Estimation of Patients Effective Dose with respect to BMI using Monte Carlo Simulation method for CT Coronary Angiography Patients

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Abstract:

The identification of coronary artery diseases has been greatly helped by computed tomography (CT) images of the coronary angiography. The patient is exposed to significantly more radiation during this radiological test than during previous similar ones. The purpose of this study was to evaluate the effective dosage for computed tomography (CT) coronary angiography and optimise the radiation dose. 380 patients with coronary artery abnormalities were referred to the Primus Diagnostic Centre and Health City Hospital in Guwahati, Assam, throughout the research period. Data on the technical aspects of CT procedures were collected in 2022. Our study's aim was to estimate the organ and surface dose to a single radiosensitive organ (the chest) using the programme imPACT 1.0.4 and the SR250 Monte Carlo dataset from the National Radiological Protection Board (NRPB). The study's 380 subjects, who ranged in age from 29 to 75, comprised 190 men and 190 women. BMI and ED had corresponding Mean SD values of 22.42±1.06 and 21.57±4.27. The mean ED is 21.57 and the mean DLP is 854.67. Males (13-27) and females (13-29) received the same effective dosages of mSv. Because other nations have previously started with more advanced CT procedures including dosages for paediatrics, coronary angiography, and CT fluoroscopy, this study is truly a pioneer in presenting fundamental data of doses of CT examinations in Assam. With this study, there may be more opportunities to create complex new studies or enhance the data from related studies that may be done in future work. To achieve high precision with minimum risk, the current study can be considered as need of the hour.

Key words: Radiation, Computed Tomography, Effective Dose, Angiography, Monte Carlo Simulation

INTRODUCTION:

Computed tomography (CT) was first used introduced in clinical settings by G.N. in 1971. J. Hounsfield and Ambrose, who have used two consecutive axial images of a patient's head to perform the first clinical CT scan. Cormack developed a technique for calculating the distribution of x-ray attenuation inside the body and created a mathematical theory for image reconstruction a few years prior[1]. In honour of their innovation in CT, Hounsfield and Cormack won the Nobel Prize for Physiology and Medicine in 1979[2]. The technological development of this imaging modality led to new practice examinations in any part of the body such as cardiac CT, CT angiography (CTA), CT perfusion (CTP) or paediatric CT and new techniques including helical acquisitions which were performed in 1989 for the first time. The introduction of multi-slice detector CT (MDCT) systems in 1998 allowed major advances in CT imaging, resulting in a reduction of the rotation time (from several minutes to 0.5 seconds) and in an increase of the volume coverage speed. Besides, the spatial and low-contrast resolution in the CT images has significantly improved over the years[2]. Therefore, the MDCT with sub-second rotation times allows for the scanning of long ranges in shorter scan times and consequently, the capability to acquire images from organs like heart or lungs reducing the movement artifacts[3]. The dose-length product is provided by modern computed tomography (CT) scanners (DLP). The DLP is unique to CT and is not suitable for comparisons with other modalities, even though it is related to patient dose and risk. The concept of effective dose (E), expressed in terms of J/kg or Sievert (Sv), is used by the International Commission on Radiation Projection (ICRP) to assess risk [4,5]. Applications for CT imaging have recently expanded from cancer diagnosis to trauma [6]. Despite the fact that CT imaging has significantly improved healthcare, worries about the cancer risks of the X-rays used to create CT images have persisted [7,8]. Ionizing radiation can be used in medical imaging techniques like computed tomography (CT) to provide important diagnostic information that is beneficial to patient care. During 1998 and 2000, the number of CT scan procedures performed increased by about 70%. Due to their greater doses, CT scan examinations have such a significant impact on the total radiation dose that society has been subjected to, even though they are performed far less often than radiological examinations.

