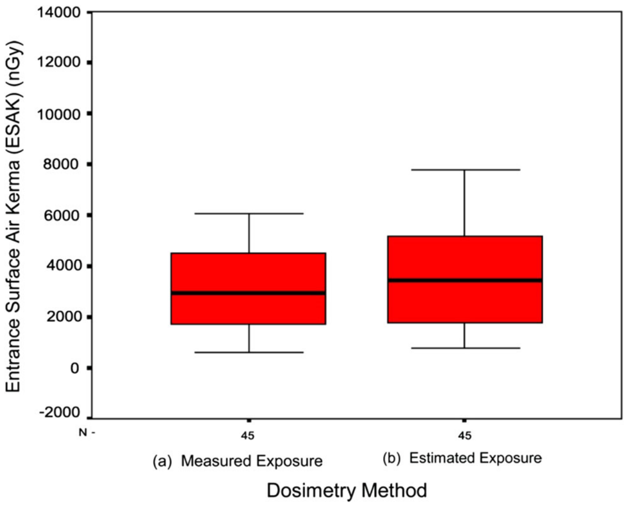


Fig. 5 Box plot of occupational exposure values of the cardiologist (nGy) which are presented for the two sets of data: **a** measured exposure and **b** estimated exposure; the *black lines* within the boxes mark the median, the box demarks the 25th and 75th percentile (the interquartile range) and the whiskers represent the highest and lowest values that are not outliers (values that are more than 1.5 times the interquartile range)

Discussion

Converting factors were obtained for 77 tube positions covering the total space around the patient's body. As

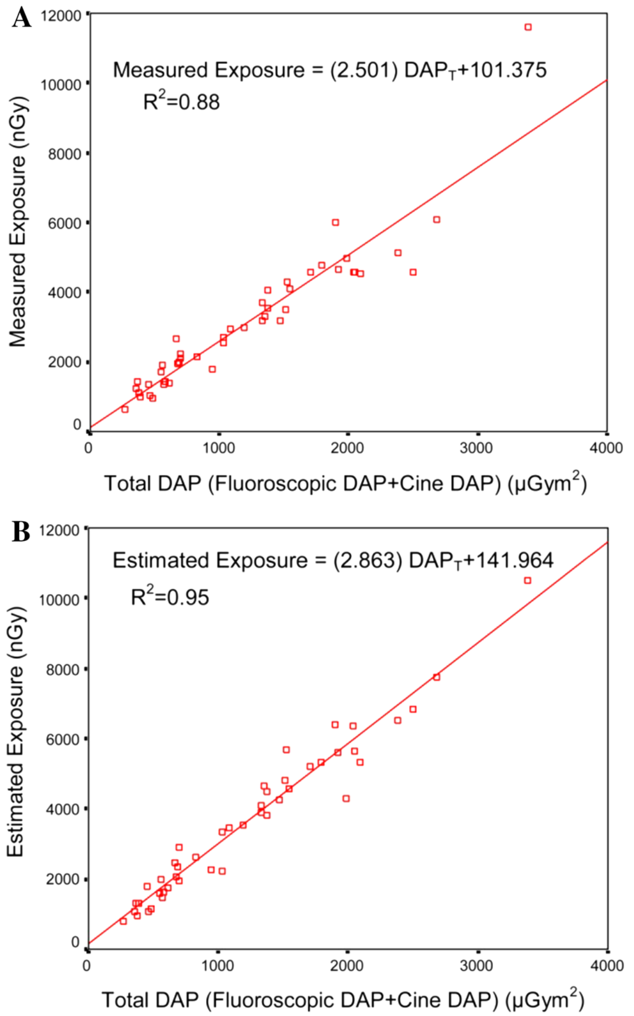


Fig. 6 The plot shows; (**a** and **b**) the relationship between the measured and estimated exposure with the recorded DAP$_{total}$ (μGym^2) values in each angiography procedure, respectively

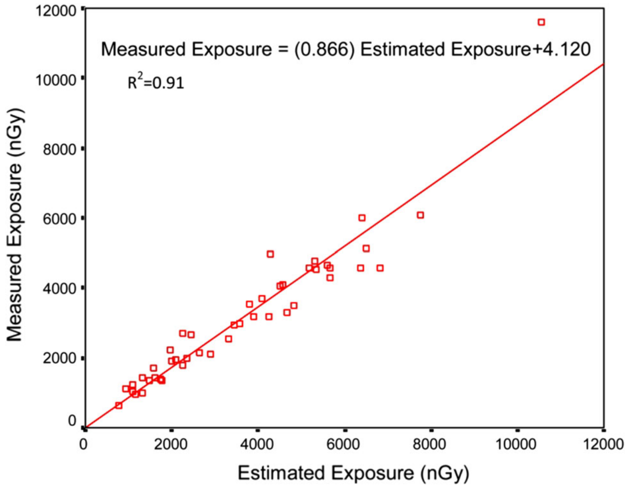


Fig. 7 The plot shows the relationship between measured and estimated exposure values in each CA procedure

expected the factor is highest for the larger angle RAO or LAO views, and also the larger Cranial (CR 40°) and Caudal (CA 40°) angulations. This is due to the increased volume of tissue in the path of the primary X-ray beam producing more scattered radiation. Also, when the tube is advancing towards the CR 40° view it moves beyond the leaded table drape. In these circumstances the shorter distance to the physician dosimeter would result in higher contribution from scattered radiation. It should be noted that the leakage from the tube also contributes to the measured exposure but to a lesser extent compared to the scattered radiation.

