ENTRANCE SKIN DOSE MEASUREMENT USING GAFCHROMIC DOSIMETRY FILM FOR ADULT PATIENTS UNDERGOING CORONARY ANGIOGRAPHY (CA) AND PERCUTANEOUS TRANSLUMINAL CORONARY ANGIOPLASTY (PTCA)

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Abstract: The complexity of interventional procedures has led to increasingly longer procedure time that require significant fluoroscopic use. Fluoroscopy time is proportional to the patient dose. Once a threshold dose has been exceeded, the severity of the radiation effect at any point on the skin increases with increasing dose. The threshold dose for transient skin injuries is typically 2 Gy for erythema, the earliest detectable effect of radiation on the skin. Therefore, it is important to monitor radiation entrance exposure to the patients. Since it is not uncommon that a patient not only perform a single examination, the skin dose per examination is recommended to note if in the future radiation effect on the patient's skin arises. The skin dose records will help further treatment. The aim of this study is to evaluate patient dose in interventional radiology. Twenty one cardiac intervention procedures were studied: 12 coronary angiography (CA) dan 9 percutaneous transluminal coronary angioplasty (PTCA). The entrance surface dose were measure using DAP (dose-area product) and GafChromic XR-RV3 radiochromic film attached to the skin. GafChromic film measurement obtained the skin dose distribution on the back of the coronary area. In addition, we also measure the patient backscattering dose on the thyroid, gonad and eyes. Image analysis was performed using red channel component of standard RGB (red, green and blue) color space image. The correlation between maximum radiation surface dose and dose area product for two interventional procedures was investigated. We found a good correlation of DAP (dose-area product) and maximum entrance skin dose (R^2 = 0.79, R^2 = 0.52 for CA and R^2 = 0.74 for PTCA). However, fluoroscopy time seems to have a poor relationship with the patient entrance surface dose (R^2 = 0.43). The total irradiation time, DAP and entrance surface dose for PTCA procedures is higher than CA procedures because of the PTCA procedure is more complex. The entrance surface dose delivered to the patient can be easily measured when GafChromic films are used. The GafChromic dosimetry allows precise mapping of the skin dose distribution, when placed close to the skin. The GafChromic film results that the radiation dose to the surface for PTCA procedure greater than CA.

Keywords: *interventional radiology, entrance skin dose, angiography, angioplasty, GafChromic*

I. INTRODUCTION

Nowadays, interventional radiology techniques and the equipment are more advanced, but the possibility of patients exposed to high radiation doses cannot be avoided. This, of course, can lead to deterministic and stochastic effects of radiation exposure. Symptoms of radiation effects are commonly found in patients with long fluoroscopy time. The effect of radiation on the body that occurs after a dose threshold is exceeded on the portion of the patient's skin, the severity on injury at that point increases with increasing dose, called deterministic effects [1].

Short-term effects that may occur from interventional cardiology procedures is the appearance of erythema (redness symptoms of skin tissue) and necrosis (tissue death) of the skin [5]. Radiation effects at any point on the skin equivalent the doses of that point. Reducing the maximum skin dose can reduce the likelihood and type of skin injury, such as minimizing fluoroscopy time and number of cine, and controlling technical factors. Levels of skin damage caused by radiation depends on several factors which include the type of radiation, the radiation dose rate, the radiation-exposed area of the skin and the skin characteristics. Since 2 Gy is used as the threshold for early detection of the radiation effect on the skin, the management of patient dose is important. However, the actual threshold dose of radiation required to cause skin damage varies among individuals, influenced by the level of individual biological radiation sensitivity and the disease that causes the skin to be more sensitive to radiation such as diabetes, genetic disease ataxia telangiectasia and connective tissue disorders [2].

Radiographic film is a method for dose monitoring during fluoroscopy and it can be used over a broad area [6]. The dosimetry film, GafChromic XR-RV3 is specially designed for measuring skin dose distribution using fluoroscopy in interventional procedures, with the size of 14" x 17" with the energy range 30 keV - 30 MeV (ISP GafChromic). From measurement, it was obtained skin dose distribution and maximum skin dose at the back area of the body, especially the coronary areas and organ at risk doses. Color change in the film can be measured with GafChromic dosimetry densitometer, scanner or spectrophotometer.

