Assessment of Effective Dose Associated with Coronary Computed Tomography Angiography in Isfahan Province, Iran

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Abstract

Computed tomography coronary angiography (CTCA) has generated a great interest over the past two decades, due to its high diagnostic accuracy and efficacy in the assessment of patients having coronary artery disease. This method is associated with high radiation dose and this has raised serious concerns in the literature. Effective dose (E) is a single parameter meant to reflect the relative risk from exposure to ionizing radiation. Therefore, it is necessary to calculate this parameter to indicate ionizing radiation relative risk. The aim of this study was to calculate the effective dose from 64-slice CTCA in Isfahan. To calculate the effective dose, an ionization chamber and a body phantom with diameter of 32 cm and length of 15 cm were used. CTCA radiation conditions commonly used in two centers were applied for this work. For all scans, computed tomography volume dose index ($CTDI_v$), dose-length product (DLP), and effective dose were obtained using dose-length-product method. The obtained $CTDI_v$, DLP, and effective dose were compared in two centers, and mean, maximum, and minimum values of effective dose for heart coronary CT angiography (CCTA) examinations and calcium score were compared with other studies. The amount of average, maximum, and minimum effective doses for heart CCTA examinations in two centers are 4.65 ± 0.06, 6.0489, and 3.492 mSv, respectively, and for calcium score test are, 1.04 ± 0.04, 2.155, and 0.98 mSv, respectively. $CTDI_v$, DLP, and effective dose values did not show any significant difference in two centers. Although the effective dose of CTCA and calcium score was lower than that of other studies, it is reasonable to reduce the effective dose to the minimum possible value to reduce the risk of cancer associated with ionizing radiation. The results of this study can be used to introduce the effective dose as a local diagnostic reference dose (DRL) for CTCA examinations in Isfahan Province.

Keywords: *Computed tomography volume dose index, coronary computed tomography angiography, dose length product, effective dose, local diagnostic reference dose, multidetector computed tomography scan*

Introduction

Computed tomography (CT) is one of the most applicable and robust medical imaging methods. Increasing repeated CT examinations during the recent years has clearly proved it.[1] Multidetector CT (MDCT) can produce three-dimensional images of all organs, even moving organs such as heart, with a high quality.[2-9] Fast technological improvements in MDCT imaging enable us to take high-quality diagnostic images of noninvasive heart and coronary artery in the minimum time.[10-12] Despite the advances in the production of high-tech CT scanners, by applying new protocols and various applications of MDCT scanners for the diagnosis of cardiovascular diseases, patients are being exposed to high radiation dose even for a single CT examination.[1,2] The dose received by a patient depends on imaging protocol and the kind of scanner. The CT volume dose index ($CTDI_v$), dose-length product (DLP), and effective dose are the most appropriate parameters indicating radiation dose in cardiac CT examinations. Using these parameters allows comparisons of the radiation doses among different CT imaging protocols.[12]

There are several studies that measured the effective dose of CT coronary angiography (CTCA).[10-22] In all these studies, researches measured or calculated the effective dose of CT examinations. These studies aimed to find a practical way to reduce radiation patient dose while image quality remains acceptable for diagnostic evaluation. In 2003, Brix and Partners by a survey in Germany collected some information about

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a patient's dose in MDCT and SSCT. They indicated that the average annual number of MDCT was remarkably higher than that of in SSCT. Furthermore, the effective dose in both MDCT and SSCT was compared to each other.[19] In 2006, Hausleiter *et al*. collected the data of 1305 candidate patients for coronary CT angiography (CCTA) by 16- and 64-slice devices and obtained effective doses for these units.[10] Mori *et al*. in 2008 measured the average effective dose of CT angiography examination using anthropomorphic phantom in 256-, 64-, and 16-slice devices. They showed that the effective dose for 256-MSCT image is lower than 16- and 64-MSCT images and acceptable for routine cardiac imaging.[20] In the study of John *et al*. in 2008, the effective dose range for calcium score and CCTA was reported and compared with that of other CT examinations.[21]

The concern about the risks associated with CT scanning has been continuing. It has been estimated that cancer incidence for patients undergoing CCTA is approximately 0.7%. Therefore, monitoring the patient dose from this procedure is vital.[8,9,13] Hence, it is important to calculate effective dose to indicate relative risk of ionizing radiation exposure.[14,15] This study aims to calculate the effective dose in CTCA in Isfahan for the first time, to compare the established CTCA dose parameters and local diagnostic reference dose (DRL) to international levels reported in literature to provide recommendations for the understudied centers in Isfahan.

