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Estimation of Radiation Doses and Lifetime Attributable Risk of Radiation-induced Cancer from A Single Coronary Artery Bypass Graft Computed Tomography Angiography

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ABSTRACT

Introduction: Despite worldwide consensus that coronary artery bypass graft computed tomography angiography (CABG CTA) confers benefit to patients when used for appropriate indications, the increased cancer risk due to radiation dose remains a concern. The aim of this study is the estimation of organ effective dose (ED) and lifetime attributable risk (LAR) of cancer incidence and mortality related to a single CABG CTA procedure.

Methods and materials: This retrospective cross-sectional designed study included 102 CABG patients who, from January 2021 to June 2021, underwent a retrospective 64-slice ECG-gated CABG CTA covering the area of the grafts with optimal image quality. The estimation of ED was done using the imPACT CT Dosimetry spreadsheet. LAR of cancer incidence was estimated for CABG CTA using the website X-rayrisk.com.

Results: The mean total ED of CABG procedure was 15.35 mSv. The highest organ doses were those to the lungs (5.04 mSv) and breast (4.49 mSv). The cancer risk is higher in female (1 in 1516) than in male patients (1 in 1762). The LAR of cancer is higher for the younger age group in both males and females. The total whole-body ED demonstrated that CABG CTA is equivalent to 154 chest radiographs or 37 screening mammography studies, which in turn correspond to approximately 4.3 or 5-years of natural background radiation, respectively.

Conclusions: Despite many benefits of CABG CTA, it is associated with a non-negligible risk of malignancy, so a careful risk/benefit assessment is recommended in justifying CABG CTA procedures, especially for young female patients.

Keywords: attributable risk of radiation-induced cancer, coronary artery bypass graft computed tomography angiography, estimation of radiation doses

INTRODUCTION

The application of ionizing radiation is increasing dramatically in medical imaging, driven primarily by the increased use of x-ray Computed Tomography (CT). Medical procedures are now responsible for approximately one-half of the ionizing radiation exposure to the human population [1,2]. Diagnostic imaging protocols based on multidetector computed tomography (MDCT) are widely used [3].

Organ doses from conventional radiography are significantly smaller than those associated with MDCT [4]. Consequently, MDCT scans are the dominant contributor to the collective dose from medical radiation sources [5,6]. Concomitant with the technological advances of MDCT, coronary computed tomographic coronary angiography (CCTA) has emerged as a non-invasive, patient-friendly diagnostic modality to detect the presence of coronary atherosclerosis [7].

Plentiful studies have demonstrated that CCTA has high diagnostic accuracy in the proper evaluation of the patency of coronary artery bypass graft (CABG) cases compared with invasive coronary angiography (ICA) and performs even better than an assessment of native coronaries [8-10]. The exceptional image quality of CCTA must be weighed against its associated radiation exposure [3]. It has been reported that CT scans currently contribute 75% of the collective radiation dose given to patients in a radiology department [11].

Although several estimates of CCTA radiation doses have been reported [12], there is little data addressing organ dose and the relationship between radiation dose and cancer risk in patients undergoing CCTA examinations [13]. Although several studies focused on the calculation of the effective dose associated with CCTA [14,15], the effective dose does not consider the age of the patients, which is considered an essential variable in determining the radiation risk [16-18]. Radiation-induced cancer has been related to radiation exposure. Consequently, the possible increased cancer risk has become an important concern related to CCTA and especially in CABG CTA [19]. A recent study by Mansour et al. [20] comparing the utility of CCTA and ICA revealed that 4.8% of patients diagnosed with ICA versus 38.9% of patients diagnosed with CCTA had CABG. Furthermore, this study revealed that the mean radiation dose of patients diagnosed with CCTA was 11.589 mSv, but the study did not explore cancer risk from CABG CTA.

The life attributable risk (LAR) of cancer incidence and mortality describes an excess of disease cases relative to a background rate of an age-matched unexposed population [21]. In the current study, we aimed to evaluate radiation doses received by CABG patients who had undergone retrospective ECG-gated CCTA, and we estimated the LAR of radiation-induced cancer incidence and mortality among this patient group.

MATERIALS AND METHODS

Patient Selection

For our retrospective cross-sectional designed study, 102 consecutive CABG patients who underwent a successful retrospective 64-slice ECG-gated CCTA protocol were recruited during the study period from January 2021 to June 2021. Inclusion criteria were based on technical factors that rendered CABG CTA optimal image quality and covered the area of the grafts. All CABG CTA that did not match the inclusion criteria were excluded from the study.

ECG-triggered dose modulation delivered the highest tube current during 40% to 80% of the RR interval. Data collection included patient characteristics, scan protocol parameters, scan time, beginning and end table positions, patient heart rate, tube voltage, maximum and mean effective mAs, volume, collimation, pitch, gantry rotation time, CT dose index (CTDIvol), and dose-length product (DLP). The study was fully approved by the local hospital ethics committee.