In interventional radiology, patient dose and estimation of effective dose can be obtained from measurements of the dose-area product (DAP) [3,4]. Based on that investigated the correlation between DAP and entrance skin dose, we also evaluated the relationship between DAP value and maximum skin dose in GafChromic.

II. MATERIALS AND METHODS

The study was carried out from April to May 2013 in the cardiac catheterization lab, National Cardiovascular Center, Harapan Kita Hospital, and included 20 patients who underwent interventional cardiology procedures. Measurement procedure was limited in adult patients Coronary Angiography (CA) and Percutaneous Transluminal Coronary Angioplasty (PTCA), respectively, 10 patients with a variety of radiation field size, the number of frames and fluoroscopy time. The doses was influenced by the fluoroscopy time, thickness of patient, the field size and the number of radiographic frames.

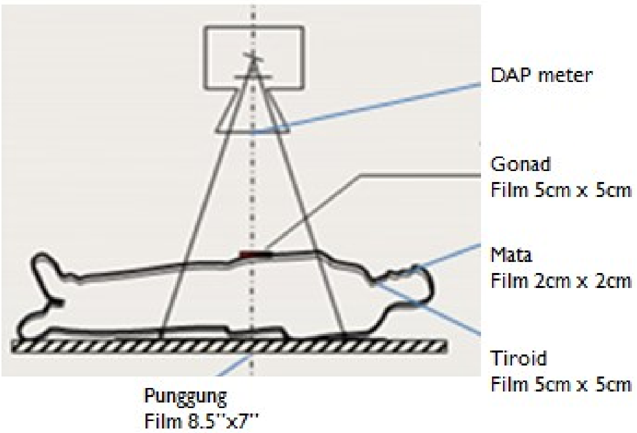

Figure 1. Measurement method

Cath lab room 1, 3 and 5 (R1, R3 and R5) were used for this study. Room 1 and 3 uses the Philips Integris Allura Xper FD10 (Philips medical systems) while Room 5 uses Innova (General Electric, Milwaukee WI, USA). While in use, fluoroscopy device's voltages and currents are regulated by a system of automatic exposure control (AEC). For each examination we recorded the fluoroscopy time, DAP value, number of sequences and cine frames per sequences, dose rate and field size. All procedures were carried out by invasive cardiologist.

Patient dosimetry measurements were performed using dose-area product (DAP) and the GafChromic XR-RV3 radiochromic film. It used Diamentor M4 system (PTW Freiburg), which includes a transmission ionization chamber attached to the collimator exit port of the x-ray tube, placed perpendicular to the beam central axis and located around the area to intercept the x-ray beam. Radiation dose is measured from the contribution fluoroscopy and cine radiography. Different from dap, GafChromic method only provides dose data post procedurally and therefore, this method may be more advantageous when used with other monitoring methods to better determine the actual area of exposure because it placed attached to the skin [6].

Because of the sensitivity of the organs to radiation varies, organs and tissues of the body has a different radiation dose threshold. Group of organs that are very sensitive to radiation than the skin such as gonad, thyroid, and eye. Therefore, in this study we also measured skin entrance dose to the gonads, eye and thyroid patients, also using GafChromic. Entrance skin dose measurement used GafChromic film in dimension 17" x7". As for the risk of organ dose measurements used for thyroid and gonads are 5x5 cm and for eye 2x2 cm.

Twenty consecutive patients cardiac intervention procedures were studied: coronary angiography and percutaneous transluminal coronary angiography. For entrance skin dose measurement, 5 coronary angiography (3 men, 2 women) and 6 PTCA patients (11 men, 4 women) were used. For organ at risk: eyes, gonad and tiroin measurements, we were used all patients (14 men, 6 women).

III. RESULTS AND DISCUSSION

A. DAP Conformance Test

To ensure that DAP in fluoroscopy work accurately, necessary to test the suitability of DAP in advance. DAP conformance testing is done by finding the DAP calibration factors used by the DAP has been calibrated. Therefore, the measurement used three different fluoroscopy in three different rooms, performed DAP conformance testing on each room.

