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Assessment of Maximum Entrance Skin Dose of Patients Undergoing Cardiac Interventional Procedures and Its Correlation with Other Dosimetric Parameters

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ABSTRACT

Introduction: In recent years, the number of complex coronary angiography (CA) is increasing rapidly. These procedures have a significant contribution to medical exposure to the general population. Exposure of patients to high doses of x-rays could cause deterministic effects on the skin. Therefore, the assessment of radiation doses of patients is of great importance. This study aimed to assess maximum entrance skin dose (MESD) of patients who underwent interventional cardiology procedures. Moreover, it was attempted to determine the correlation between MESD and other relevant dosimetric parameters.

Material and Methods: The MESDs of 32 patients who underwent CA procedures were measured by an array of thermoluminescence dosimeters (TLDs). In this study, a Perspex tray consisting of 5 rows and 6 columns was used to hold the TLDs. Its long axis was perpendicular to the long axis of the table, and the top edges of the tray were approximately equal to the patient's shoulders.

Results: The results revealed a linear relationship between dose area product (DAP) values and MESDs (R^2=0.89; P=0.00). In addition, there was a significant association between MESD and fluoroscopy time (R^2=0.89). Moreover, a weak correlation was observed between MESD and the number of frames per second (R^2=0.23).

Conclusion: According to the results, the recorded DAP values and fluoroscopy time can be used to estimate the MESDs of patients undergoing coronary fluoroscopy procedures.

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Introduction

Cancer and genetic defects are the adverse and statistical effects of exposure to radiation. Absorption of ionizing radiation in living organisms causes molecular and cellular damage, which is the primary cause of cancer [1, 2]. Evaluation of the absorbed dose leads to the assessment of the risk of exposure to radiation. Due to the increasing incidence of cardiovascular diseases, including coronary artery disease in the world and considering the fact that these diseases are the most common causes of death, more attention has been paid to this issue. Fluoroscopy of cardiac arteries in the catheterization laboratory (i.e., Cath Lab) is one of the most common methods of diagnosis and treatment of these diseases [3].

In centers, coronary x-ray procedures are divided to angiography and angioplasty [3]. These procedures are used to diagnose and treat coronary artery blockage and narrowing as well as some other failures [1, 3, 4]. Due to the long-term X-ray exposure of the patients, their exposure to radiation is significant [5-7]. The patient's dose varies according to the volume of irradiated tissue, radiation angle to the patient's body, the distance between the X-ray tube and patient's skin, fluoroscopy time, and the number of Dilated Cardio Myopathy (DCM) cases [8].

In recent years, the US Food and Drug Administration and the International Commission on Radiological Protection (ICRP) have presented guidelines to reduce the level of exposure in the medical examination as much as possible. It has also been suggested to record the maximum entrance skin dose (MESD) of patients in the diagnostic procedure in order to take preventive measures against adverse radiation effects. In ICRP report No. 85, 2 Gy has been assigned as the incidence threshold of definitive skin

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complications from exposure to ionizing radiation. According to this report, the patients receiving a skin dose over 3 Gy should be subjected to clinical follow-up [7, 9-12]. The report also emphasizes that the actual dose in each radiological activity should be much lower than the maximum recommended dose in accordance with the concept of As Low As Reasonably Achievable (ALARA) [9, 13]. Furthermore, the report No.85 of ICRP has suggested cost-benefit analysis for lower limits of operational dose and subsequent choice of protection level against radiation to optimize the cost of harmful effects of radiation exposure versus benefits of radiation application. As social and economic factors must be considered in ALARA application, it is evident to see different interpretations from the phrase "As Low As Reasonably Achievable" [9, 13-15]. As such, the aforementioned radiation safety measures indicate the importance of careful monitoring of patients' exposure to radiation in Cath Labs in hospitals [16].

Recently, several studies have been conducted on the relationship between patients' dose and the dose area product (DAP), which is one of the most accessible radiation parameters of patients [1, 17-19]. Morrish et al. estimated the dose of cardiologists and their patients when performing cardiac fluoroscopy in six different Cath Labs [20]. In this study, the mean dose and effective dose for patients were separately measured in cardiac angiography and angioplasty using DAP. In another study, Zontar et al. measured skin dose in 16 patients undergoing cardiac angioplasty using radiochromic film [21]. In addition, the collective dose values in reference points, which are reported as the skin dose by the DAP system, were recorded for 161 patients. The comparison of the skin dose with the collective dose values in the reference point showed that the dose value at the reference point was higher than the actual maximum dose which was received by the patient. Moreover, it was reported that based on the dose in the reference point, the level of 75% was declared as 920 mGy, and it was observed that 9 out of 16 patients received a dose higher than 2 Gy.

According to a study conducted by Bahreyni Toosi et al., DAP values of 90 patients were measured during cardiac fluoroscopy using thermoluminescence dosimeters (TLD) in private and public hospitals in Mashhad, Iran. In this study, there were linear correlations between MESD and DAP (R^2=0.88) as well as MESD and fluoroscopy time (R^2=0.85) [22]. In another study by Ying et al., the skin dose of cardiac angiography patients was measured by EDR2 X-ray film calibrated for the energy range of coronary angiography in the cardiology ward of a hospital in Penang, Malaysia [23]. This study was conducted on 27 patients, and the films were placed between the chest region of the patients and the bed. The MESD was reported in 35-684 mGy range and DAP was estimated at 5.5-93.1 Gy/cm^2. In this study, a strong correlation was found between MESD and DAP (R^2=0.82); however, there was a weak correlation between MESD and the duration of fluoroscopy (R^2=0.29). Similarly, Bogart et al. reported the average maximum skin doses of 318 patients in 8 hospitals [1]. This study was performed by designing a cotton belt in which 70 TLDs had been embedded at a distance of 7.5 cm.