CCTA Acquisition Parameters

CT examinations were performed using the 64-slice Siemens SOMATOM Definition AS. Standard scan parameters were used: modulated tube current (mA) range was 178–320 mA, a tube voltage of 120 kVp, collimation 64 x 0.6 mm, pitch 0.2, and gantry rotation time 0.33 s. The CCTA scan for patients with CABG was performed craniocaudal with scan range between the top of the lung apices and extending to the inferior margin of the heart to include the entire heart and the ligation of the grafts. The patients were instructed to hold their breath during the scan acquisition. Automatic tube current modulation and automatic ECG-pulsing were used to reduce radiation exposure.

Effective Dose Estimation

The estimation of CT organ dose was done using the imPACT CT Dosimetry spreadsheet, a tool for calculating patient organ and effective doses from CT scanner examinations. It makes use of the National Radiological Protection Board (NRPB) Monte Carlo dose data sets produced in report SR250 (Health Protection Agency Centre for Radiation, Chemical and Environmental Hazards, Didcot, UK). SR250 provides normalized organ dose data for irradiation of a model medical internal radiation dose (MIRD) phantom by a range of CT scanners. Organ doses were calculated on the basis of the tissue weighting factors of the International Commission

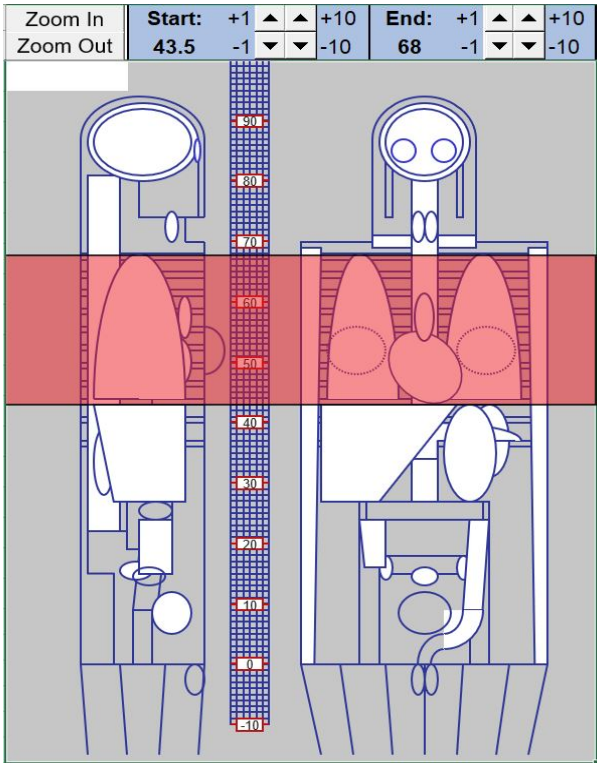


Figure 1. An adult, hermaphrodite, model phantom

on Radiation Protection (ICRP) report 103. The focus was to estimate CT organ dose using an adult, hermaphrodite, model phantom (**Figure 1**).

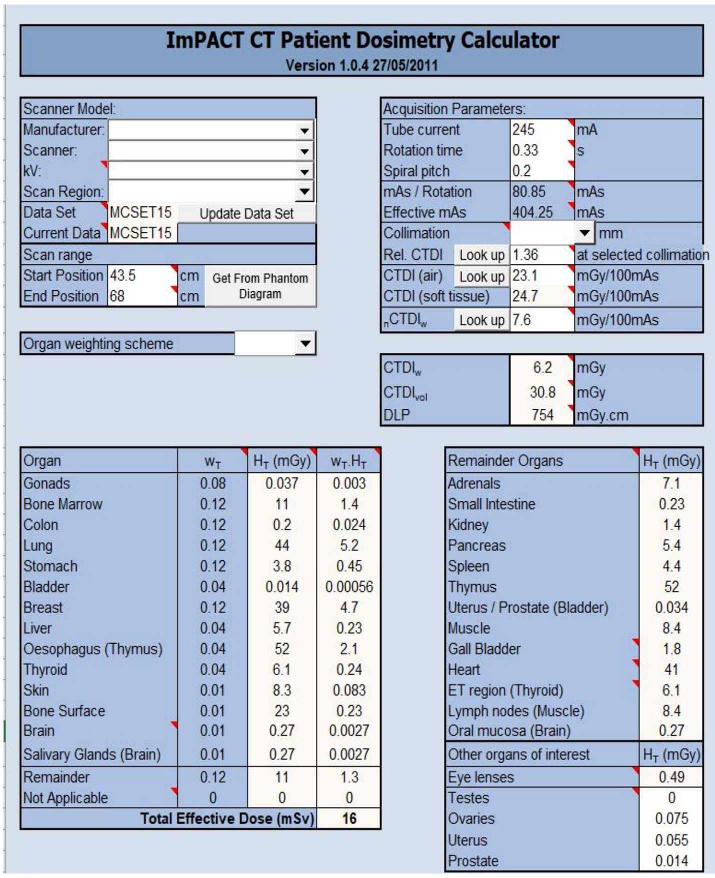
The imPACT CT Dosimetry spreadsheet is based on Monte Carlo Data Set with pre-calculated Computed Tomography Dose Index measurements in free air (CTDI100), center (CTDI100, C) and peripheries (CTDI100, P) that had been measured in a standard Perspex head and body dosimetry phantom, using the same ionization chamber and a consistent technique that have proven to be good for most of the CT scanners used. These measurements in turn are useful for calculation of the weighted CTDI (CTDIw), volume CTDI (CTDIvol), DLP and other dose parameters (**Figure 2**). Parameters that were inputted manually into the CT Dosimetry spreadsheet were the tube current, rotation time and spiral pitch, which vary with protocol and from vendor to vendor.