Table 1 shows the value of the DAP calibration factor is obtained. Each calibration factor of the rooms is different, 1.12; 1.24; 1.64 for R1, R3 and R5, respectively. The maximum DAP calibration factors is in R5 (room no. 5), indicating that the lowest accuracy of DAP at room no. 5. Of all the DAP calibration factors, it is known that the DAP in the three rooms need to be recalibrated, especially room no. 5, which presented the highest calibration factor of 1.64.

Table 1. DAP calibration factors of each room

DAP R1	1.1156
DAP R3	1.240
DAP R5	1.64

B. Patient Data Analysis

Of the total 11 patients who underwent entrance surface dose measurements, 5 CA and 6 PTCA, the data measurement obtained in Table 2. The data consists of irradiation factor, total fluoroscopy time and total DAP for each examination.

Total fluoroscopy time was the total of fluoroscopy and cine time. The total fluoroscopy time varied for each patient and was affected by several factors such as the complexity of the procedure, the type of procedure, the structural characteristics of the patient's anatomy, and work experience the interventionist.

Table 2. Measurement data of CA and PTCA procedures

No. of patient	Procedure	Sex	Weight [kg]	Exposure Factors			Total fluoroscopy time [min]	Total DAP [cGy.cm^2]
				kV	mA	ms		
1	CA	P	38	67	351	4	12.78	2806
2	CA	L	65	85	878	7	12.25	9614
3	CA	L	70	96	6	5	10.38	7662
4	CA	L	73	80	897	8	6.95	3544
5	CA	L	72	80	18.7	6	5.62	2671
6	PTCA	P	58	72	704	6	20.83	15184
7	PTCA	L	65	100	11.9	7	8.55	5320
8	PTCA	L	62	86	18.5	7	28.22	25926
9	PTCA	L	61	100	12.8	6	29.48	19303
10	PTCA	L	52	80	17.2	7	6.47	5556
11	PTCA	P	51	78	18.2	7	46.38	16219

Complexity of the procedure allows the use of multiple projections needed to do varying illumination geometry. This can be seen in Figure 2, the post-irradiation GafChromic films in the measurement of patient no. 8, beam irradiation on the film looks not only at one area but some areas, in fact, there is absence of field overlapping. The use of projection geometry is to avoid the buildup of radiation dose at only one point / area that can lead to the possibility of erythema when cumulative doses exceed the dose limit of 2 Gy. In a single procedure conducted, the FDA (Food and Drug Administration) suggest that the cumulative dose at a point not more than 1 Gy.

Of each procedure, total DAP values constitutes the combined fluoroscopy dose and cine contribution. For imaging optimization, each patient’s radiation factor tube voltage and current are varied. This is because in the cardiac catheterization, the use of kV and mA is set automatically by the ABC (Automatic Brightness Control) based on the thickness of the patient's body. The differences of the body thickness produces backscattering radiation which is also different. The thicker the body, backscattered dose will be greater. The greater backscattered radiation certainly raise the entrance surface dose.

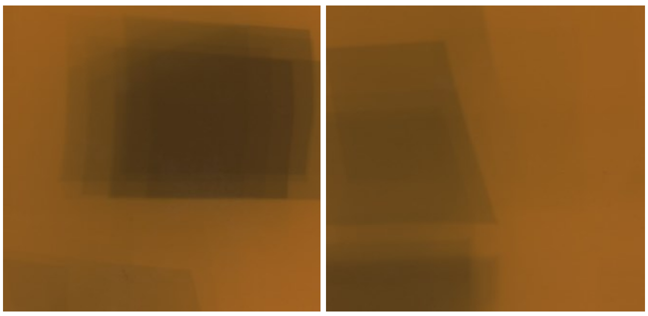

Figure 2. Post-irradiation films of patients no. 8 and 11

From Table 3, note the value of the maximum ESD for each examination. The maximum ESD values characterized in bold, for CA procedures was 29.54 cGy whereas PTCA was 208.06 cGy. Entrance dose of 208.06 Gy is clearly dangerous for patients because it has exceeded the threshold of the radiation effects erythema (redness symptoms of the skin). Therefore, the hospitals are encouraged to give special attention to cardiac catheterization especially PTCA. Catheterization team expected to record the medical data of the radiation dose received by the patient so that when later the biological radiation effects occur in patients can be dealt with appropriately.