Several techniques have been reported to measure the skin dose of patients, including TLD [18, 24], films [25], combined TLD and film [26], semiconductor dosimeters [27], and real-time mathematical modeling of skin dose distribution [28]. Most of these studies were performed in order to take effective measures, protect the health of patients, and prevent unwanted exposure as recommended by international health institutions and organizations.

Among the presented dosimeters, TLD is appropriate to measure MESD due to the high measurement accuracy and the possibility of repeated use of TLD as well as the simultaneous use of several TLDs on an extensive surface. Skin dose distribution can be measured using a set of TLDs. Due to the high level of skin exposure to radiation, conventional imaging films cannot be used for this surface [29].

This study assessed the MESD in patients underwent coronary artery fluoroscopy using a TLD array. Moreover, the relationship between patients' MESD and other dosimetry values was also reviewed in this study. It should be noted that the assessment of the correlation between MESD and other dosimetry values in this scale has not been evaluated so far using this method in Mashhad, Iran.

This is the first attempt to evaluate the relationship between MESD and DAP in coronary angiography (CA) and Percutaneous transluminal coronary angioplasty (PTCA) procedures in Mashhad.

Materials and Methods

Dose area product extraction

This study employed a Siemens AXIOM Artis X-ray system (Axiom Artis dFA, Siemens, Erlangen, Germany) which was equipped with a DAP meter consisting of an ionization chamber located in front of the x-ray tube collimator. This device records DAP value for each imaging projection and stores all obtained DAP values. The DAP meter was also calibrated and examined by the Siemens company's official representative. This study was conducted in the Cardiology Department of subspecialist at Shariati Hospital which is equipped with this tube in Mashhad, Iran.