MATERIALS & METHODS:

This study sought to develop local DRL and assess the patient effective dose during coronary CT scans. The data for this study were given by one hospital (X) and one diagnostic facility (Y) in the Kamrup (Guwahati) district of Assam state. For this investigation, data from two CT scanners were gathered. These tools are available in two private radiological departments. All quality control tests were performed on the equipment prior to any data collection. Every set of data's information falls within a reasonable range. To ensure the accuracy of the data shown during CT scans, data were gathered using a data sheet for each patient (Appendix). A CT dosimetry unit is included with every CT machine. To assess the patient doses and the radiation-related factor, a data collecting sheet was created. Gender, age, tube potential (mA), tube current-time product settings (mAs), pitch, slice thickness, and total number of slices were among the information gathered. Additionally, all scanning parameters as well as the dose-length product (DLP) in (mSv.cm) and the CT Dose Index volume (CTDIvol) in (mSv) were recorded. The radiation dosage is directly impacted by each of these variables.

Table 1: Patient population of the study classified per hospital and type of examination

Hospital & Diagnostic Centre	Examination Types	Male Patients	Female Patients	Grand Total
X	CT Coronary Angiography	100	95	190
Y		90	95	190
				=380

The Table 1 depicts the population of the study and classification of Hospital and Diagnostic Centres of the CT Coronary Angiography Examination.

Using the ImPACT (Imaging Performance Assessment of Computed Tomography Scanners) CT Patient Dosimetry Calculator, we calculated BMI-to-E conversion factors for adult patients (version 1.0.4) [9]. Based on Monte Carlo dosage data published in the National Radiological Protection Board's report SR250, the ImPACT CT Patient Dosimetry Calculator was developed as an excel spreadsheet[10]. The ImPACT spreadsheet calculates the CT dose index (CTDI), DLP, BMI and E for a typical hermaphrodite phantom after user enters the CT scanning parameter and the start and end locations of the CT scan.

Table 2: Selection of Tube Current and pitch factors for the Coronary CT Angiography Examinations

Age Group	Pitch Factors	Tube Current
<40	>0.25	350-380
41-50	0.22-0.28	350-380
51-60	0.25-0.29	340-360
>60	0.22-0.30	350-380

Each scanner model's BMI-to-E conversion factors were computed, and then they were averaged across all scanner models. Their standard deviations and largest deviations from the mean were also calculated. Figure-1 illustrated the start and end locations of patients cardiac scans on the ImPACT spreadsheet.