After the films were analyzed using Matlab software, the entrance surface dose distribution as shown in Figures 10 and 11. Figure 10 shows dose distributions of patient no. 8 with a total fluoroscopy time 28.22 min, DAP 321.49 Gy.cm^2 and the maximum entrance dose 208.06 cGy. Figure 11 shows dose distributions of patient no. 11 with a total fluoroscopy time 46.38 minutes, DAP 265.50 Gy.cm2 and maximum entrance dose 92.97 cGy. From the differences in both fluoroscopy exposure duration, even though the patient no. 11 had longer fluoroscopy time than patients no. 8, but the maximum entrance doses patients no. 8 was greater. It is informed that the total fluoroscopy time was not the only one of factor that influences the patient's entrance dose.

In Table 3 is also known that the PTCA procedure average of the total fluoroscopy time is higher (23.32 min) than in CA (17.08 min). Neither the average of DAP and average of maximum ESD, for both greater in PTCA procedures (195.26 Gy.cm^2 and 93.02 cGy) than CA (72.73 Gy.cm^2 and 34.88 cGy). In the PTCA procedure, the DAP and ESD is greater than CA because of PTCA is more complex; it does not only look at the position of the heart artery blockage but also open the blockage treatment with / without stent. As a result of course fluoroscopy time in the PTCA procedures are longer than the CA, so the DAP and ESD will be greater in PTCA procedures.

From the graph of the correlation between the maximum entrance dose and total fluoroscopy time in the procedure CA (Figure 4) shows that the linearity less significant (R^2 = 0.24) or it can be said that the relationship is not linear. Likewise PTCA procedures (Figure 5), both linearity relationship was not significant (R^2 = 0.27). However, when seen from the whole procedure (Figure 6), the correlation between

Table 3. DAP and maximum ESD measurable

Patient	Procedure	Total fluoroscopy time [min]	DAP corrected	MSED [cGy]
1	CA	12.78	3130.60	19.83
2	CA	12.25	11921.36	75.9
3	CA	10.38	12543.84	33.2
4	CA	6.95	4395.68	**29.54**
5	CA	5.62	4372.43	15.93
6	PTCA	20.83	18828.78	62.40
7	PTCA	8.55	6597.05	52.49
8	PTCA	28.22	32148.98	**208.06**
9	PTCA	29.48	23935.84	118.27
10	PTCA	6.47	9095.17	24.94
11	PTCA	46.38	26550.50	91.97

maximum entrance dose and total fluoroscopy time was more significant ($R^2 = 0.43$). From this information, it can be seen that although the correlation between entrance surface dose with the fluroscopy time is less linear (R^2 = 0:43), the increase of fluoroscopy time tended to increase the entrance surface dose.