The information of fluoroscopy and DAP parameters in each view is stored in this machine as a digital file in the control system of the instrument (Figure 1). The file is stored for each patient separately and contains several data lines. Each line is representative of an angular imaging view of coronary arteries.

```
1   CARD      FIXED   Coro ND 1k                    7s  15F/s  15-Jan-03 09:16:21
A  81kV  744mA   6.0ms  200CL small 0.3Cu 17cm      211.4µGym² 36.2mGy   0LAO   0CRA 105F

2   CARD      FIXED   Coro ND 1k                    6s  15F/s  15-Jan-03 09:17:01
A  86kV  734mA   6.0ms  600CL small 0.2Cu 17cm      376.9µGym² 63.8mGy  29RAO   0CRA  94F

3   CARD      FIXED   Coro ND 1k                    5s  15F/s  15-Jan-03 09:17:43
A 124kV  553mA   8.0ms ****** small 0.2Cu 17cm      490.3µGym² 94.1mGy  48RAO  22CRA  75F

4   CARD      FIXED   Coro ND 1k                    6s  15F/s  15-Jan-03 09:18:16
A 115kV  591mA   8.0ms ****** small 0.2Cu 17cm      460.4µGym² 97.8mGy  48RAO  22CRA  84F

5   CARD      FIXED   Coro ND 1k                    *****  15F/s  15-Jan-03 09:19:05
A  96kV  714mA   8.0ms ****** small 0.2Cu 17cm      9.3µGym²  1.9mGy  15RAO  30CRA   2F

6   CARD      FIXED   Coro ND 1k                    *****  15F/s  15-Jan-03 09:19:07
A 102kV  666mA   8.0ms ****** small 0.2Cu 17cm      17.2µGym²  3.5mGy  15RAO  30CRA   3F
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Figure 1. A part of the digital information file exported from Siemens instrument after cardiac fluoroscopy procedure.

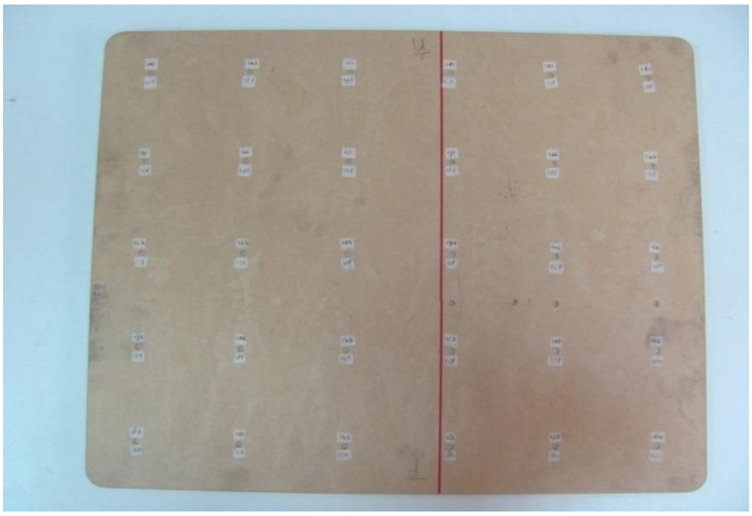


Figure 2. A view of the TLDs used for measuring skin dose of patients in this study

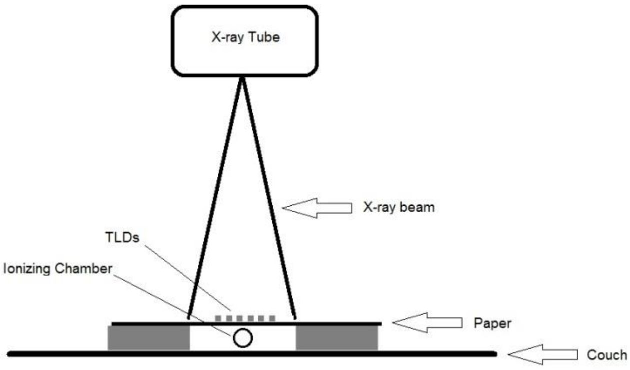


Figure 3. Experimental setup used for TLD calibration

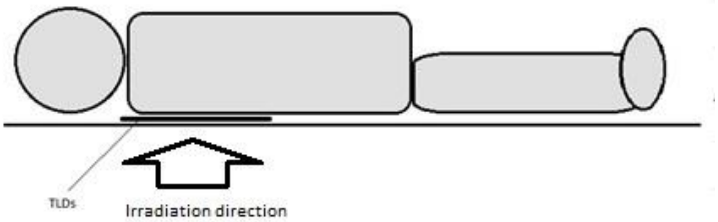


Figure 4. The position of TLD tray used for patient dosimetry

The information contained in each line of this file is as follows: 1) X-ray tube angle in each of the four orientations around the patient, namely cranial, caudal, right anterior oblique, and left anterior oblique, 2) The duration of patient exposure at that view, and 3) $DAP_{Cinemode}$ registered at that view. The $DAP_{Cinemode}$ value in cardiovascular fluoroscopy of coronary arteries and the total duration of patient's exposure from the beginning to the end of the CA procedure were recorded at the end of this file information. This study was mainly aimed at making connection between MESD and other dosimetry parameters of the patients (i.e., DAP, number of frames/second, and fluoroscopy time) in order to eliminate the physical dosimeters and estimate the patients' MESD using other dosimetry parameters.

Patient Dosimetry

The TLD lithium fluoride crystals (Model: TLD 100: Harshaw) are in the form of chips with 9×3.7×3.7 mm^3 dimensions, which are suitable for measuring the skin dose. The skin dose in this study was measured by a 2D array of TLD chips embedded in 5-mm thick Perspex plate with 30×40 cm^2 dimensions. The Perspex plate is tissue-equivalent and has no interference with diagnostic image quality. Thirty TLDs were set with 7.5 cm distance from each other. Figure 2 illustrates the setup of the TLDs.

Before using TLDs for the patients, TLDs were grouped in groups of 10. Afterward, TLDs were calibrated by a diagnostic x-ray instrument in the same conditions for 60 to 120 kVp energy. An ionization chamber (Radcal Ionization chamber-model 10x5-180), which was calibrated by SSDL of Iranian Atomic Energy Agency, was used as the reference ionization chamber. Actually, the sensitive volume of the chamber was placed immediately under TLDs (Figure3). After calibration, a unique calibration factor was determined for each TLD, which was considered while reading TLDs. It is worth mentioning that in all stages of this study, background radiation was measured by three separate TLDs and included in the calculations. All TLD chips were annealed using a standard procedure before use (i.e., 400^{o}C for 1 h followed by 100^{o}C for 2 h).

