Assessment of Patient Dose with Special Look at Pediatrics during Cardiovascular Imaging

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ABSTRACT

Background: During interventional cardiology processes, patients especially women and children receive high radiation doses due to their sensitivity.

Objective: In this study, we evaluated a pediatric patient dose separately in those undergone intervention cardiac procedure.

Material and Methods: In this cross sectional study, a public hospital with 252 patients, Entrance Skin Dose (ESD) and Dose-Area Product (DAP) were recorded. Prior to the beginning of fluoroscopic procedure, the chest thickness and Body Mass Index (BMI) of patients were measured. Furthermore, kV, mAs, angle of tube and time of angiography and angioplasty were recorded.

Results: Children ratio to all patients underwent the cardiovascular imaging was 1.8. The means of patients' ESD, DAP and fluoroscopy time were 178.3 ± 17 mGy, 1123.6 ± 11 µGycm^2 and 281.4 ± 181.2 s, respectively for coronary angiography. The females were 96.8 under 30 years and their dose mean was 276 ± 37 mGy, 368 ± 24 µGycm^2 for ESD and DAP received, respectively with 376s fluoroscopy time. Mean mAs was 359 ± 34 and kV was 71.23 ± 2.7. Above all, a direct and significant correlation was found between the patients' chest thickness with kV ($p=0.037$, r = 0.11) and mAs ($p<0.001$, r = 0.28) variations.

Conclusion: The results demonstrated that the number of children referred to the cardiology department and also the dose rate received by them during this test was higher than the data provided for children in developing countries. Paying attention to the children's perception of high-fluorescence time is necessary in comparison with total angiography time in order to reduce the number of radiation injuries among pediatrics.

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Introduction

One of the diagnostic and treatment methods for heart diseases is using ionizing radiation, which has quickly made progress recently. Interventional procedures have become more common in most countries owing to their prosperous clinical results and improved patients' safety [1, 2].

The increasing number of cardiovascular diseases in adults is due to high job stress and lifestyle changes [3]. Considering infant and child mortality, congenital heart diseases are the second reason as among chil-

dren. In developing countries, the frequency is 10 infants in every 1,000 ones who were born with the congenital cardiac disease [4]. To assess the dose of children under the age of 10 and investigate the most important cause of their referral to the heart center, it is vital to know the etiology that is unknown; however, the most important reason of etiology is considered to be genetic for 5% such as Trisomy on the chromosome 21 or some maternal diseases such as Phenylketonuria, primary mother diabetes, Rubella, using anti-depressants and some diagnostic and therapeutic imaging processes by X-ray taken by mother [5, 6].

Studies have shown that cardiac imaging modalities induced high doses to patients at every angiography or angioplasty procedure [7]. Moreover, Khalafall showed that angioplasty induced high doses to patients in various imaging assays [8].

Heart diseases are usually chronic and patients come to imaging centers for two or more times; this causes radiation risk to increase in interventional methods. Consequently, the national and regional monitoring indicates that there are some changes in patient dose every year and the subsequent risk of this imaging will be in the community [9]. Vulnerable groups such as females and children at an early age are in a high-risk situation [10].

Exposure of children showed that the received dose by critical organs of the body was high for children's organs that are nearby and more sensitive than adults [11]. The delivered dose in CHD children during interventional cardiology for diagnostic and therapeutic purposes were for breasts (among females) 1.78 and 1.36 mGy and active bone marrow organ 0.90 and 0.64 mGy, lungs 3.56 and 2.59 mGy, heart 1.99 and 1.46 mGy [12]. In women, there are highly sensitive organs such as breasts located in the chest, which are subject to exposure always during cardiovascular imaging. Therefore, one of the cancer risk increasing cases is high-dose X-ray or long-time modality of it such as angiography and angioplasty [13].

Nowadays, fluoroscopy remains a critical part of diagnostic procedures in radiology for critically ill children. Attending to clinical concerns among children is important in planning with the most efficient examination, with the highest diagnostic yield at the lowest possible radiation dose. In the study of methods, reducing doses in children's fluoroscopy image, increasing the amount of FOV and using the pause-and-pulse technique are appropriate. While in most children's interventional cardiology, the FOV changes with thickness based on the age of children [11].

Effective factors in the dose such as exposure conditions (kV, mAs, and total time) were considered [14]. One of the most important factors in the received dose is the weight and height of patients; studies revealed that the impact of BMI on the dose was significant [15, 16].

In the position of tube under table, the received dose of ESD was higher and the damage to skin had an increase [17].