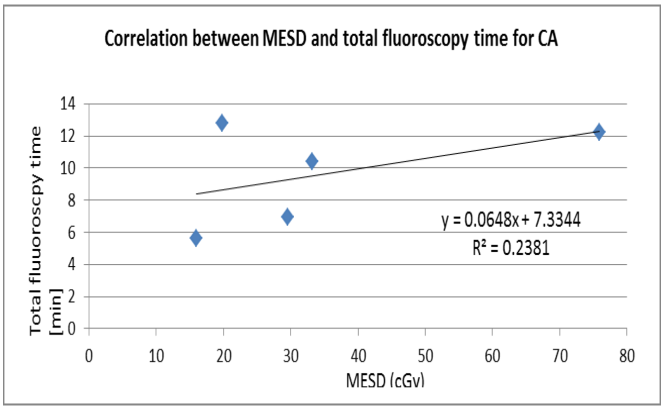

Figure 4. The correlation between MESD and total fluoroscopy time for CA

Figure 7 shows the correlation between the DAP and maximum entrance surface dose for CA procedure. Although both of them shown less linear relationship ($R^2 = 0.52$), but it appears that DAP tend to increase with increasing the entrance surface dose. While the correlation of DAP and maximum entrance surface dose for PTCA procedure (Figure 8), the relationship has more significant linearity ($R^2 = 0.74$). The graph of DAP and maximum entrance surface dose for the entire procedure (Figure 9) shows a significant relationship ($R^2 = 0.79$). This graph informs that the increase the entrance surface dose is directly proportional to increase in DAP. This is because the DAP is air Kerma dose from source multiplied with the field of radiation, while the dose entrance is the total the air Kerma dose and backscattered dose. So both of them has directly proportional relationship.

Table 4. Mean values for DAP, the maximum ESD and total fluoroscopy time

Procedure	Mean DAP [Gy.cm2]	Mean MESD [cGy]	Mean total fluoroscopy time [min]
CA	72.73	34.88	17.08
PTCA	195.26	93.02	23.32

