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

Husam H Mansour 1,2*, Yasser S Alajerami 2, Thomas Foster 3

1 Radiology Department, Al-Shifa Hospital, Gaza, PALESTINE  
2 Medical Imaging Department, Al-Azhar University, PALESTINE  
3 Department of Imaging Sciences, University of Rochester, Rochester, NY, USA  
*Corresponding Author: husam-rt2007@hotmail.com

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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 (CTDvol), 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 data sets produced in report SR250 (Health Protection Agency Centre for Radiation, Chemical and Environmental Hazards, Didcot, UK). SR250 provides normalized organ dosimetry 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 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 (CTDvol), 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 (CTDvol), 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.
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          |
| CTDlw (mGy)      | Male     | 62 | 4.5     | 7       | 5.75    | 0.844          |
|                  | Female   | 40 | 4.5     | 8       | 5.91    | 0.974          |
|                  | All      | 102| 4.5     | 8       | 5.91    | 0.974          |
| CTDIvol (mGy)    | Male     | 62 | 22.60   | 40.20   | 28.76   | 4.156          |
|                  | Female   | 40 | 22.60   | 40.20   | 29.57   | 4.829          |
|                  | 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   | 0.0006         |
| 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      | 1.60      | 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   | 0.00073   | 0.00052  | 0.00008        |
|                  | All      | 102| 0.00041   | 0.00073   | 0.00053  | 0.00009        |
| Breast           | Male     | 62 | 3.40      | 5.30      | 4.37     | 0.625          |
|                  | 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 (HT) 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.
appropriately expressed in terms of LAR values. In general, the cancer incidence and mortality from ionizing radiation are greater than CCTA due to an increased scan range. Risk of procedures. CABG CTA examinations have risks potentially increased. However, medical staffs may not have adequate knowledge of the risks of the ionizing radiation used in these procedures. The LAR of cancer is higher for the younger age group in both males and females as shown in Table 3.

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 carried out using a specific scan parameter such as a limited 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 CTA 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 Tomography 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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