The main aim of this research is to evaluate the received dose by patients during cardiac interventional procedures, including Coronary Angiography, percutaneous coronary intervention and congenital heart disease. Furthermore, effects of the exposure factors, chest thickness, fluoroscopic time and patients' BMI on the dose received by the entrance skin and area were presented.

Material and Methods

Material Selection

In this cross sectional study, 252 patients participated with heart disease (HD) who underwent CAG (Coronary Angiography), PCI (percutaneous coronary intervention) and CDH (Congenital Heart Disease) in cardiovascular department of Shahid Madani Hospital in Tabriz, Iran during a one-year term. Among all eligible patients, 116 cases were undergoing PCI, 124 cases were undergoing CAG and

12 cases were undergoing CDH.

Digital single-plane Siemens angiography unit was used in CDH, PCI and CAG practices. X-ray tube moves rotationally on two perpendicular planes, which makes each obligatory kind of projection feasible as RAO, LAO from 0 to 90 degrees.

Entrance skin dose (ESD) and Dose-area product (DAP) were utilized as indicators of radiation dose from data recorded by the angiography machine.

The DAP meter software records the whole exposure time (fluoroscopy and cine angiography) and the place of radiation (in cm^2) on a plane which was perpendicular to the X-ray beam.

The ESD (mGy) was measured for patients under angiography; this value was determined at the intersection of X-ray and the skin surface of the patient at the center of the radiation field. ESD includes scattered beams and can be measured easily.

Digital cine acquisition was performed at 15 frames per second for each procedure. The generators were set to 50 to 125 kV and to 24 to 820 mAs depending on the patient's condition especially weight. The mA and kV in both cine mode and fluoroscopy were tidied using an automatic exposure control system. Maximum and minimum among ESD (mGy), DAP ($\mu Gy.cm^2$) and times in real-time and cine (s) were measured in all projections for each patient. The body mass index (BMI, kg/m^2) of patient and chest thickness (cm) were recorded

for each patient. The BMI groups were classified into group A: BMI below <18.5 kg/m^2, group B: BMI 18.51-25 kg/m^2, group C: BMI 25. 1-30 kg/m^2 and group D: BMI above >30.

Statistics analysis were performed using SPSS (ver. 23). The analyzing mixed model was applied for measurements repeated. Pearson correlation coefficient for the interaction-dependent variables and standard deviations for the independent variables were used.

Results

Female children were 34% in CDH group. In the study population, the women were 48 in CAG and 44 of them in PCI group. Approximately 98 of angiography and angioplasty patients had at least two times of interventional tests. Details are shown in Table 1.

The average age of patients was 55±16 (2-80) years and the chest thickness was 20.2±3 (10.5-32). The study of patients revealed that percentage of BMI groups A, B, C and D were 4.4%, 32%, 37.5% and 26.1%, respectively. Fuethermore, a significant increase in DAP was observed by higher chest thickness of patients (p=0.0001).

Mean DAP in CAG, PTCA and CDH

The total means of DAP ($\mu Gy \times cm^2$) in male and female children groups were 1123.6±11, 3622.8±24, 147.8±62 in CAG, PCI and CDH in this project. The mean fluoroscopy times were 281.4±181.2, 798±576 and 552±72 second for CAG, PCI and CDH, respectively as

Table 1: Frequency of CAG (Coronary Angiography), PCI (percutaneous coronary intervention) and CDH (Congenital Heart Disease), Gender and angiography previous recorded in studded patient.

		N (%)	CAG	PCI	CDH
			124(49.20)	116(46.03)	12(4.76)
Gender	male	156(61.9)	76(61)	72(62)	8(66)
	Female	96(38.1)	48(39)	44(38)	4(34)
Previous recorded		98(39)	32(12.7)	66(26.3)	-

presented in Table 2. The correlation among DAP, fluoroscopy time and chest thickness was significant (P=0.0001). There was a significant difference in DAP patients with BMI Group C; this means that by increasing the body mass index, DAP will also increase (P=0.0001).