The dosimetry was performed on 32 patients underwent CA and angioplasty procedures. The exposure factors were automatically set by the system with the aim of creating a clear image with high contrast in all directions of the tube. As such, the exposure factors and patient's skin entrance dose would vary due to the size of patient's body in the direction of the beam. For this reason, patients with weight ranging from 70-80 kg were selected in this study. The Perspex tray, containing TLDs, was placed on the imaging bed in the irradiation field so that the top of the tray corresponded with the first cervical vertebrae (Figure 4). The TLDs were read using Harshaw 3500 reader after exposure and the results were recorded in the fact sheet for each patient.

The recorded dose for each patient under coronary artery fluoroscopy was the maximum dose read from 30 TLDs placed between the patient and the imaging table. There were relationships between patients' MESD and DAP readings as well as total fluoroscopy time and the number of frames per second for this group of patients.

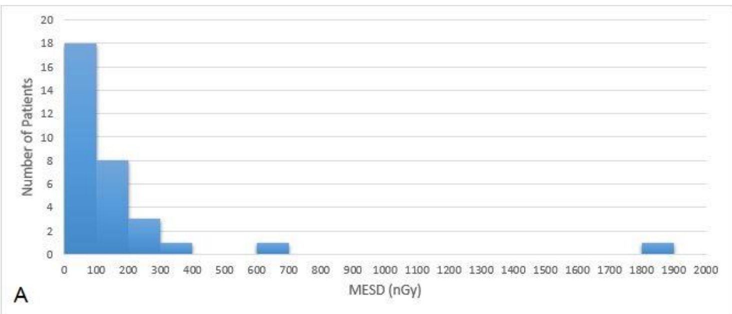
Statistical Analysis

The data were analyzed in SPSS software (Version 23) (SPSS, Chicago) with a confidence interval of 95%. Therefore, a P-value less than 0.05 was considered statistically significant. Moreover, the normality of data distribution was examined using the Kolmogorov-Smirnov, and Pearson's correlation or non-parametric equivalent test was used to evaluate the correlation between the relevant quantities.

Results

Dosimetry results

All the dose values have been recorded in micro grays (μGy). The DAP readings and fluoroscopy time for all coronary artery angiography and cardiac angioplasty were extracted from a Siemens X-ray tube data file. These values have been reported as μGym^2 and minutes, respectively. Table 1 summarizes the details of the patients and procedures in this study. Moreover, the MESD distribution in CA and PTCA groups is shown in Figure 5.



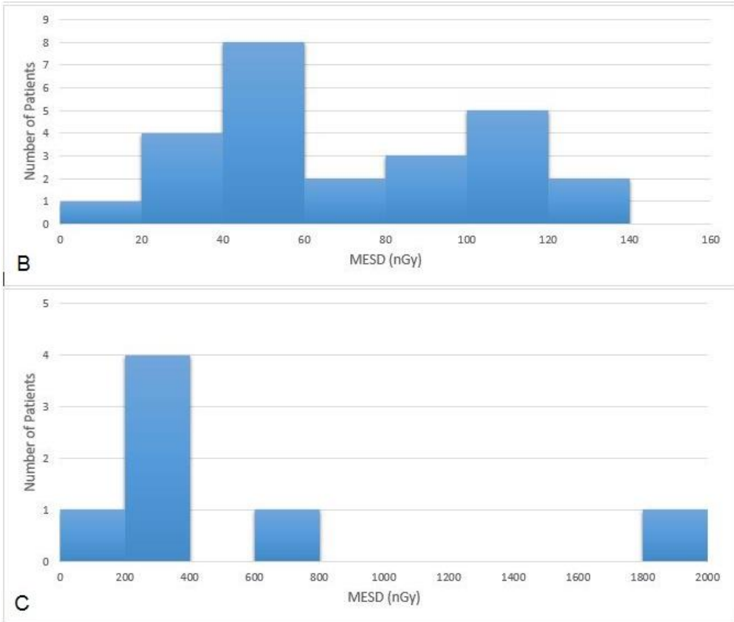


Figure 5. MESD distribution histograms for all fluoroscopic procedures (A), CA procedures (B), and PTCA procedures (C)

Table 1. Patients' dosimetric data obtained from the x-ray system

Patient no.	MESD (μGy)	Average of entrance skin dose (μGy)	Number of frames per second	Fluoroscopy time (min) (in fluoroscopy mode)	DCM time (min)(in DCM mode)	Total fluoroscopy time (min)	Total DAP (μGy.m^2)	Fluoroscopy DAP (μGy.m^2)	Type
1	100200	22961.03333	489	1.2	0.53	1.73	3717.2	772.3	CA
2	68970	13992.31724	234	0.4	0.27	0.67	1705.4	239	CA
3	245700	20507.78	307	3.2	0.42	3.62	2246	1476.2	PTCA
4	1803000	161674.3667	862	22.9	0.97	23.87	21932	15553	PTCA
5	43970	11234.01	263	1.4	0.30	1.70	1355.8	704.7	CA
6	58760	9716.410345	744	0.9	0.53	1.43	1226.1	210.6	CA
7	122100	31121	509	3.3	0.55	3.85	3303.7	1442.6	CA
8	87970	28699.70333	438	1.8	0.48	2.28	3741.2	1018.7	CA
9	52270	13762.65862	460	1.4	0.52	1.92	2194.4	564.8	CA
10	30080	7728.726667	718	1.1	0.40	1.50	1212.5	229.2	CA
11	87990	12740.1	418	0.6	0.45	1.05	1720	197.4	CA
12	45350	14124.59667	376	1	0.40	1.40	1763.8	317.2	CA
13	139900	24450.9	366	2.1	0.40	2.50	3905.8	1703.8	CA
14	38120	6184.036667	236	1.3	0.28	1.58	1012.4	499.8	CA
15	48200	7516.013333	308	0.8	0.33	1.13	1428.3	346.8	CA
16	56100	15366.6	384	0.5	0.42	0.92	Missing	Missing	CA
17	32980	7281.337931	645	0.7	0.37	1.07	1264.9	140.9	CA
18	90440	20959.17241	462	0.9	0.53	1.43	3232	606.5	CA
19	192500	36011.2	626	0.8	0.68	1.48	6250.9	631.3	PTCA
20	58840	17036.63667	447	5.4	0.50	5.90	3018.6	1585.2	CA
21	101100	16290.83	542	0.6	0.32	0.92	2226.8	216.6	CA
22	12290	2462.616667	144	0.7	0.17	0.87	320	151.4	CA
23	58340	9956.493333	222	0.8	0.25	1.05	1223.7	351.1	CA
24	61570	14374.97333	missing	0.6	missing	missing	Missing	Missing	CA
25	103100	17909.47667	338	0.4	0.38	0.78	2105.2	180.2	CA
26	108200	36172.1	778	2.6	0.87	3.47	5600.1	1515.8	CA
27	231600	30079.53333	508	3.2	0.57	3.77	3382.4	1407.4	PTCA
28	116500	23769.75	315	1.8	0.35	2.15	3915.4	1565	CA
29	35250	5926.886667	missing	0.6	missing	missing	Missing	Missing	CA
30	627700	96750.7	628	14	0.68	14.68	13204	10226	PTCA
31	206100	25825.98333	354	0.7	0.38	1.08	2458.8	441.9	PTCA
32	349000	40039.53333	410	5.7	0.47	6.17	Missing	Missing	PTCA

Relationship between MESD and patients dosimetric data obtained from the x-ray system

Table 2 tabulates the mean, minimum, and maximum doses measured on the patient's skin, recorded DAP values, and the fluoroscopy time for the patients during the cardiac angiography procedures.