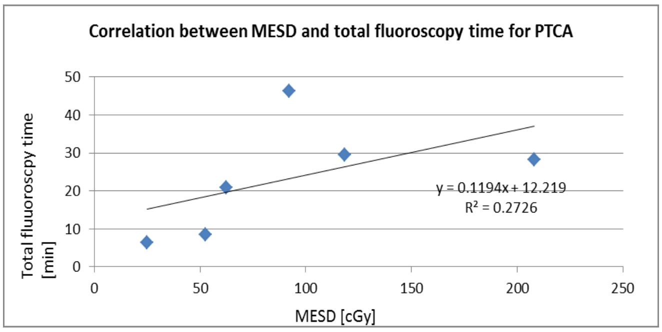

Figure 5. The correlation between MESD and total fluoroscopy time for PTCA

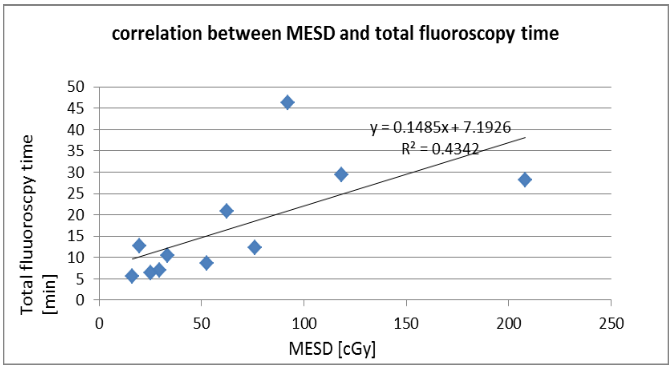

Figure 6. The correlation between MESD and total fluoroscopy time

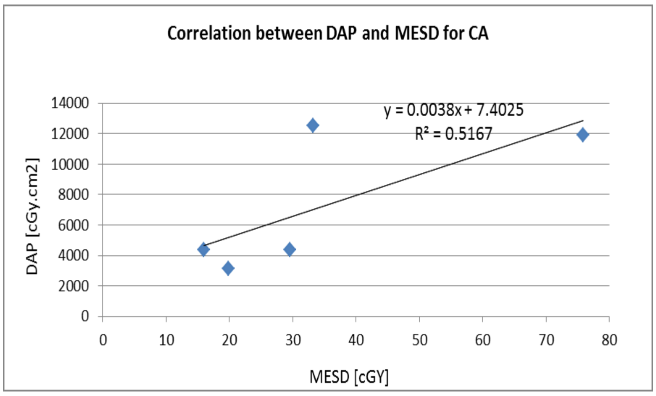

Figure 7. The correlation between DAPand MESD for CA

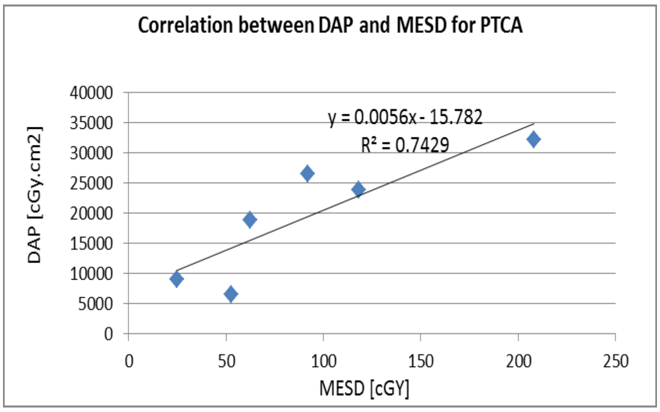

Figure 8. The correlation between DAP and MESD for PTCA

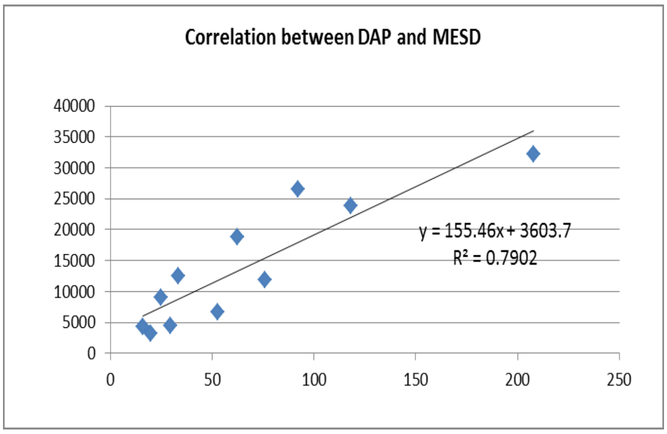

Figure 9. The correlation between DAP and MESD for PTCA

C. *Organ At Risk Dose*

The entrance surface dose measurements on the Organ at Risk (gonadal, thyroid and eye) was performed in 21 patients undergoing cardiac catheterization. Overall patients observed were 12 CA and 9 PTCA. ESD is recorded in Table 5. Entrans dose is the backscattering radiation dose because the point are not on the primary radiation beam. Entrance dose distribution for all patients can be seen in Figure 7, displayed entrance dose on eyes, gonads and

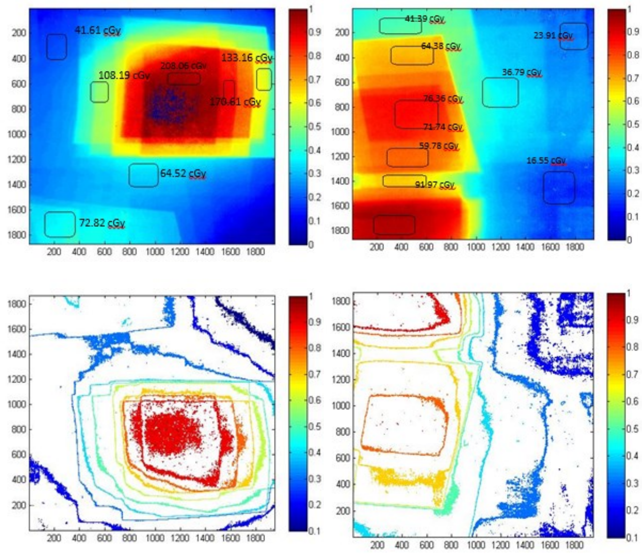

Figure 10. Radiation dose distribution of patient no. 8 (left) and patient no. 11 (right)

thyroid. Each patient received a different entrance dose of OAR. For the eye, the highest dose is 2.63 cGy in the patient no.4. As for the gonads and thyroid, the highest entrance dose received by the patient no. 10, 2.93 cGy and 3.67 cGy. Overall the thyroid received the highest of backscattering dose (2.34 cGy) compared to the gonads (1.83 cGy) and eyes (1.49 cGy). This is because the location of the thyroid that is closest to the heart so that it gets the maximum backscattering radiation.