Materials and Methods

In this study, the effective dose in CCTA was determined using DLP and conversion factor in the following steps. The examinations for CT angiography of the heart were performed in two hospitals of Isfahan. CT dosimetry equipment used for the measurement of CTDI values included a pencil-shaped ionization chamber (Piranha X-ray Analyzer, RTI Electronics, Sweden) with an active length of 10 cm. The ionization chamber was calibrated in Secondary Standard Dosimetry Laboratory. The accuracy and uncertainty of the chamber was 5%. A cylindrical phantom with 32 cm diameter and 15 cm length was used for measurements. The most frequently used protocols available in these centers including radiation conditions (mA (millamps) x Time (seconds) (mAs) and kilo Volt peak (kVp) and scanning time), slice thickness, number of slices, and pitch factor to calculate the CTDI values were applied to expose the phantom [Table 1].

The chamber was placed three times in central hole and also three times in peripheral hole of phantom and the corresponding readings of each position were recorded. CTDI was determined based on the following formula:

$$CTDI_w = (1/3\ CTDI_C) + (2/3\ CTDI_P) \quad (1)$$

CTDIc is the dose index value in the central hole and CTDIp is the dose index in the peripheral hole of the phantom. Then, volume of CTDI and DLP was calculated using the following formulas 2 and 3, respectively:

$$CTDI_v = CTDI/pitch \quad (2)$$

$$DLP = CTDI_v \times \text{irradiated length} \quad (3)$$

Finally, effective dose was calculated using the following formulation:

$$E = k \times DLP \quad (4)$$

k-factor for body is 0.015 (mSv. $mGy^{-1}.cm^{-1}$).[16,17]

Results

The values of $CTDI_v$, DLP, and effective dose for CTCA routine tests by 64-slice multi-detector units were calculated in centers entitled A and B and were compared. These values are summarized in Table 2.

Analysis of variance showed no significant difference in centers A and B ($P < 0.001$). P values calculated for $CTDI_v$, DLP, and effective dose are 0.017, 0.018, and 0.02, respectively.

The overall average, maximum, and minimum values of $CTDI_v$, DLP, and effective dose of two centers are

Table 1: Scan parameters of routine scans in two centers

Centers	CT scan type	CT angiography procedures	kVp	mAs	Slice thickness (mm)	Pitch
A	Light speed-MDCT_64 slice	Calcium score	100	430	2.5	0.5
			100	350	2.5	0.5
			100	250	2.5	0.5
		Scan	120	400	1.25	0.5
			120	500	1.25	0.5
			120	600	1.25	0.5
B	Philips VCT-MDCT_64 slice	Calcium score	120	50	2.5	0.5
			120	55	2.5	0.5
			120	100	2.5	0.5
		Scan	120	500	0.6	0.5
			120	600	0.6	0.5
			120	800	0.6	0.5

CT – Computed tomography; MDCT – Multidetector CT; VCT – Volume computed tomography summarized in Table 3. Table 4 summarizes these values for other studies similar to this work. For better comparison, the effective dose calculated in this work and that of other studies is compared in Diagram 1.

In addition, personnel of center B were divided in two groups using different exposure setting for calcium score. Table 5 summarizes these settings and corresponding dose parameter for center B.