The relationship between DAP_{TOTAL} and MESD values is shown in Figure 6A. A strong linear correlation was reported between DAP_{TOTAL} and MESD values for all CA and PTCA procedures (R^2=0.89). This relationship is presented as *Equation* (1):

MESD=73.985 (DAP_{TOTAL})-90558 (1)

Moreover, a strong linear relationship was observed between MESD and total fluoroscopic time for 32 patients (R^2=0.89) (Fig. 6B). Additionally, there was a linear association between MESD and total duration time for 32 patients (R^2=0.89) (Fig. 6C). This relationship is presented as *Equation* (2).

MESD=65698 (TIME) – 32914 (2)

In the same line, there were relationships between MESD and fluoroscopy time (R^2=0.89) as well as MESD and cardiac radiography time (R^2=0.43). On the other hand, a weak correlation was observed between MESD and the number of frames per second (R^2=0.22) (Figure 6D).

Figures 7 A, B, and C illustrate the correlation between DAP and MESD for patients who underwent CA procedures, as well as DAP and MESD for patients who underwent PTCA procedures, and total fluoroscopic time and MESD values for patients who underwent PTCA procedures. Similarly, a correlation was reported between DAP and fluoroscopy time for patients who underwent CA and PTCA (Figure 8).

Table 2. Summary of the dosimetric data for the current study

	Number	Max	Mean	Min	Standard deviation
DAP (μGy. m^2)	28	21932	3595.26	320	4344.13
MESD (μGy)	32	1803000	169193.44	12290	321002.54
Total fluoroscopy Time (min)	30	23.87	3.20	0.67	4.75
Number of Frame / S	30	862	451.00	144	178.75

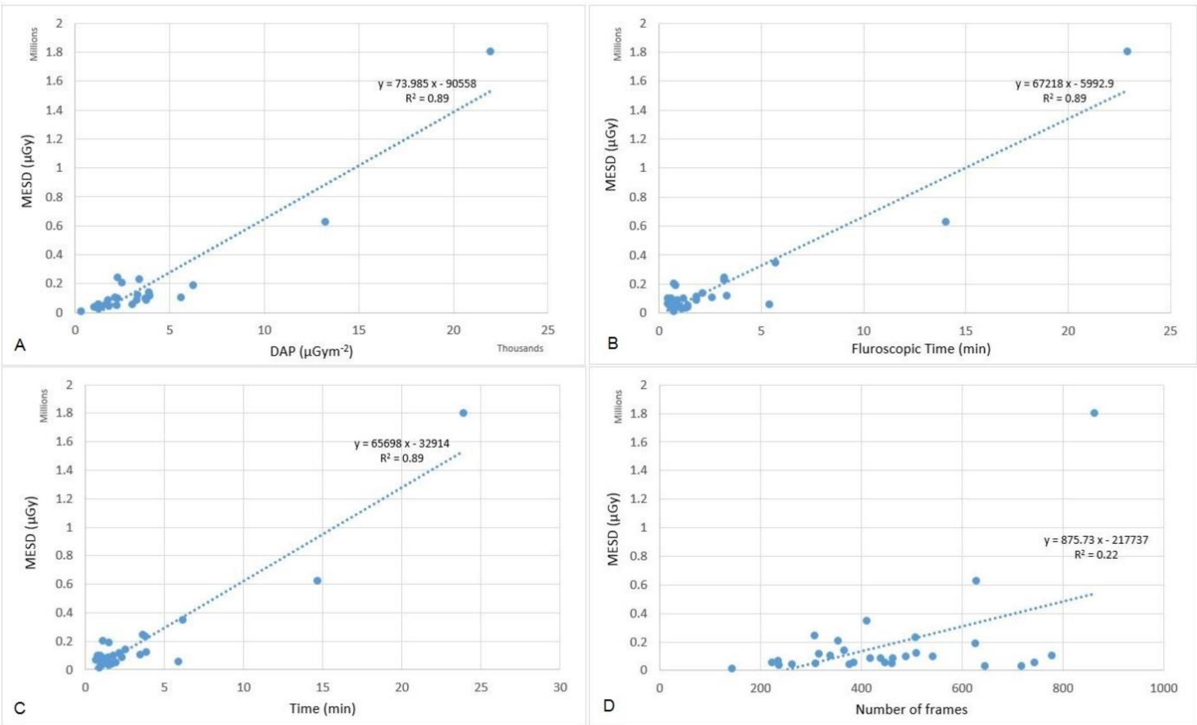


Figure 6. Correlation between total DAP and MESD values for 32 patients who underwent fluoroscopic procedures (i.e., CA and PTCA procedures) (A), Correlation between fluoroscopic time and MESD values for 32 patients who underwent fluoroscopic procedures (i.e., CA and PTCA procedures) (B), Correlation between total time and MESD values for 32 patients who underwent fluoroscopic procedures (i.e., CA and PTCA procedures) (C), Correlation between the number of frames per second and MESD values for 32 patients who underwent fluoroscopic procedures (i.e., CA and PTCA procedures) (D)

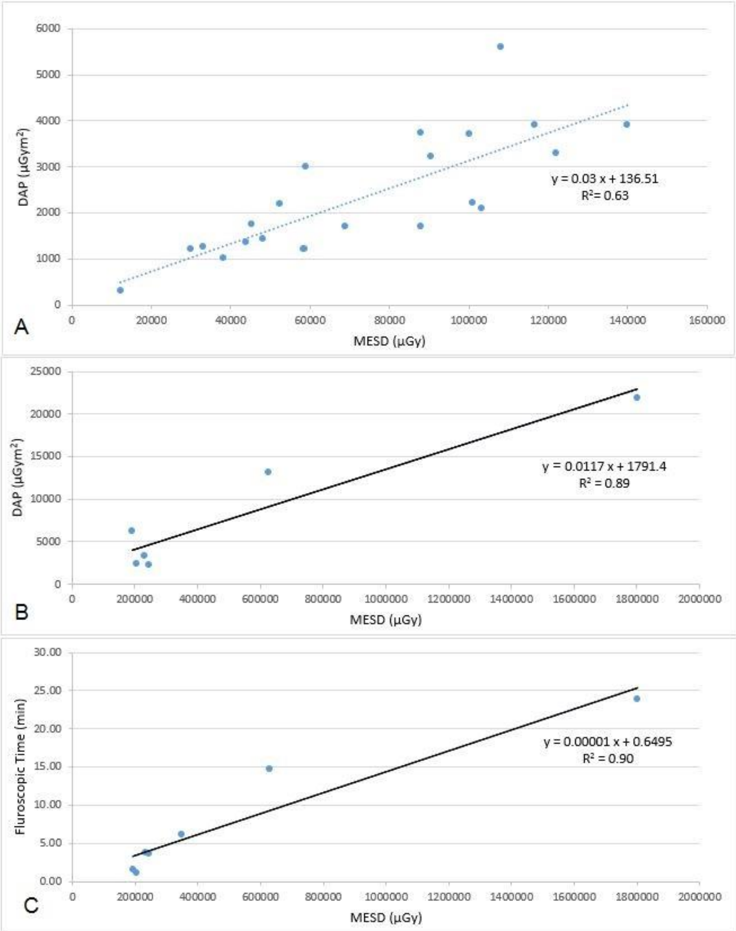


Figure 7. Correlation between DAP and MESD for 22 patients who underwent CA procedures (A), Correlation between DAP and MESD for 6 patients who underwent PTCA procedures (B), Correlation between total fluoroscopic time and MESD values for 7 patients who underwent PTCA procedures (C)

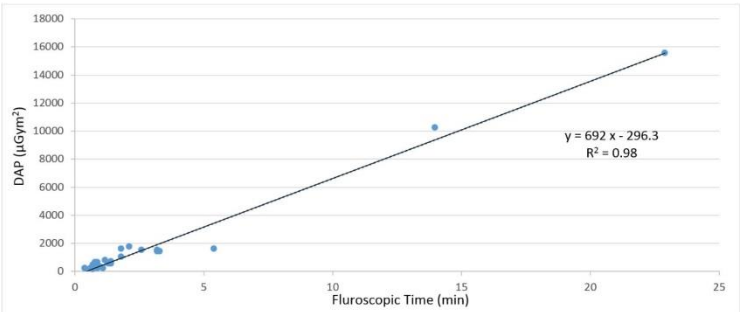


Figure 8. Correlation between DAP and total fluoroscopic time for 32 patients who underwent fluoroscopic procedures (i.e., CA and PTCA procedures)

Discussion

As shown in Figure 5, the patients undergoing PTCA are those with higher MESD values. This result is predictable due to the higher duration of patients' fluoroscopic time during PTCA, which is a therapeutic intervention. In this study, dose distribution curves were in complete agreement with those in the studies conducted by da Silva et al. [30] and Ying et al. [23].

There is a correlation between the MESD values of patients and DAP_{Total} (R^2=0.89) (Figure 6A). The MESD can be predicted from the DAP readings using *Equation* (1). However, the *Equation* is only applicable to this x-ray system (Siemens AXIOM Artis X-ray C-arms) and for patients with a weight range between 70 and 80 kg. Due to the variable dosimetric parameters, such as the patient's size, x-ray system condition, DAP meter calibration, and exposure parameters, the equation would vary between different cardiac centers. As can be seen in Table 3, these results are in line with the findings of the studies performed by Putte et al. [31], Bor et al. (using gap chromic film) [32], Domienik et al. [33], Zentar et al. [21], and Ying et al. [23] in which the relationship between these two quantities has been indicated by using different dosimetry methods. However, there are subtle differences among the results of the aforementioned studies which are acceptable.

On the other hand, the results are not consistent with the findings of the studies performed by Bor et al. [32] (using TLD), Domienik et al. (room 1) [33], and Morrell et al. [34]. The difference in the results can be attributed to the improved relationship between the MESD values of patients and DAP_{Total} (R^2=0.89) in this study. The reason for each of these cases will be reviewed separately.