Estimates of Lifetime Attributable Risk of Cancer

Lifetime attributable risk (LAR) of cancer incidence and mortality was estimated for CABG CTA using the website X-rayrisk.com (**Figure 3**), which, in addition to being an educational site, contains a web-based calculator that allows estimation of the LAR of cancer based on the body-region scanned, age, gender, and average dose for a given patient. The LAR of cancer incidence and mortality is defined as additional cancer risk above and beyond baseline cancer risk.

Statistical Analysis

Data were analyzed using IBM SPSS version 25 (IBM Corporation, Armonk, New York, USA). The Kolmogorov-Smirnov Test was used to determine the normality of the estimated effective dose. The quantitative variables were expressed as a mean ± standard deviation. Pearson (r) was computed to assess the correlation of the estimate of the LAR of cancer incidence and effective dose. A value of $p < 0.05$ was considered statistically significant.



ImPACT CT Patient Dosimetry Calculator
Version 1.0.4 27/05/2011

Scanner Model:		
Manufacturer:		
Scanner:		
kV:		
Scan Region:		
Data Set	MCSET15	Update Data Set
Current Data	MCSET15	
Scan range		
Start Position	43.5 cm	Get From Phantom Diagram
End Position	68 cm	
Organ weighting scheme		

Acquisition Parameters:			
Tube current		245	mA
Rotation time		0.33	s
Spiral pitch		0.2	
mAs / Rotation		80.85	mAs
Effective mAs		404.25	mAs
Collimation			mm
Rel. CTDI	Look up	1.36	at selected collimation
CTDI (air)	Look up	23.1	mGy/100mAs
CTDI (soft tissue)		24.7	mGy/100mAs
$_nCTDI_w$	Look up	7.6	mGy/100mAs

$CTDI_w$	6.2	mGy
$CTDI_{vol}$	30.8	mGy
DLP	754	mGy.cm

Organ	w_T	H_T (mGy)	$w_T.H_T$
Gonads	0.08	0.037	0.003
Bone Marrow	0.12	11	1.4
Colon	0.12	0.2	0.024
Lung	0.12	44	5.2
Stomach	0.12	3.8	0.45
Bladder	0.04	0.014	0.00056
Breast	0.12	39	4.7
Liver	0.04	5.7	0.23
Oesophagus (Thymus)	0.04	52	2.1
Thyroid	0.04	6.1	0.24
Skin	0.01	8.3	0.083
Bone Surface	0.01	23	0.23
Brain	0.01	0.27	0.0027
Salivary Glands (Brain)	0.01	0.27	0.0027
Remainder	0.12	11	1.3
Not Applicable	0	0	0
		Total Effective Dose (mSv)	16

Remainder Organs	H_T (mGy)
Adrenals	7.1
Small Intestine	0.23
Kidney	1.4
Pancreas	5.4
Spleen	4.4
Thymus	52
Uterus / Prostate (Bladder)	0.034
Muscle	8.4
Gall Bladder	1.8
Heart	41
ET region (Thyroid)	6.1
Lymph nodes (Muscle)	8.4
Oral mucosa (Brain)	0.27
Other organs of interest	**H_T (mGy)**
Eye lenses	0.49
Testes	0
Ovaries	0.075
Uterus	0.055
Prostate	0.014