Average exposure measured and estimated in this study (Table 3) are very close to the results reported by Häusler et al. in 2009 (4 µGy with 0–14 µGy range) [29]. Our results for average and range of total DAP values per procedure are comparable with the corresponding values obtained by Kuon et al. [30] and Vano et al. [10]. The results of Kuon and Vano et al. are (12.9 Gycm^2 with 3–30 Gycm^2) respectively. The marginal differences between our results and those reported by other researchers are in favor for the accuracy of our results. In other words, factors which influence physician exposure have been correctly chosen. These factors include patient weight, procedure type, protective material and the method of selection and use of the protective material. In this study we have tried to reduce the effect of confounding factors on the physician dose, thus the correlation between DAP values and cardiologist exposure is improved considerably ($R^2 = 0.88$), when compared with the corresponding figures reported by Tsapaki et al. ($R^2 = 0.43$) [23] and Kuipers et al. ($R^2 = 0.55$) [21].

Patient weight and size have significant effects on the cardiologist exposure; a large patient produces more scattered radiation from his/her body [4, 9]. Kuipers et al. did not include patients of limited weight in their study, while in this work patients within the weight range of 75 ± 5 kg have been selected. Kuipers et al. presented results of both CA & PTCA procedures while our data are acquired only from CA examinations. Cardiologist exposures during CA and PTCA procedures are different from each other. In PTCA, due to the longer period of patient exposure, the physician exposure is higher [7, 23]. Kuipers et al. included seven physicians in their work; our data have all been obtained from examinations performed by one cardiologist. In other words, each physician (depending on his/her skills and experience) behaves differently in identical conditions [18]. This could be one of the main reasons for the differences observed between two sets of results in the aforementioned studies.

The results obtained in the present study cannot be simply and generally extended, because the different sizes of patients, variety of operators and the type of the procedure will increase the variability of the results and the related uncertainties. However, a comparison between our results and the others gives an indication of the uncertainty that is normally encountered in description of these variables.

Correlation between DAP and estimated ESAK for the physician would be 100 % if only a single conversion factor was used. The use of more conversion factors for more narrowly defined projections would be expected to decrease the correlation between total DAP and estimated ESAK. A strong correlation between total recorded DAP and physician estimated exposure ($R^2 = 0.95$) was observed in this work, in spite of the division of the rotational space into relatively small angles (77 views). Additionally, a larger number of tube positions should provide a more accurate estimation of the cardiologist ESAK due to the use of various DAP components in comparison to simply use of a compound DAP. For this reason, various DAPs for different small angles and different modes of exposure (fluoroscopy and cine) were extracted separately for each patient. The existence of a strong correlation between measured and estimated physician exposure ($R^2 = 0.91$) achieved in this work is evidence that the conversion factors obtained in this study can be employed to estimate cardiologist exposure with reasonable accuracy.

Conclusions

This study is the first step towards calculating of physician's over apron ESAK arising from CA procedures in a fast and accurate manner. However further studies are required to allow for variation of factors such as patient's weight which have been assumed constant in this work. In a more comprehensive work PTCA procedure has to be included.

Acknowledgments This article is based on part of the results extracted from a thesis code no: A-358 presented for the degree of Master of Science to medical physics department of Mashhad University of Medical Sciences. The authors would like to thank Javad-Al-Aeme Heart Hospital (Mashhad, Iran) for their sincere cooperation. This work was fully funded by the office of vice president for research affairs of Mashhad University of Medical Sciences.