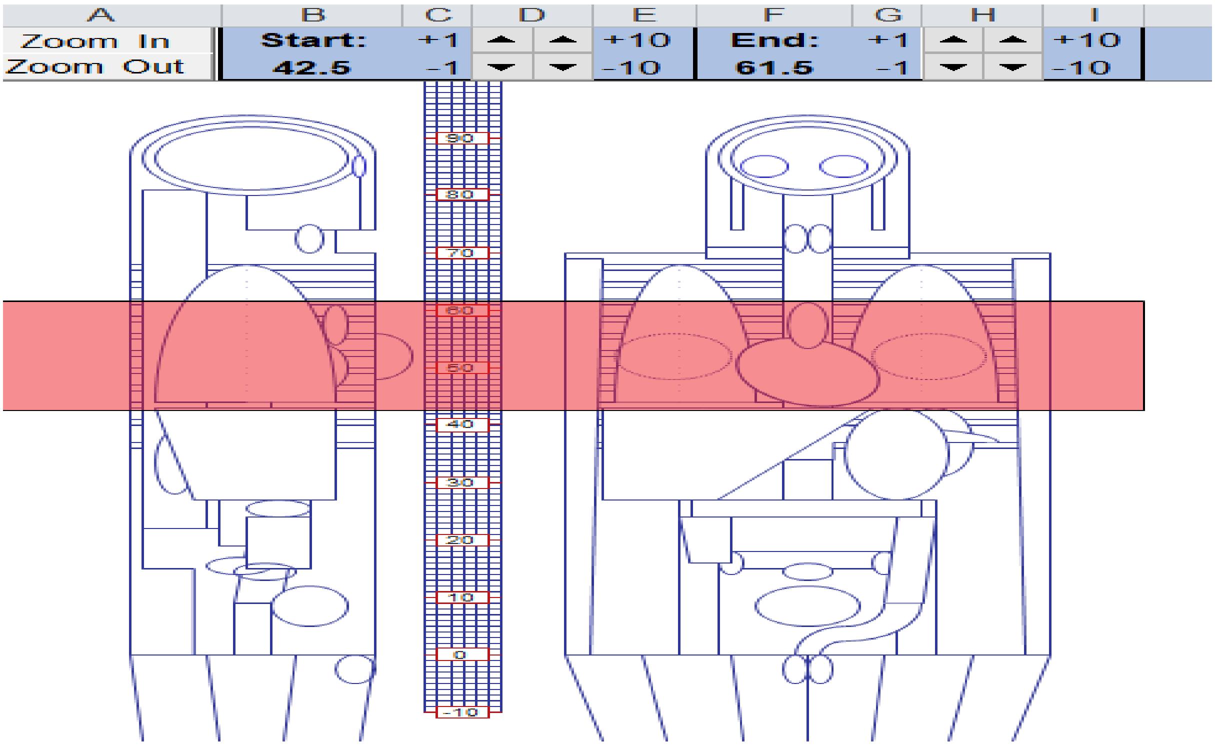

Figure-1: Imagining Performance Assessment of Computed Tomography Scanners (ImPACT). The scan range for the heart is displayed numerically by the CT Patient Dosimetry Calculator, starting at 42.5 cm and ended at 61.5 cm.

RESULTS:

The results of this study were presented for dose measurements performed in two hospitals, hospital (X) with CT scanner Siemens model Defination AS (128-slice) versus hospital (Y) with CT scanner Philips model Ingenuity (128-slice). A total of 380 CT Coronary Angiography examinations in patient doses were estimated in terms of DLP and effective dose (E).

The CTDIvol, DLP, E, and organ doses were used in this study to express doses. This was a representation of the average absorbed dose in the area being scanned (CTDIvol), the integrated absorbed dose for the entire CT scan along a perpendicular line to the radiation axis (DLP), and the effective dose.

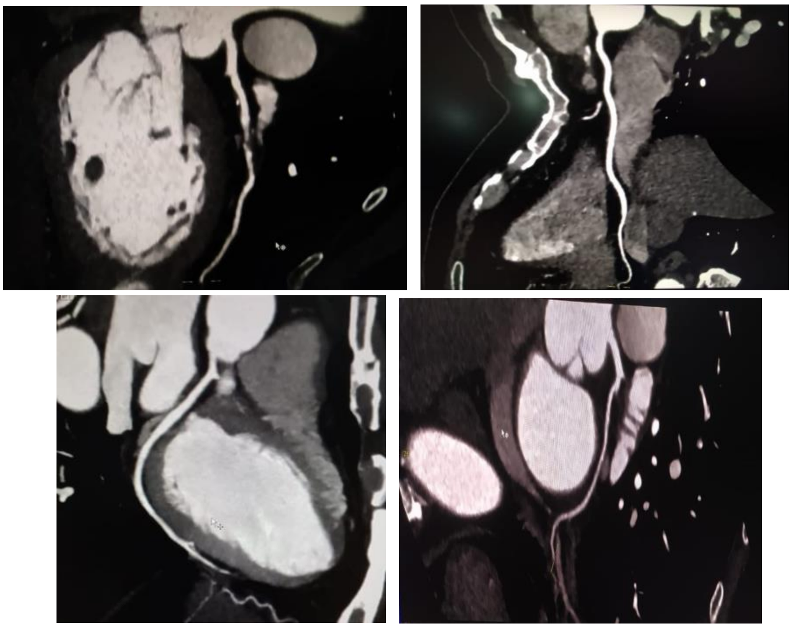

Figure-2: Reconstructed 3D CT images illustrate the coronary artery branches.