Figure 2. An overview of the imPACT CT dosimetry spreadsheet

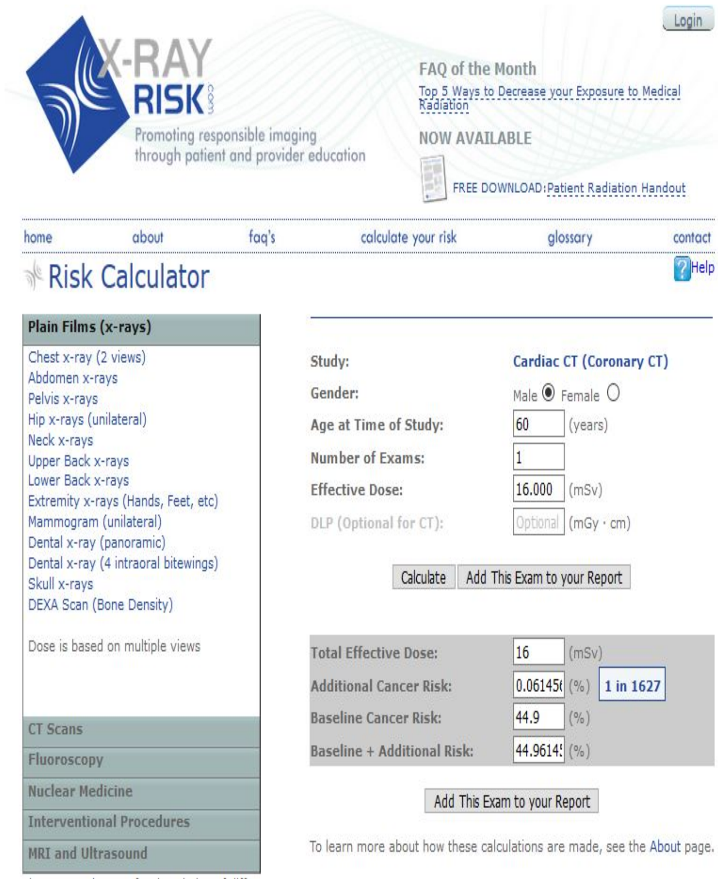


Figure 3. The website X-ray risk Calculator

Table 1. Image acquisition parameters.

Parameters	Gender	N	Minimum	Maximum	Mean	Std. Deviation
mA	Male	62	178	320	240.66	41.073
	Female	40	178	280	227.85	32.596
	All	102	178	320	235.64	38.323
Acquisition Time	Male	62	11	12.5	11.56	0.524
	Female	40	11	12.5	11.83	0.583
	All	102	11	12.5	11.67	0.560
CTDIw	Male	62	4.5	8	6.01	1.042
	Female	40	4.5	7	5.75	0.844
	All	102	4.5	8	5.91	0.974
CTDIvol (mGy)	Male	62	22.60	40.20	30.09	5.189
	Female	40	22.60	34.80	28.76	4.156
	All	102	22.60	40.20	29.57	4.829
DLP (mGy*cm)	Male	62	554	985	737.34	126.535
	Female	40	554	852	704.55	101.202
	All	102	554	985	724.48	117.829

Table 2. Effective and organ doses estimations during CABG CTA procedure

Organ	Gender	N	Minimum	Maximum	Mean	Std. Deviation
Gonads	Male	62	0.0022	0.0039	0.0029	0.0005
	Female	40	0.0022	0.0034	0.0028	0.0004
	All	102	0.0022	0.0039	0.0029	0.0005
Bone marrow	Male	62	1.00	1.80	1.35	0.236
	Female	40	1.00	1.60	1.30	0.209
	All	102	1.00	1.80	1.33	0.226
Colon	Male	62	0.018	0.031	0.0237	0.0040
	Female	40	0.018	0.027	0.0226	0.0032
	All	102	0.018	0.031	0.0233	0.0037
Lung	Male	62	3.90	6.90	5.1323	0.8809
	Female	40	3.90	5.90	4.9000	0.6921
	All	102	3.90	6.90	5.0412	0.8165
Stomach	Male	62	0.33	0.59	0.4427	0.07629
	Female	40	0.33	0.51	0.4228	0.06093
	All	102	0.33	0.59	0.4349	0.07103
Bladder	Male	62	0.00041	0.00073	0.00054	0.00009
	Female	40	0.00041	0.00063	0.00052	0.00008
	All	102	0.00041	0.00073	0.00053	0.00009
Breast	Male	62	3.40	5.30	4.37	0.652
	Female	40	3.40	6.10	4.57	0.806
	All	102	3.40	6.10	4.49	0.753
Liver	Male	62	0.17	0.30	0.22	0.038
	Female	40	0.17	0.26	0.21	0.030
	All	102	0.17	0.30	0.22	0.035

RESULTS

Demographic Characteristics

Gender distribution in the CABG patients showed that there were 62 (60.8%) male and 40 (39.2%) female. The age of patients ranged from 45 to 75 years (mean ± SD = 60.1 ± 7.56).

Image Acquisition Parameters

Standard image acquisition parameters such as tube voltage of 120 kVp, collimation 64 x 0.6 mm, pitch 0.2 and gantry rotation time 0.33 s were constant for all CABG patients. Image acquisition parameters that were varied according to the patient's status are summarized in **Table 1**. These include: tube current, acquisition time, CTDIw, CTDIvol, and DLP.

Correlation between mA, Acquisition Time and DLP (mGy*cm)

The Pearson Correlation (r) shows a statistically significant, strong, positive correlation between mA and DLP (mGy*cm) (r = 0.989). Moreover, the Pearson Correlation (r) shows a statistically significant, moderate, positive correlation between acquisition time and DLP (mGy*cm) (r = 0.621).

Effective and Organ Dose Estimations During CABG CTA Procedure

The organ equivalent dose (mSv) is estimated by the imPACT CT Dosimetry spreadsheet and given by wT.HT, where (wT) indicates tissue weighting factors given in ICRP publication 103 and (HT) is the absorbed radiation dose to the organ (mGy). The Total Effective Dose (mSv) associated with the CABG procedure ranged from 12 mSv to 21 mSv (mean ± SD = 15.35±2.428). The highest organ doses were those to the lungs (mean weighted equivalent dose 5.04 ± 0.82 (3.9-6.9) mSv) and breast (mean 4.49 ± 0.75 (3.4-6.1) mSv). These were followed by the esophagus (2.0 ± 0.35 (1.5-2.7) mSv), bone marrow (1.33± 0.23 (1-1.8) mSv), and stomach (0.44 ± 0.07 (0.33-0.59) mSv) as shown in **Table 2**.