In a study conducted by Bore et al., a number of TLDs were placed on the patients' back to measure the skin dose [32]. To measure the patient's skin dose, the patient's back was completely covered with TLDs with a distance of 7.5 cm apart, and a few TLDs were placed in front of a tube which then recorded the dose of the primary beams. However, in a study carried out by Bore et al., skin dose was measured just in 9 common direction of tube, actually when the tube was placed in a direction other than these 9 positions, TLDs might not exactly face the tube and could cause errors in MESD recording. This can be an explanation for the presence of discrepancies in the results of this study [32]. Moreover, the size of the patients was not mentioned in the study by Bore et al., whereas the patients enrolled in this study were in a specified weight range (75±5 Kg) which was approximately the weight of the phantom. This is while the patient's weight is effective in their exposure factors. The bulkier the patient, the higher the exposure factors used, thereby increasing the skin dose of the patient.

The difference between this study and that by Domienik et al. regarding the correlation between MESD of the patients and DAP values [33] seems to be due to the utilization of different types of the x-ray unit and dosimetry. In the present study, the x-ray unit was Siemens AXIOM Artis; however, the x-ray which was used in the study by Domienik et al. [33] was GE Innova 2000. Therefore, in fact, the variations in the types of the x-ray unit and dosimetry might lead to the differences in the data obtained. Furthermore, TLD was utilized in this study; however, Kodak EDR2 film was used in the study performed by Domienik et al. [33] and Morrell et al. [34]. Radiography films, such as Kodak EDR2 have low accuracy and high probability of error because they are sensitive to light and have to undergo a chemical process to obtain the result (31). On the other hand, it is difficult to work with TLD and read its results. Moreover, the increased dose-response in low-energy photons for TLD dosimeters is one of the reasons for the inaccuracy of these dosimeters [37]. That is why the difference in dose readings by this type of dosimeter can be high. Therefore, a dosimeter with high precision and sensitivity, which is suitable for skin dosimetry, can be a good reference for measuring the skin dose accurately. Radio-chromic films, which are operating in low and high energies between 30 keV and 30 MeV, show high sensitivity in the range of 1 cGy to 50 Gy [23].

Table 4 tabulates the comparison between average dosimetry parameters in the present study and some other studies. The results indicate consistency between the findings in this study and the results of the studies by Bor et al. [32] and Morrell et al. [38] regarding the average maximum measured MESD of patients and the mean extracted DAP amount. As it is shown in table 4, Bor et al. investigate many patients [32], and the mean fluoroscopy time for patients undergoing cardiac interventional procedures is compatible with the equivalent amount in the present study.

Table 3. Comparison of the data of the current study with previous studies

Study	Year	Number of Patients	Method	Correlation between patients' MESD and DAP_T based on the type of fluoroscopic procedure: Angiography (CA)	Angioplasty (PTCA)	Angiography and Angioplasty
Putte et al. [31]	2000	100	TLD			R^2=0.77
Delichas et al. [35]	2005	93	TLD	R^2=0.67		
Morrell et al. [36]	2006		Kodak EDR2	R^2=0.58	R^2=0.37	
Bor et al. [32]	2009	325	Gafchromic Film			R^2=0.92
			TLD			R^2=0.49
Domienik et al. [33]	2008		Kodak EDR2 Room 1			R^2=0.21
			Kodak EDR2 Room 2			R^2=0.60
Zontar et al. [21]	2010	16	Gafchromic Film		R^2=0.66	
Ying et al. [23]	2012	27	Kodak EDR2	R^2=0.82		
Current Study	2014	32	TLD arrays	R^2=0.63	R^2=0.89	R^2=0.89

Table 4. Comparison between the current study and other studies in terms of mean dosimetry parameters

Study	Number of Patient	Fluoroscopy Time (min)	Number of Frame/S	Max measured MESD (mGy)	DAP ($Gycm^2$)
Bor et al., 2009 [32]	325	3.4			49.1
Suzuki et al., 2005 [37]	24			284	73.3
Hansson et al., 2000 [18]	78	9.9	1079	270	73
Morrell et al., 2006 [34]	52				45.5
Ying et al., 2012 [23]	27	1.4	482.4	136.6	25