Discussion

Effective dose is influenced by several scanning parameters such as kVp, mAs, slice thickness, and pitch factor. By increasing kVp and mAs, the effective dose is increased due to rising $CTDI_W$ and $CTDI_v$; however, it is reduced by increasing pitch factor due to decrease in $CTDI_v$.[18] In this study, we used parameters routinely used in CT angiography in the understudied centers. In these centers, kVp, slice thickness, and pitch factor were almost constant while mAs was considered as the variable factor. According to Table 2, the obtained values of $CTDI_v$, DLP, and effective dose did not show significant differences because the exposure conditions of both main scan and calcium score were the same at the two centers. There are several studies that measured the effective dose of CTCA.[10-22] Brix *et al*. (2003) measured the effective dose in four single-slice CT centers and four 64-slice CT centers using Alderson phantom and TLD in German hospitals [Table 3]. The effective dose for CTCA and calcium score was, respectively, reported to be 10.5 mSv and 3.1 mSv, respectively. They concluded that there is a substantial potential for dose reduction by optimization protocols and personnel education in CTCA.[19] In 2006, Hausleiter *et al*. estimated the effective dose of CTCA and obtained values of 6.4 and 11 mSv for 16- and 64-slice units, respectively. Having evaluated several parameters, they found that decrease in voltage tube had a significant role in radiation dose reduction without deterioration of image quality. They concluded that dose-saving algorithms are very effective in dose reduction and should be used.[10] In the study by John *et al*., the effective dose range for calcium score and CCTA was, respectively, reported to be 1–3 mSv and 5–14 mSv, respectively. It can be concluded from their study that, among all CT examinations, CTCA has had the highest effective dose. Therefore, they pointed out that monitoring the patient dose should be considered as an important issue in CTCA.[21]

The values of effective dose in this study ranged from 0.95–2.15 mSv to 3.49–6.05 mSv for the Ca score and the main scan, respectively. Comparing these values to those obtained in other studies, it can be illustrated that the average effective dose in this study is significantly lower than that of other studies. In general, it could be due to the precision in device calibration, more skillful technicians in selecting appropriate radiation conditions, and scanner type. As shown in Table 3, some personnel of center B voluntarily used the lower exposure setting for calcium score test. Table 3 shows that mA is the only variable factor that has had a significant effect on dose parameters in this study. In addition to reducing mA, some studies demonstrate that using the low concentrate of contrast media is one of the reasonable options resulting in the lower absorbed dose to

Table 2: Dose parameters associated with routine scans in centers A and B

Parameters	Hospital	Average	SD	*P*
$CTDI_W$ (mGy)	A	6.03	0.78	0.72
	B	6.22	1.22	
$CTDI_v$ (mGy)	A	12.06	1.57	0.72
	B	12.44	2.44	
DLP (mGy/cm)	A	301.61	39.28	0.71
	B	311.01	60.89	
Effective dose (mSv)	A	4.52	0.59	0.49
	B	4.79	0.89	

$CTDI_v$ – Computed tomography volume dose index; $CTDI_W$ – Weighted computed tomography dose index; DLP – Dose length product; SD – Standard deviation

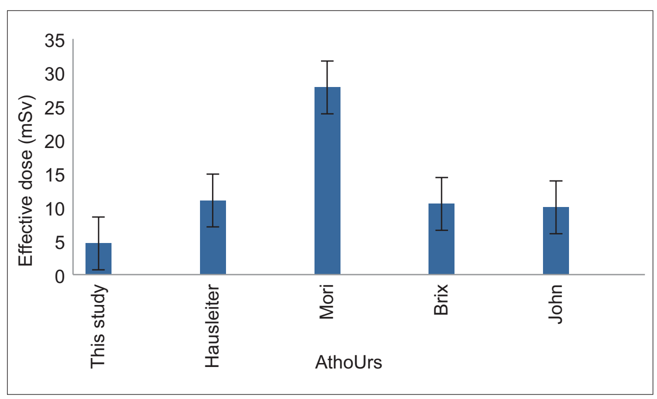

Diagram 1: Comparison of effective dose between this study to other studies

Table 3: Values of average, maximum, and minimum computed tomography volume dose index, dose length product, and effective dose of computed tomography coronary angiography in Isfahan 64-slice centers