Table 2 (continued). Effective and organ doses estimations during CABG CTA procedure

Organ	Gender	N	Minimum	Maximum	Mean	Std. Deviation
Esophagus	Male	62	1.50	2.70	2.04	0.368
	Female	40	1.50	2.40	1.94	0.302
	All	102	1.5	2.70	2.00	0.345
Thyroid	Male	62	0.18	0.32	0.237	0.041
	Female	40	0.18	0.27	0.226	0.032
	All	102	0.18	0.32	0.233	0.038
Skin	Male	62	0.061	0.110	0.081	0.015
	Female	40	0.061	0.093	0.077	0.011
	All	102	0.061	0.110	0.080	0.013
Bone surface	Male	62	0.17	0.31	0.230	0.041
	Female	40	0.17	0.27	0.220	0.033
	All	102	0.17	0.31	0.226	0.038
Brain	Male	62	0.0020	0.0035	0.0027	0.0005
	Female	40	0.0020	0.0031	0.0026	0.0004
	All	102	0.0020	0.0035	0.0026	0.0004
Salivary gland	Male	62	0.0020	0.0035	0.0027	0.0005
	Female	40	0.0020	0.0031	0.0026	0.0004
	All	102	0.0020	0.0035	0.0026	0.0004
***Remainder Organs**	Male	62	0.93	1.70	1.227	0.214
	Female	40	0.93	1.40	1.168	0.162
	All	102	0.93	1.70	1.203	0.197
Total Effective Dose (mSv)	Male	62	12	21	15.61	2.607
	Female	40	12	18	14.95	2.087
	All	102	12	21	15.35	2.428

*Remainder Organs: Adrenals, Small Intestine, Kidney, Pancreas, Spleen, Gall Bladder, Thymus, Muscle, Heart, Lymph nodes, Oral mucosa, Eye lenses, Uterus, Ovaries, Prostate and Testes

Table 3. Comparison of LAR of cancer for male and female patients regarding age group

Age group	Gender	LAR of cancer			
		N=102	Mean (%)	Std. Deviation	(1 in)
45y to 55y	Male	22	0.000713	0.0001125	1447 Male
	Female	12	0.000926	0.0001799	1114 Female
56y to 65y	Male	22	0.000624	0.0001205	1658 Male
	Female	18	0.000749	0.0001078	1362 Female
66y to 75y	Male	18	0.000476	0.0009405	2181 Male
	Female	10	0.000496	0.0008718	2073 Female
All Age groups	Male	62	0.000613	0.000146	1762 Male
	Female	40	0.000739	0.000205	1516 Female
	All	102	0.000662	0.000183	1639 Patient

Comparison of LAR of Cancer for Male and Female Patients Regarding Age Group

The Pearson Correlation (r) shows a statistically significant negative correlation between age and LAR (r = 0.718). The average value of LAR of cancer for all CABG patients is 1 in 1639 patients who underwent CABG CTA. The cancer risk is higher for female patients (1 in 1516 females who underwent CABG CTA) than male patients (1 in 1762 males who underwent CABG CTA). The LAR of cancer is higher for the younger age group in both males and females as shown in **Table 3**.

DISCUSSION

Despite the great medical benefits derived from advances in MDCT, the increased radiation dose presents a potential future cancer risk. Requests for CCTA examinations have increased. However, medical staffs may not have adequate knowledge of the risks of the ionizing radiation used in these procedures. CABG CTA examinations have risks potentially greater than CCTA due to an increased scan range. Risk of cancer incidence and mortality from ionizing radiation are appropriately expressed in terms of LAR values. In general, the use of radiation doses as low as reasonably achievable consistent with acceptable image quality remains the most significant strategy for diminishing this potential risk.

Previously published estimations of organ dose were often carried out using a specific scan parameter such as a limited range of tube current, heart rate, or a specific range of patient ages. In the current study, as described in Materials and Methods, the calculation of organ dose in the ImPACT CT was based on CTDIvol, so that the effect of all relevant variables, such as the tube current, pitch factor, automatic exposure control (AEC) and heart rate have been considered [22,23].

Although some scan parameters were fixed (120 kVp, collimation 64 x 0.6 mm, pitch 0.2 and gantry rotation time 0.33), the variable scan parameters (mA, Acquisition Time) contribute directly to the CTDIvol (mGy) and the DLP (mGy*cm), from which the ED is computed. This approach is consistent with Sun and Ng [24], who recommended the assessment of radiation exposure of CCTA by use of DLP (mGy*cm) and CTDIvol (mGy). An increase in the scan range of 1 cm was associated with an increase in the DLP of approximately 5%, and thus corresponding increases in the ED and LAR [25]. In patients undergoing CABG CTA, the larger scan range increased the organ dose and ED. In the current study, the ED for CABG CTA was 15.35 ± 2.428 mSv, which was lower than the 16.42 mSv in a recent study conducted by Hosseini Nasab et al. [19].