Trianni et al., 2005 [39]		6.2		280	
Current Study	32	3.2	451	169.19	35.95

Table 5. Comparison between the current study and other international studies in terms of the mean dosimetry data

Study	Total Fluoroscopy Time (min)	Number of Frame / S	MESD (mGy)	DAP (Gycm^2)	Type of procedure	Number of Patients	Country
Putte et al. (2000) [31]	2		412	60.6	CA		Belgium
			760	115.2	PTCA		
Padovani et al. (1998) [42]	3.6	878	41	39.3	CA	13	Italy
	18.6	1434	101.9		PTCA	54	
Padovani et al. (2005) [44]	6.5	700	650		CA		Italy
	15.5	1000	1500		PTCA		
Morrel et al. (2006) [36]				45.5	CA		UK
				151.7	PTCA		
da Silva et al. (2011) [30]			570	6	CA		Brazil
			3040	30.1	PTCA		
Cusma et al. (1999) [41]	4.5		1250		CA	597	US
	19		3300	358	PTCA	202	
Bor et al. (2009) [32]	3.4			49.1	CA		Turkey
	8.7	844	1278.8	66.8	PTCA		
Giordano et al. (2010) [40]	3.8	562.5	90	29±9	CA		Italy
	16.2	963.5	490		PTCA		
Bahreyni et al. (2008) [7]	3.4			32.47	CA	116	Iran
	7.8			44.49	PTCA	31	
Trianni et al. (2005) [39]	6.2		280		CA		Italy
	13.4		1030		PTCA		
Neofotistou et al. (2003) [43]	6.2	1270	280		CA		Greece
	16	1355			PTCA		
Current Study	1.80	427.65	70.34	23.27	CA	25	Iran
	7.81	527.86	522.23	82.46	PTCA	7	

It seems that the exposure time is a crucial parameter in determining the amount of DAP and MESD. This relationship has been demonstrated in the present study. On the other hand, there is not enough information about the exposure time in a study performed by Morrell et al. [38]; however, it seems that the mean exposure time is compatible with that in the present study since the mean DAP and MESD amounts reported by Morrell et al. [38] is the same as those in the present study.

The comparison of the mean DAP amount reported in the present study with the amount in the studies by Hansson et al. [18] and Trianni et al. [39] reveals a lower amount in this study, compared to that in the aforementioned studies [39]. According to the results presented in Table 4, the mean exposure time in all cardiac interventional procedures in these studies is higher, compared to that in the present study. Therefore, it seems that this factor has caused an increase in the amount of reported DAP in these studies. Obviously, there is a strong correlation between the exposure time and the DAP amount. Accordingly, the cardiologist's method or expertise in using X-ray might have caused a higher exposure time, and, as a result, the higher DAP amount in these studies. As was shown in this study, the DAP amount correlated significantly with MESD amount, and it can be seen clearly in these studies that the increase in the amount of DAP could lead to an increase in MESD amount. It is noteworthy that in a study conducted by Hansson et al.[18], the number of frames per second might also affect the amount of DAP and MESD. There is no more information about the mean exposure time in a study carried out by Suzuki et al. [37]; however, regarding the high amount of DAP and MESD, it appears that time led to an increase in DAP, and consequently, an increase in MESD.

The results also indicated that DAP and MESD were lower in this study, compared to those in a study by Ying et al. [23]. Considering the exposure time in this study, it can be concluded that the lower exposure time in cardiac interventional procedures has led to the lower DAP and MESD. Nevertheless, the number of frames per second in a study by Ying et al. [23] was higher than that in the present study, whereas DAP value was lower. Therefore, it can be concluded that the correlation between the exposure time and DAP is stronger than that between the number of frames and DAP. It is worth mentioning that the present study investigated and proved these correlations.

In this study, the mean fluoroscopy time/DCM time was 12.12 in PTCA; however, it was 3.16 in CA procedures. In total, 92% of the time in PTCA procedures belonged to fluoroscopy time (i.e., fluoroscopy time/ total time=0.92), and the remaining time was related to DCM, whereas this ratio decreased to 73% in CA procedures. These results are normal since fluoroscopy mode is used in several therapeutic interventions. Increased X-ray emission time seems to be the main reason for an increase in the MESD in patients undergoing PTCA procedures relative to those undergoing CA procedures. In other words, the mean exposure time was 7.81 min in PTCA and 1.80 minutes in CA procedures. This ratio is comparable with the results obtained from studies performed by Bahreyni et al. [7], Giordano et al. [40], Cusma et al. [41], and Padovani et al. [42]. Moreover, these amounts were higher, compared to those obtained by Trianni et al. [39], Neofotistou et al. [43], Bore et al. [32], and Padovani et al. [44] (Table 5).