Table 3: Statistical analysis of BMI and Effective Dose(ED) in both Male and Female Contrast enhanced Coronary CT Angiography.

Parameters	Total no of Cases (N)	Mean±SD	Minimum	Median	Maximum
BMI	380	22.423±1.059	19.68	22.42	24
Effective Dose		21.573±4.267	12.73	22.12	29.74

The data presented in the Table 3 shows that the statistical analyzing data of 380 patient's correlation in BMI and Effective Dose for Contrast CT Coronary Angiography. The mean values of BMI and Effective Dose were 22.423 and 21.573 respectively. The standard deviations of BMI and Effective Dose were found to be 1.059 and 4.267 with median values of 22.42 and 22.12 respectively.

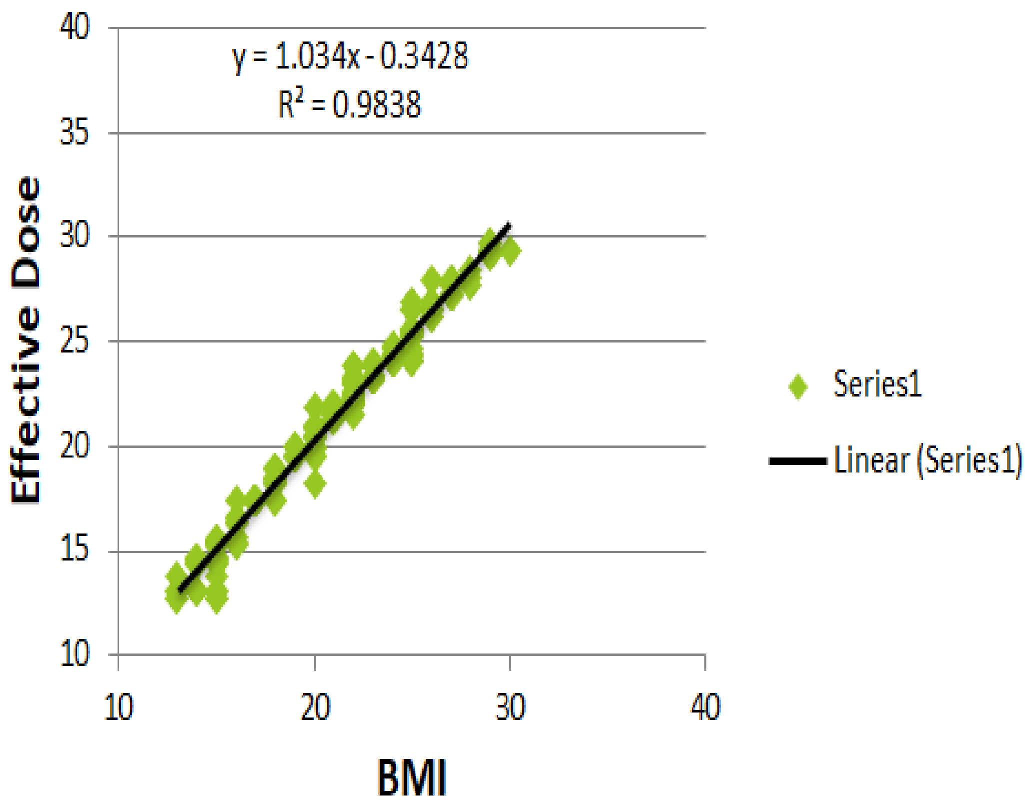

Figure-3: Correlation between BMI and Effective Dose in both sexes of Contrast Enhanced Coronary CT Angiography.

The above graph (Figure-3) shows the relation between BMI and effective dose. There was highly significant correlation between BMI and Effective dose and the values were found to be linear. The Pearson's r value is 0.09838 and the equation of the graph is **Y=1.034X-0.3428**.