Cancer risk due to radiation exposure from a single cardiac imaging test depends on age (higher risk with younger age at exposure) and sex (greater for women) [14,24,25]. Consequently, an optimal strategy is to perform CCTA with the lowest possible exposure to radiation [26]. A study reported by Coles et al. [27] revealed that radiation dose and attendant risk associated with CCTA versus selective diagnostic coronary angiography in the same patients were 14 mSv and 6 mSv, respectively. In disagreement with our results, Hirai et al [28] reported higher retrospectively ECG-gated CCTA doses (21 mSv for males and 18 mSv for females). Huang et al [29] reported even higher doses (27.7 for males and 23.6 for females). A study conducted by Einstein et al. [30] on CCTA examination performed with a 16-slice MDCT revealed that the mean risk of death from cancer was approximately 1 in 1900. Another study conducted by Einstein et al. [25] on CCTA performed with a 64-slice MDCT revealed that the mean risk of death from cancer varied from 1 in 143 for a 20-year-old woman to 1 in 3261 for an 80-year-old man. It is estimated that effective doses of CCTA may reach as high as 30 mSv if no dose-saving strategy is applied, thus, increasing the potential risk of associated radiation-induced malignancy [31].

The LAR of cancer incidence and mortality in adult patients for all cancers is greater in females than in males (1:1516 female vs. 1:1762 male). Further, the LAR of cancer incidence and mortality decreases with age ($r = 0.718$, $P < 0.001$), consistent with established relationships between radiosensitivity and age [21]. A study by Faletra et al. [32] reported ranges from approximately 1:300 to 1:1800 for exposure from retrospective ECG-gating CCTA. Therefore, CCTA should be used particularly cautiously for females in cardiac disease evaluation [25].

To put the dose estimates in a context that patients and physicians can readily understand, the ED for CABG CTA was compared with the effective doses for the two most common conventional radiology studies: a frontal and lateral chest radiography series (ED of 0.1 mSv and equal to 10 days natural background radiation); and a screening mammography series (including 2 views of each breast, ED of 0.42 mSv and equal to 7 weeks natural background radiation) [14]. Our comparison of organ-specific doses demonstrated that CABG CTA delivers a dose to the lung that is approximately equivalent to 51 chest radiography series and 72 weeks natural background radiation (5.04 mSv lung dose for CABG CTA vs 0.10 mSv lung dose for a frontal and lateral chest radiograph). The dose to the breast is equivalent to approximately 11 mammography studies and 77 weeks natural background radiation (4.57 mSv female breast dose for CABG CTA vs 0.42 mSv breast dose for a mammography series). Concerning the total whole-body ED (15.35 mSv), CABG CTA is equivalent to 154 chest radiography series and 37 mammography studies, corresponding to approximately 4.3 and 5-years natural background radiation, respectively.

There are limitations in the estimation of doses and cancer risks in this study. Our results may be underestimations, because doses simulated using ImPACT have been reported by Groves et al. to be about 15% lower than those measured by using thermoluminescent detectors directly [33]. This underestimation has been attributed to differences between the phantoms used in creating ImPACT and those used in the work of Groves et al. Because the ImPACT results are used to determine organ doses for a standard-size person, differences in patient size and tissue composition can result in inconsistencies in the organ dose estimation. There are limitations in calculating the LAR of cancer incidence insofar as LARs were calculated based on the ED from the CABG CTA protocols used in our clinic. Hence there may be some variation in risks, depending on the protocols used across centers and in different countries. Even with these variations, the ED simulated using ImPACT are robust and have been reported widely in the literature [5,19,29,34-37].

CONCLUSION

Organs receive a significant radiation dose during CABG CTA procedures, thereby motivating the use of rigorous justification criteria and protocol optimization. Furthermore, CABG CTA is associated with a nonnegligible LAR of cancer. This risk varies markedly and is significantly greater for women and younger patients. Knowledge of ED and LAR helps to improve medical staff awareness of radiation exposure consequences and contributes to keeping the patient radiation dose as low as reasonably achievable. A national survey is highly recommended to establish a national diagnostic reference level for all CT examinations.

ABBREVIATIONS

CABG CTA: Coronary Artery Bypass Graft Computed Tomography Angiography

CCTA: Coronary Computed Tomographic Angiography

CTDIvol: Volume Computed Tomography Dose Index

DLP: Dose Length Product

ED: Effective Dose

LAR: Lifetime Attributable Risk

MDCT: Multidetector Computed Tomography

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Ethical statement: Ethical approval for this study was obtained from the Helsinki Committee, Gaza strip-Palestine.

Declaration of interest: The authors declared no conflict of interest concerning the research, authorship, and publication of this article.