Relations between Received Dose and Exposure Factors of X-ray Tube Angle and Patient's Chest Thickness

The ranges of tube angle were from 10° to 57° in Right Anterior Oblique (RAO) and Left Anterior Oblique (LAO). The minimum amount of kV was 70 for all three tests in RAO view and maximum of 94 in LAO view. As regards the minimum value, mAS for all three tests was 31 in view of RAO and a maximum of 820 in LAO view. The DAP in cine angiography was 85.41±69 in LAO view, in RAO positions was 52.2±42, ESD in cine angiography was 12.1± 9.6 in LAO view, in RAO positions was 8.1 ±7.1 (Table 3). The difference in the average amount of DAP was significant between the two views (P=0.0001). Fluoroscopy

Table 2: DAP, ESD and Time in the diagnosis coronary angiography, percutaneous coronary intervention and Congenital Heart Disease in Fluoroscopy and Cine angiography. Min, Max and Mean values were shown for DAP, ESD and Time.

		DAP (µGy×cm²)			ESD (mGy)			Time (s)		
		Min	Max	Mean						
Fluoroscopy	CAG	25.3	5133.7	1123.6±11	19.3	822.7	178.3±17	4	25.3	281.4±18
	PCI	14.1	11691.9	3622.8±24	14.1	1871	548.2±36	1.5	45.1	798±57
	CDH	75.8	272.6	147.8±62	13.7	43.9	24.0±9.8	7.5	10.9	552±72
Cine angiography	CAG	9	306.5	79.6±61	1	40.1	11.2±9.3	1	7	3.27±0.9
	PCI	4.2	540.6	66.8±58	5	42.4	10.1±8.1	1	35	3.0±4.3
	CDH	8	18.8	5.75±5.4	1	2.5	0.85±0.71	1	4	2.5±0.9

Table 3: The variation of exposure parameters (min, max and mean) in two projections of RAO and LAO.

		*RAO			**LAO		
		Min	Max	Mean	min	max	mean
CA	kV	70	80	70.391±1.53	70	94	72.68±5.96
	mA	51	807	391.94±241.251	94	820	535.013±229
PTCA	kV	70	87	71.61±3.3	70	92	72.82±5.2
	mA	35	810	519.2±249	35	819	553.250±244.239
R&LV	kV	70	70	70	70	70	70
	mA	31	260	97.0±92.97	24	146	58.37±41.70
Degree		10	50	21.16±8.5	14	57	35.44±8.8
Time	(S)	4	45.1	9.131±8.6	4	45.1	9.5±88
DAP cine	µGycm²	1.7	222.8	52.283±42.39	8	540.6	85.41±69.63
ESD cine	mGy	3	35.9	8.106±7.1	1	42.4	12.105±9.6

*RAO: Right Anterior Oblique, **LAO: Left Anterior Oblique

time amount was not significant for two views of RAO and LAO (P=0.492). Mean DAP was minimum at 35° RAO (75.8 μGy×cm²), and it was maximum at 47° LAO (272.6 μGy×cm²) (Table 4).

Pearson correlation in the impact of chest thickness variation on kV (p =0.037, r=0.11) and mAS (p <0.001, r=0.28) is straight. Furthermore, there is a direct and significant relation in variations of DAP with kV (p =0.016, r =0.13) and mAs (p<0.001, r=0.25). Ultimately, there is a direct and significant relation between ESD with kV (p =0.002, r=0.17) and mAs (p<0.001, r=0.27) (Table 3).

ESD (mGy) of women and children were 276±37 and 24.08±9.85, respectively. ESD of patients with BMI and chest thickness were significantly related. As the patient's chest thickness increased to 3 cm, ESD changed to towicy same detector.

In examination of CAG, mean BMI of women under 30 was 35.16 which represented mean DAP 384.1±85, ESD 42.5±10 and fluoroscopy time 48±0.5 seconds, and in the examination of PCI, mean BMI was 30.89 with mean DAP 3513.9±24, ESD 510.9±37 and fluoroscopy time 708±2.7 seconds.

The children are considered as a sensitive group and their data was investigated separately as in Table 4. For under-ten-year old children, mean DAP was 147.8±62 (75.8 - 272.6) μGy×cm² and the mean EDS 24±9 (13.7-43.9) mGy. Correlation between DAP and ESD was strongly positive (p=0.0001).

Discussion

This study demonstrated that children are among the patients referred to the heart center. They were about 12 out of 252 patients, which is more than the published worldwide statistics of children in which they are between total heart patients. However, it was reported that the congenital heart disease (CHD) happened in 1% of newborns in developing countries [4].

Because children's radiation sensitivity is more than adults and sensitive organs are close together in the field of view under X-ray beams, the possibility of receiving higher doses of radiation and cancer risk increases in children [11].

There is valuable reasonable evidence that pediatrics are more sensitive to radiation-induced cancer. Correlation between age and risk during exposure time does not vary between organs in a manner fully determined [18].