In the present study, fluoroscopy DAP (i.e., extracted DAP from fluoroscopy views) ratios to total DAP were 28% and 60% in CA and PTCA procedures, respectively. With respect to the significant correlation between DAP and total fluoroscopy time (R^2=0.98, Figure 8), these results seem to be normal given the higher fluoroscopic time utilized in cardiac angiography procedures (Table 5). In this study, the mean DAP values in therapeutic procedures were reported to be 3.5 times higher than those in the diagnostic procedures; however, this value was 3.3 times in the study conducted by Morrell et al. [34] which seems to be in line with the values obtained in the present study.

Moreover, the ratio of DAP values in PTCA to those in CA procedures in this study was higher than that in the studies conducted by Bore et al. [32], Putte et al. [31] and Bahreyni et al. [7], in which they were 1.36, 1.90 and 1.37, respectively. In the present study, the mean numbers of frames per second were 427.65 and 527.86 in CA and cardiac angioplasty procedures, respectively. In other words, the mean number of frames per second in coronary angioplasty was 23% higher than that in CA. These ratios were 6% and 42% in the studies conducted by Neofotistou et al. [43] and Padovani et al. [44]. A high number of frames per second seems to be normal in the therapeutic interventions, compared to the diagnostic procedures, such as CA which is due to the high fluoroscopy time in the therapeutic interventions.

The mean MESD of the patients undergoing cardiac angioplasty procedures was 4.7 times higher than the value reported in the diagnostic procedures. Moreover, Trianni et al. [39], Giordano et al. [40], Padovani et al. [44], Padovani et al. [42], Putte et al. [31], and da Silva et al. [30] obtained the ratios of 3.7, 5.4, 2.6, 2.3, 2.5, 1.8, and 4.1, respectively. It seems that this ratio is higher in this study, compared to those in previous studies. This difference might be due to the assessment of a small number of patients who underwent cardiac angioplasty in the present study. Moreover, the discrepancies can be attributed to the presence of one of the patients (patient No. 4) with a very long fluoroscopy time (23.87 min) and the mean MESD of the patients undergoing the coronary angioplasty significantly. Due to unusual high fluoroscopy time for patient No.4, the analysis could be carried out regardless of the results for this patient. If this patient was excluded from the study, the ratio of the mean MESD of the patients undergoing cardiac angioplasty was 4.4, compared to CA patients. This result is consistent with the results of the aforementioned studies.

As it is demonstrated in figures 7A, B, and C, there is a significant relationship between DAP and total fluoroscopy time as well as that between MESD and DAP_{TOTAL} in therapeutic interventions, compared to that in diagnostic procedures. As such, it appears that the longer the intervention time, the more significant the relationship between DAP and dosimetry parameters, such as fluoroscopy time and frame rate. The incidence threshold of definitive skin complications has been reported to be 2 Gy by ICRP report No.85 and it is recommended to monitoring the patients with skin dose over 3 Gy. With this background in mind, none of the patients undergoing interventional cardiac procedures in this study received a higher dose than that declared by ICRP [10].

Conclusion

The results show that DAP values and time are fairly good estimators of MESD in CA and PTCA procedures. The outcome of the present study suggests a method to estimate the MESD value for cardiovascular patients undergoing angiography and angioplasty of the coronary arteries. The results obtained in this study can form a basis for further studies to perform a rapid, accurate, and cost-effective estimation of the exposure in these patients.

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