Table 5. ESD on gonadal, thyroid and eye

Patient	Exposure factor			Entrance Dose [cGy]		
	kV	mA	ms	Eye	Gonadal	Thyroid
1	79	867	7	2.53	2.67	3.25
2	74	17	7	0.67	1.99	2.75
3	81	899	7	0.97	1.85	2.75
4	98	19	7	2.63	2.63	3.15
5	93	19	7	1.67	2.21	1.85
6	81	70	5	0.49	0.18	2.05
7	68	394	5	0.31	1.50	2.10
8	81	19	7	2.16	1.45	3.68
9	83	19	7	0.23	1.70	2.68
10	78	19	7	1.08	2.93	3.67
11	67	351	4	1.82	1.57	1.11
12	72	704	6	1.25	2.46	1.41
13	85	878	7	0.55	2.63	3.03
14	100	12	7	2.36	2.66	1.65
15	86	19	7	1.65	1.19	2.09
16	96	6	5	2.45	2.45	2.02
17	80	897	8	0.79	2.29	2.60
18	100	13	6	2.35	2.65	2.61
19	80	19	6	1.12	0.00	2.20
20	80	17	7	2.59	1.00	1.81
21	78	18	7	1.68	0.36	0.63
	Mean			**1.49**	**1.83**	**2.34**

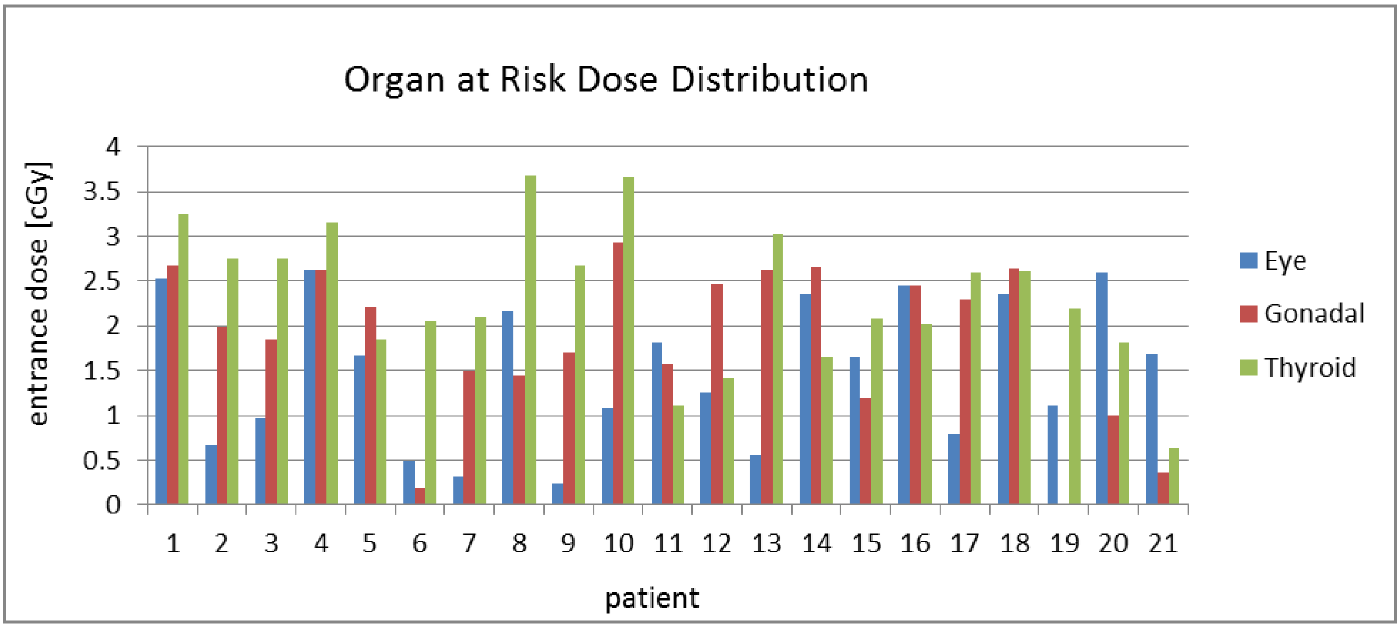

Figure 12. ESD distribution on gonadal, thyroid and eye

IV. CONCLUSION

The entrance surface dose delivered to the patient can be easily measured when GafChromic films are used. The GafChromic dosimetry allows precise mapping of the skin dose distribution when placed close to the skin. The GafChromic film results that the radiation dose to the surface for PTCA procedure greater than CA.

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