References

1. Libby P, Bonow RO, Zipes DP, Douglas LM (2008) Braunwald's Heart disease: a textbook of cardiovascular medicine. Saunders, Philadelphia
2. Fuster V, Walsh RA, O'Rourke RA, Poole-Wilson P (2007) Hurst's the heart. McGraw-Hill Professional, New York
3. Ferrari P, Venturi G, Gualdrini G, Rossi PL, Mariselli M, Zannoli R (2010) Evaluation of the dose to the patient and medical staff in interventional cardiology employing computational models. Radiat Prot Dosim 141:82–85
4. International Commission on Radiological Protection. (2013) Radiological protection in cardiology. ICRP Publication 120. Ann ICRP 42(1)
5. Bor D, Olgar T, Onal E, Caglan A, Toklu T (2009) Assessment of radiation doses to cardiologists during interventional examinations. Med Phys 36:3730–3736
6. Vaño E, Gonzalez L, Fernandez JM, Alfonso F, Macaya C (2006) Occupational radiation doses in interventional cardiology: a 15-year follow-up. Br J Radiol 79:383–388
7. Morrish OW, Goldstone KE (2008) An investigation into patient and staff doses from X-ray angiography during coronary interventional procedures. Br J Radiol 81:35–45
8. International Commission on Radiological Protection (2007) Recommendations of the international commission on radiological protection. ICRP Publication 103. Ann ICRP 37(2–4):2
9. Vano E, Gonzalez L, Fernandez JM, Prieto C, Guibelalde E (2006) Influence of thickness and operation modes on occupational and patient radiation doses in interventional cardiology. Radiat Prot Dosim 118:325–330
10. Vano E, Ubeda C, Leyton F, Miranda P, Gonzalez L (2009) Staff radiation doses in interventional cardiology: correlation with patient exposure. Pediatr Cardiol 30:409–413
11. Martin CJ (2009) A review of radiology staff doses and dose monitoring requirements. Radiat Prot Dosim 136:140–157
12. Vano E (2003) Radiation exposure to cardiologists: how it could be reduced. Heart 89:1123–1124
13. Technical reports series. Dosimetry in diagnostic radiology: an international code of practice. TRS No. 457. Vienna: International Atomic Energy Agency (2007)
14. The International Commission on Radiation Units and Measurements. Quantities and Units in Radiation Protection Dosimetry. ICRU Report 51. Bethesda, MD (1993)
15. Martin CJ, Sutton DG (2002) Practical Radiation Protection in Health Care. OUP Oxford
16. Clerinx P, Buls N, Bosmans H, de Mey J (2008) Double-dosimetry algorithm for workers in interventional radiology. Radiat Prot Dosim 129:321–327
17. Prlic I, Suric Mihic M, Vucic Z (2008) Active electronic personal dosemeter in interventional radiology. Radiat Prot Dosim 132:308–312
18. Fardid R, Toossi MTB, Mehrpouyan M, Ghorbani M (2013) Evaluation of occupational radiation exposure of cardiologists in interventional radiography in Mashhad CATHLABs. Int J Low Radiat 9:160–168
19. Delichas M, Psarrakos K, Molyvda-Athanassopoulou E, Giannoglou G, Sioundas A, Hatziioannou K, Papanastassiou E (2003) Radiation exposure to cardiologists performing interventional cardiology procedures. Eur J Radiol 48:268–273
20. Kuipers G, Velders XL (2009) Effective dose to staff from interventional procedures: estimations from single and double dosimetry. Radiat Prot Dosim 136:95–100
21. Kuipers G, Velders XL, Piek JJ (2010) Exposure of cardiologists from interventional procedures. Radiat Prot Dosim 140:259–265
22. The International Commission on Radiation Units and Measurements (2005). Patient Dosimetry for X Rays used in Medical Imaging. ICRU Report 74. Bethesda, MD
23. Tsapaki V, Kottou S, Vano E, Parviainen T, Padovani R, Dowling A, Molfetas M, Neofotistou V (2005) Correlation of patient and staff doses in interventional cardiology. Radiat Prot Dosim 117:26–29
24. Bozkurt A, Bor D (2007) Simultaneous determination of equivalent dose to organs and tissues of the patient and of the physician in interventional radiology using the Monte Carlo method. Phys Med Biol 52:317–330

25. Siiskonen T, Tapiovaara M, Kosunen A, Lehtinen M, Vartiainen E (2007) Monte Carlo simulations of occupational radiation doses in interventional radiology. Br J Radiol 80:460–468
26. Järvinen H, Buls N, Clerinx P, Miljanic S, Nikodemová D, Ranogajec-Komor M, Struelens L, d'Errico F (2008) Comparison of double dosimetry algorithms for estimating the effective dose in occupational dosimetry of interventional radiology staff. Radiat Prot Dosim 131:80–86
27. Bogaert E, Bacher K, Thierens H (2008) A large-scale multicentre study in Belgium of dose area product values and effective doses in interventional cardiology using contemporary X-ray equipment. Radiat Prot Dosim 128:312–323
28. Pantos I, Patatoukas G, Katritsis DG, Efstathopoulos E (2009) Patient radiation doses in interventional cardiology procedures. Curr Cardiol Rev 5:1–11
29. Häusler U, Czarwinski R, Brix G (2009) Radiation exposure of medical staff from interventional x-ray procedures: a multicentre study. Eur Radiol 19:2000–2008
30. Kuon E, Glaser C, Dahm JB (2003) Effective techniques for reduction of radiation dosage to patients undergoing invasive cardiac procedures. Br J Radiol 76:406–413