Nowadays, there are advances in the intervention of procedures radiation protection; however, recent publications have reported surprisingly large doses. In pediatrics exposed to radiation early in life, the amount of patient dose should be recorded to present any possible increase in risk of radiation inducing heart diseases, especially cancers [19].

There is a significant correlation between patient doses (DAP) and entrance skin dose (ESD) with thickness of chest, BMI and fluoroscopy time (P = 0.0001).

Table 4: Relation between DAP and different angulations of tube in RAO and LAO position in the children under 10 years.

		N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12
AGE		2	2	4	9	7	7	2	2	4	9	7	7
*RAO	DAP	75.8	104.2	119.5	131.5	181.1	272.6	75.8	104.2	119.5	131.5	181.1	272.6
	Degree	35	47	15	14	35	44	35	47	15	14	35	44
**LAO	DAP	75.8	104.2	119.5	131.5	181.1	272.6	75.8	104.2	119.5	131.5	181.1	272.6
	Degree	35	45	15	14	35	47	35	45	15	14	35	47

*RAO: Right Anterior Oblique, **LAO: Left Anterior Oblique

The highest fluoroscopy time is related to children in comparison with coronary angiography. Owing to the direct relationship between fluoroscopic time, received doses and consequently direct radiation effects, it will cause an increase in cancer in children due to radiation.

One of the effective factors in the patient dose is exposure to field in obese patients due to the large area under radiation, thus it is necessary to have a high dose beam for greater influence. Thus, exposure conditions and radiation output are increased in order to achieve satisfactory imaging in this group of patients. With increasing BMI, dose increases and significant difference is observed in patients with BMI= 25-30, (P = 0.000) which is also evident in other studies [15, 16].

Whereas, reduction value of X-ray beam is dependent on the photon energy and the thickness of the body. Data revealed that an increase in thickness of patient's body about 3cm will increase the entrance dose by twice [20]. In this study, we found a significant correlation between patient doses (DAP) and the thickness of the patient's chest (P= 0.0001).

Another factor is a tube angle increase; when in RAO or LAO, it causes an increase in the entrance dose of the patient. Along with LAO, the increase of exposure factors such as kV and mAs were recorded. Data showed the thickness of body and tube current in LAO induced the patient dose up significantly (P=0.0001).

A study exhibited that in 40° LAO highest dose was recorded for interventional cardiology [21]. In the current study, the highest and the lowest dose were presented at 47° LAO and 35° RAO, respectively.

Cardiovascular intervention processes with high doses are sometimes more dependent on the operator action of the center as well as in different and complex ways run from center to center. Furthermore, in infants and children, the performance of cardiologist and their training of radiation protection for reducing the radiation exposure is important [22].

In the present study, population percentage of patients with a history of previous coronary angiography was 12.7 % and 26.3% in angioplasty; moreover, the total dose of radiation received by the patients will be dependent on the total number of all interventional cardiology procedures performed, thus sometimes the cumulative dose of patients increased twice or more; this increased radiation increases risk of cancer [9].

There are some notifications about the dose interventions of patients in angiography equipment's to measure the patient doses totally, and fluoroscopy time should be measured. If the entrance dose to the body of a patient is 1Gy, it must be recorded in documents, and if it is more than 3 Gy, patients should be under supervision and laboratory testing for 14-28 days [20].

More than 2Gy was introduced as a threshold dose that causes skin damage. Entrance skin dose observed in PCI was in a maximum range of 1.87, and mean about 0.5Gy in the study of Seguchi et al. the amount of ESD was 1.3-1.4Gy; in some cases, the values were higher and lower than the mentioned study but all values were less than 2 Gy which is introduced as an erythema [23].

Overall, this study showed that being faced with fluoroscopy time and exposure conditions, and the number of pictures or requests to subsequent referrals for radiation about patients who are women or children, it is necessary to consider safety measures. In addition, paying attention to the age and gender of the patients and their sensitivity to radiation are important in order to avoid radiation injury to the patient or secondary damage.

Conclusion

The results demonstrated that the number of children referred to the cardiology department and also the dose rate received by them during this test were higher than the data provided for children in developing countries, thus the factors causing such diseases require more

attention. Moreover, the number of women was more than twice the referred patients to the heart imaging center, the doses received by these women can be causes of maternal diseases in children. Paying attention to the children's perception of high-fluorescence time is necessary in comparison with total angiography time in order to reduce the number of radiation injuries among pediatrics.

Acknowledgment

Conflict of Interest

None

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