REFERENCES

1. Wall BF. Ionising radiation exposure of the population of the United States: NCRP report No. 160. Radiat. Prot. Dosim 2009;136(2):136-8. https://doi.org/10.1093/rpd/ncp162
2. Raman SP, Johnson PT, Deshmukh S, Mahesh M, Grant KL, Fishman EK. CT dose reduction applications: Available tools on the latest generation of CT scanners. J. Am. Coll. Radiol 2013;10(1):37-41. https://doi.org/10.1016/j.jacr.2012.06.025 PMid:23290672
3. Valentin J. Managing patient dose in multi-detector computed tomography (MDCT). ICRP Publication 102. Ann ICRP 2007;37(1):1-79.

4. Brenner DJ, Hall EJ. Computed tomography-An increasing source of radiation exposure. N. Engl. J. Med 2007;357(22):2277-84. https://doi.org/10.1056/nejmra072149 PMid:18046031
5. Nickoloff EL, Alderson PO. A comparative study of thoracic radiation doses from 64-slice cardiac CT. Br. J. Radiol 2007;80(955):537-44. https://doi.org/10.1259/bjr/34603706 PMid:17704315
6. Johnson JN, Hornik CP, Li JS, et al. Cumulative radiation exposure and cancer risk estimation in children with heart disease. Circulation 2014;130(2):161-7. https://doi.org/10.1161/CIRCULATIONAHA.113.005425 PMid:24914037 PMCid:PMC4103421
7. Kim HY, Choi JH. How to utilize coronary computed tomography angiography in the treatment of coronary artery disease. J. Cardiovasc. Ultrasound 2015;23(4):204-8. https://doi.org/10.4250/jcu.2015.23.4.204 PMid:26755927 PMCid:PMC4707304
8. Barbero U, Iannaccone M, d'Ascenzo F, et al. 64 Slice-coronary computed tomography sensitivity and specificity in the evaluation of coronary artery bypass graft stenosis: A meta-analysis. Int. J. Cardiol 2016; 216:52-7. https://doi.org/10.1016/j.ijcard.2016.04.156 PMid:27140337
9. Eisenberg C, Hulten E, Bittencourt MS, Blankstein R. Use of CT angiography among patients with prior coronary artery bypass grafting surgery. Cardiovasc. Diagn. Ther 2017;7(1):102-5. https://doi.org/10.21037/cdt.2016.11.08 PMid:28164019 PMCid:PMC5253442
10. Di Lazzaro D, Crusco F. CT angio for the evaluation of graft patency. J. Thorac. Dis 2017;9(S4):S283-S288. https://doi.org/10.21037/jtd.2017.03.111 PMid:28540071 PMCid:PMC5422671
11. Wiest PW, Locken JA, Heintz PH, Mettler F. CT scanning: A major source of radiation exposure. Semin. Ultrasound CT MR 2002;23(5):402-10. https://doi.org/10.1016/S0887-2171(02)90011-9
12. Hausleiter J, Meyer T, Hadamitzky M, et al. Radiation dose estimates from cardiac multislice computed tomography in daily practice. Circulation 2006;113(10):1305-10. https://doi.org/10.1161/CIRCULATIONAHA.105.602490 PMid:16520411
13. Hunold P, Vogt FM, Schmermund A, et al. Radiation exposure during cardiac CT: Effective doses at multi–detector row CT and electron-beam CT. Radiology 2003; 226(1):145-52. https://doi.org/10.1148/radiol.2261011365 PMid:12511683
14. Smith-Bindman R, Lipson J, Marcus R, et al. Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. Arch. Intern. Med 2009;169(22):2078-86. https://doi.org/10.1001/archinternmed.2009.427 PMid:20008690 PMCid:PMC4635397
15. Van der Molen AJ, Schilham A, Stoop P, Prokop M, Geleijns J. A national survey on radiation dose in CT in The Netherlands. Insights into Imaging 2013;4(3):383-90. https://doi.org/10.1007/s13244-013-0253-9 PMid:23673455 PMCid:PMC3675255
16. Streffer C. The ICRP 2007 recommendations. Radiat. Prot. Dosim 2007;127(1-4):2-7. https://doi.org/10.1093/rpd/ncm246 PMid:17933786
17. McCollough CH, Christner JA, Kofler JM. How effective is effective dose as a predictor of radiation risk? AJR Am. J. Roentgenol 2010;194(4):890-6. https://doi.org/10.2214/AJR.09.4179 PMid:20308487
18. Pradhan AS, Kim JL, Lee JI. On the use of "effective dose" (E) in medical exposures. J. Med. Phys 2012;37(2):63-5. https://doi.org/10.4103/0971-6203.94739 PMid:22557794 PMCid:PMC3339144
19. Hosseini Nasab SMB, Deevband MR, Shabestani-Monfared A, Amoli SAH, Feyzabad SHF. Organ equivalent dose and lifetime attributable risk of cancer incidence and mortality associated with cardiac CT angiography. Radiat. Prot. Dosim 2020;189(2):213-23. https://doi.org/10.1093/rpd/ncaa033 PMid:32195547
20. Mansour HH, Alajerami YS, Najim AA. Coronary computed tomography angiography versus invasive coronary angiography: medical staff perceptions and diagnostic interest in Gaza-Palestine. Ir J Med Sci. 2021;190(2):567-75. https://doi.org/10.1007/s11845-020-02376-3 PMid:32978639
21. Council NR. Health risks from exposure to low levels of ionizing radiation: BEIR VII Phase 2. (National Academies Press) (2006).
22. Brenner DJ, Elliston CD, Hall EJ, Berdon WE. Estimated risks of radiation-induced fatal cancer from pediatric CT. AJR Am. J. Roentgenol 2001;176(2):289-96. https://doi.org/10.2214/ajr.176.2.1760289 PMid:11159059
23. Huda W, Schoepf UJ, Abro JA, Mah E, Costello P. Radiation-related cancer risks in a clinical patient population undergoing cardiac CT. AJR Am. J. Roentgenol 2011;196(2):W159-W165. https://doi.org/10.2214/ajr.10.4981 PMid:21257857
24. Sun Z, Ng K. Prospective versus retrospective ECG-gated multislice CT coronary angiography: A systematic review of radiation dose and diagnostic accuracy. Eur. J. Radiol 2012;81(2):e94-e100. https://doi.org/10.1016/j.ejrad.2011.01.070 PMid:21316887
25. Einstein AJ, Henzlova MJ, Rajagopalan S. Estimating risk of cancer associated with radiation exposure from 64-Slice computed tomography coronary angiography. JAMA 2007;298(3):317-23. https://doi.org/10.1001/jama.298.3.317 PMid:17635892
26. Neglia D, Rovai D, Caselli C, et al. Detection of significant coronary artery disease by noninvasive anatomical and functional imaging. Circulation 2015;8(3):1-10. https://doi.org/10.1161/circimaging.114.002179 PMid:25711274
27. Coles DR, Smail MA, Negus IS, et al. Comparison of radiation doses from Multislice computed tomography coronary angiography and conventional diagnostic angiography. J. Am. Coll. Cardiol 2006;47(9):1840-5. https://doi.org/10.1016/j.jacc.2005.11.078 PMid:16682310
28. Hirai N, Horiguchi J, Fujioka C, et al. Prospective versus retrospective ECG-gated 64-Detector coronary CT angiography: Assessment of image quality, stenosis, and radiation dose. Radiology 2008;248(2):424-30. https://doi.org/10.1148/radiol.2482071804 PMid:18574140
29. Huang B, Li J, Law MW, Zhang J, Shen Y, Khong PL. Radiation dose and cancer risk in retrospectively and prospectively ECG-gated coronary angiography using 64-slice multidetector CT. Br. J. Radiol 2010;83(986):152-8. https://doi.org/10.1259/bjr/29879495 PMid:20139263 PMCid:PMC3473541