Tables 1 presented parameters for the different CT systems for two hospitals (X) and (Y) respectively. The results showed that the two hospitals used the same kVp (120 kv), different mAs (100-150 approximately) and different pitch (0.25 to 1). Accordingly Table 3 presented the estimation of (mean, median, std, min and max) and BMI, E calculated by software imPACT 1.0.4 using data collection from CT scanner Siemens Somatom Defination AS(128 slice) model and Philips Ingenuity(128 slice). The 380 cardiac angiography cases of CT scan where both male and female patients are representing with different age groups.

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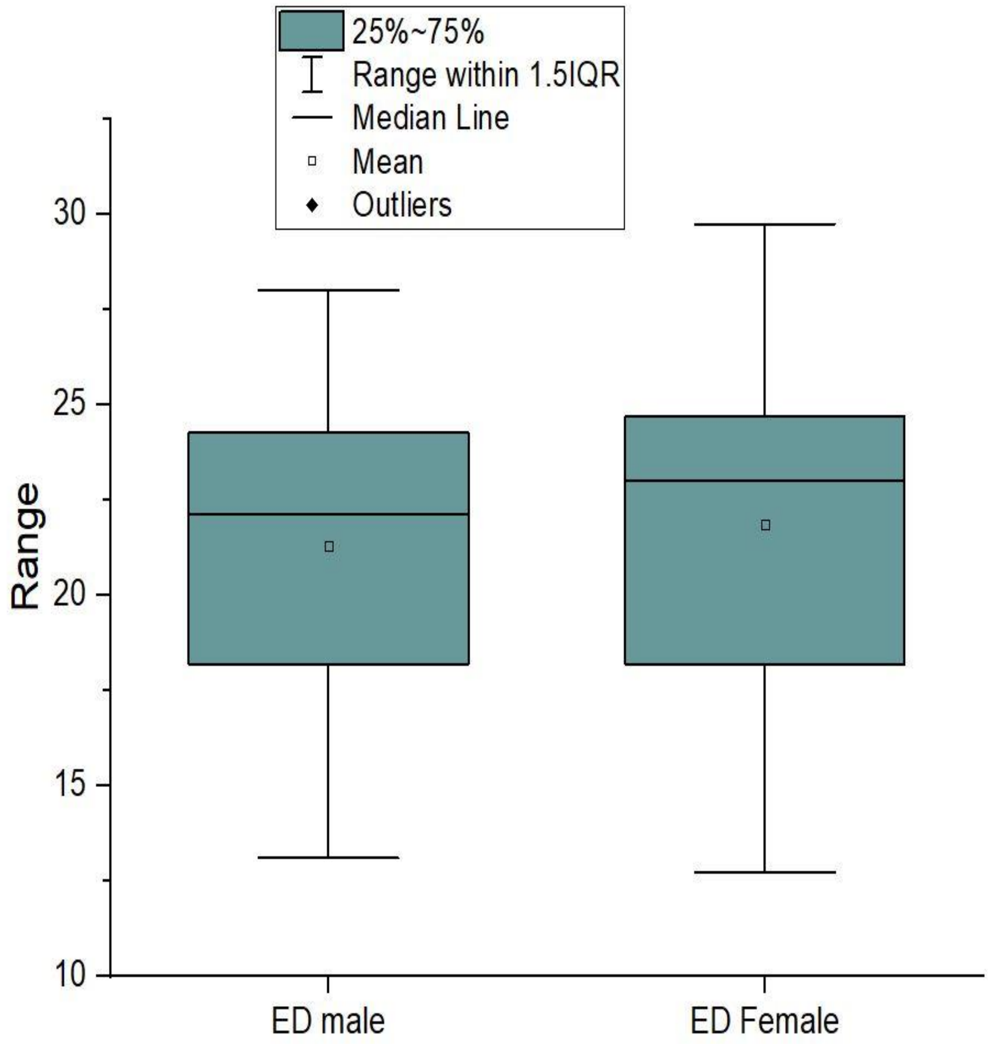

Figure-4: Shows the graphical representation of effective dose for both male and female Contrast Enhanced CT Coronary Angiography patients.