Parameters	Calcium score			CCTA		
	Average	Maximum	Minimum	Average	Maximum	Minimum
$CTDI_v$	2.77	5.77	1.05	12.25	16.13	9.31
DLP	69.18	143.67	17.11	306.31	403.25	232.80
Effective dose	1.04±0.04	2.15	0.95	4.65±0.06	6.05	3.49

$CTDI_v$ – Computed tomography volume dose index; DLP – Dose length product; CT – Computed tomography; CCTA – Coronary CT angiography

Table 4: Values of average, maximum, and minimum effective dose in other studies

Author	Test type	Effective dose (mSv)		
		Average	Maximum	Minimum
This study	CT angiography	4.65	6.05	3.49
	Calcium score	1.04	2.15	0.95
Hausleiter *et al*.[10]	CT angiography	11	*	*
Mori *et al*.[20]	CT angiography	10.5	*	*
Brix *et al*.[19]	CT angiography	10.5	*	*
	Calcium score	3.1	*	*
Bauhs *et al*.[21]	CT angiography	*	14	5
	Calcium score	*	3	1

CT – Computed tomography

Table 5: Exposure setting selected by two different groups of center B for calcium score

	Exposure setting		Number of slices	Pitch	Slice thickness (mm)	$CTDI_v$	DLP	Effective dose (mSv)	SD
	kVp	mA							
First group	100	160	80	0.5	2.5	3.19	63.8	9.57	0.08
	100	170	80	0.5	2.5	3.39	67.8	10.17	0.09
	100	200	80	0.5	2.5	3.99	79.8	11.97	0.04
Second group	100	250	80	0.5	2.5	4.51	90.2	13.53	0.05
	100	350	80	0.5	2.5	5.18	103.6	15.54	0.08
	100	430	80	0.5	2.5	5.93	118.6	17.79	0.02

$CTDI_v$ – Computed tomography volume dose index; DLP – Dose length product; SD – Standard deviation

patients.[23,24] Therefore, technologists have an important role in selecting the optimized protocol and exposure conditions of imaging to reduce patient dose. From the protection point of view and regarding the ALARA principle, using the protocols with lower setting is preferable over other alternatives to create a reasonable justification between image quality and patient dose.

DRL is defined as the 75th percentile of dose parameter and is the most acceptable criterion by which we can compare dose values to international levels. There are several literatures in which international DRL of CTCA is reported. These values are collected from the USA, Canada, Europe, East Asia, Middle East, and Australia.[6] Four national DRLs have been performed in Europe and one local DRL is reported in Gunma State of Japan.[25-28] The literature has shown a broad variation in DRL ranging from 671 to 1510 mGy in DLP. These values are significantly higher than the 75th percentile of the DLP obtained in this study which is 390 mGy.

Conclusion

According to literature, dosimetry of CTCA has not been done in Isfahan using the specialized CT phantom and ionization chamber previously. Therefore, it was a good step forward in CTCA dosimetry in Isfahan province. Regarding that CTCA is rather new compared to other CT procedures, monitoring the patient dose from this procedure should be considered in researches in the area of radiation protection. Hence, the effective dose is calculated in this study which is an indicator for estimating the probability of cancer incidence of each organ exposed under ionizing radiation. In this study, we showed that, among several parameters affecting dose parameters, mA had a substantial influence on patient dose. It needs to be emphasized here that, since kV is always constant in these centers, mA is the only factor which can be changed manually by technologists. Hence, it can be concluded that personnel education has a key role in selecting the appropriate protocol scan to deliver lower dose to patients while image quality is diagnostically preserved. At the time of writing this manuscript, we had not found data neither related to national DRL nor local DRL of CTCA in Iran or any province in Iran. We showed that local DRL for DLP in CTCA examinations is dramatically lower than other DRLs reported in literature. The collected data can be used in a broader study in the future concluding all provinces of Iran to report national DRL for CTCA. Then, we can organize a comprehensive comparison to international guide levels.

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Conflicts of interest

There are no conflicts of interest.

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