30. Einstein A, Sanz J, Dellegrottaglie S, et al. Radiation dose and cancer risk estimates in 16-slice computed tomography coronary angiography. J. Nucl. Cardiol 2008;15(2):232-40. https://doi.org/10.1016/j.nuclcard.2007.09.028 PMid:18371595 PMCid:PMC2397551
31. Xu L, Zhang Z. Coronary CT angiography with low radiation dose. Int. J. Cardiovasc. Image 2010;26(S1):17-25. https://doi.org/10.1007/s10554-009-9576-5 PMid:20058080
32. Faletra FF, D'Angeli I, Klersy C, et al. Estimates of lifetime attributable risk of cancer after a single radiation exposure from 64-slice computed tomographic coronary angiography. Heart 2010;96(12):927-32. https://doi.org/10.1136/hrt.2009.186973 PMid:20538668
33. Groves AM, Owen KE, Courtney HM, et al. 16-detector multislice CT: Dosimetry estimation by TLD measurement compared with Monte Carlo simulation. Br. J. Radiol 2004;77(920):662-5. https://doi.org/10.1259/bjr/48307881 PMid:15326044
34. Brenner DJ. Radiation risks potentially associated with low-dose CT screening of adult smokers for lung cancer. Radiology 2004;231(2):440-5. https://doi.org/10.1148/radiol.2312030880 PMid:15128988
35. Sawyer LJ, Starritt HC, Hiscock SC, Evans MJ. Effective doses to patients from CT acquisitions on the GE Infinia Hawkeye: A comparison of calculation methods. Nucl. Med. Commun 2008;29(2):144-9. https://doi.org/10.1097/mnm.0b013e3282f258ef PMid:18094636
36. Myronakis M, Perisinakis K, Tzedakis A, Gourtsoyianni S, Damilakis J. Evaluation of a patient-specific Monte Carlo software for CT dosimetry. Radiat. Prot. Dosim 2009;133(4):248-55. https://doi.org/10.1093/rpd/ncp051 PMid:19329513
37. Kim KP, Lee J, Bolch WE. CT dosimetry computer codes: Their influence on radiation dose estimates and the necessity for their revision under new ICRP radiation protection standards. Radiat. Prot. Dosim 2011;146(1-3):252-5. https://doi.org/10.1093/rpd/ncr163 PMid:21515617