The above graph (Figure-4) shows the Effective Dose range of Male and Female patients undergo Contrast CT Coronary Angiography Study. The average effective dose range for male was approximately 13 to 27 mSv whereas total Effective dose coverage in female was more than male in the study (Approximately 13-29).

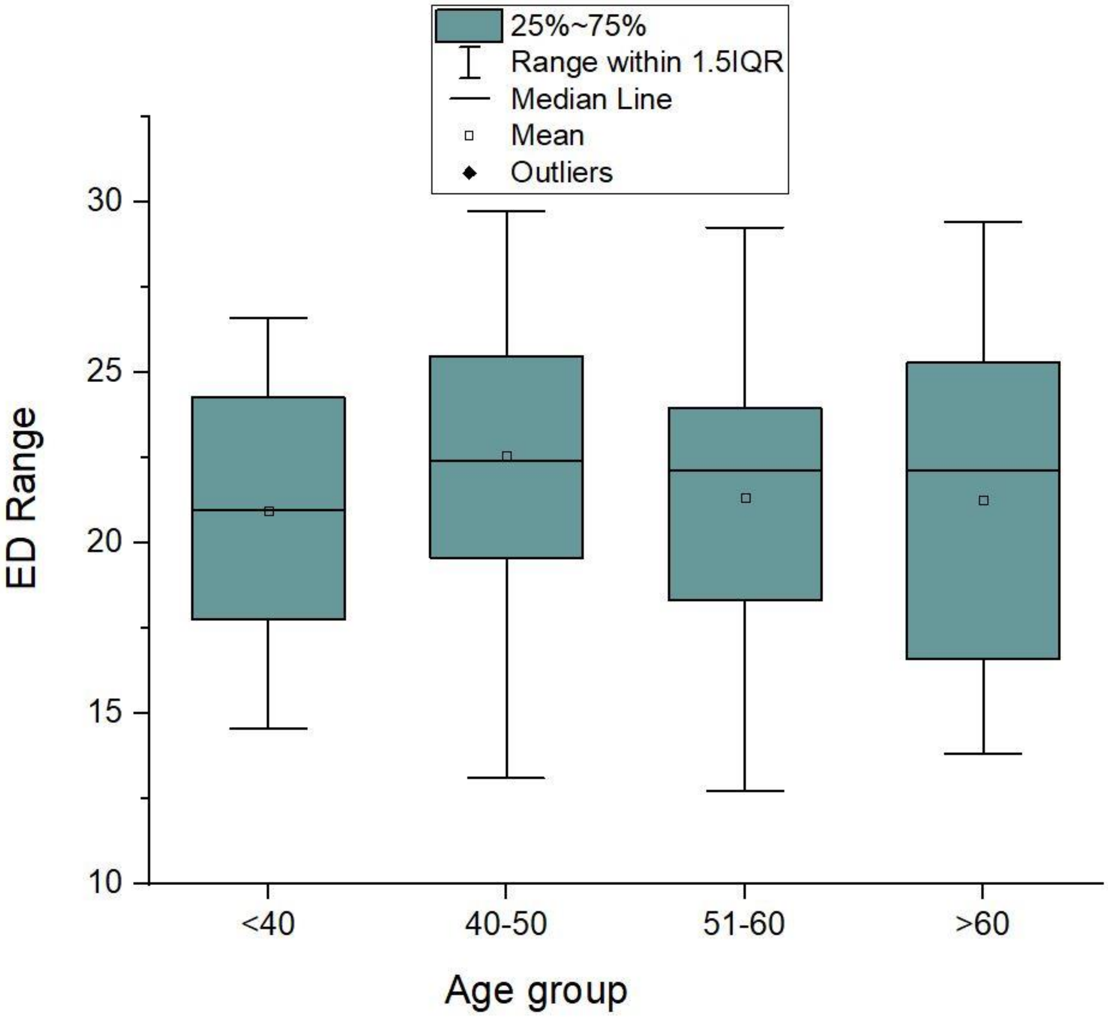

Figure-5: Shows the graphical representation of effective dose in both Male and Female Contrast Enhanced CT Coronary Angiography with respect to age variations.

The above graph (Figure-5) depicts the Effective Dose range of Male and Female patients undergo Contrast CT Coronary Angiography Study. The average effective dose ranges for both male and female were found to be significantly increasing with an age of 40 to 50 years and similarly it decreases with increase in ages.

DISCUSSION:

The spiral mode is used for typical cardiac CT exams with retrospective ECG gating. Effective dosages up to 21 mSv have been recorded without the use of ECG-based tube current regulation [11]. Using ECG-based tube current regulation reduced the mean effective dosage for 64-slice CT coronary angiography from 15 mSv to 9 mSv [12]. Recent research using ECG-based tube current modulation and dual-source CT coronary angiography had revealed radiation dose values ranging from 7 to 9 mSv [13]. In our study when we represent the effective dose graphically for the two hospitals, we found that the effective doses for males (13-27) mSv were lower than females (13-29) mSv. This difference of effective doses for males and females may be due to difference in composition of tissue and weight. That means the Body Mass Index (BMI) can also be a factors for variations in effective dose. Accordingly the relation between BMI and effective doses were found to be significant at p value <0.05 and graphically representing the straight line in Figure -3. Figure -4 & 5 presented the effective dose with respect to different ages for male and female patients. The mean effective doses were more at the age of 40-50 years patients in case of both male and female age groups. Technical and technological-related factors seem to have an impact on high doses and dose variations. The development of CT technology and changes to the protocol, including exposure and technical parameter selection, should help to reduce dosage variations[14].

By altering the examination's physical characteristics, accounting for the patients' BMI, monitoring the patients' heart rates, and monitoring the R-R interval during exposure, it is possible to optimise and reduce the dose of CT Coronary angiography examinations. An individual approach to each patient is a crucial part of exposure optimization. The correct regulation of radiation protection laws and the implementation of a national DRL for the CT Coronary angiography exams are crucial to this process. It has been established that our study has some flaws and has to be redone. A follow-up study that takes into consideration more variables, such as the modality of the CT Coronary angiography examination, the value of heart rate during exposure, blood pressure, and more, will be the focus of the effort to provide answers to issues that emerged as a result of our previous findings[15].

CTCA has recently adopted a variety of radiation dose reduction strategies, such as prospective ECG-triggered scanning, heart rate control, lowered tube voltage, and tube current modulation [16].The British Society of Cardiovascular Imaging and the British Society of Cardiac Computed Tomography performed an audit of radiation exposure as a result, which has led to rapid advances in the decrease of radiation dose from CTCA. Coronary CT angiography radiation dosage in 2014 and 2016. They discovered a 30% decrease in the median exam DLP over the 2-year period for prospective ECG-gated acquisitions with tube current padding [17].

The application of patient size-specific protocols is essential to good CT imaging practise. These should be customised based on the patient's size, age, imaging region, and frequently clinical indication. Patient-specific methods reduce patient dose without compromising the ability to diagnose from obtained images[18]. Clinical professionals who prescribe ionising radiation should educate patients on its risks and benefits before exposing them to it for medicinal purposes, as according European 2014 Council Directive 2013/59/EURATOM[19].

Otherwise an experimental study was done with respect to DLP and effective dose where DLP value measures the total radiation exposure of a patient received during a single scan. The metric is therefore an indirect technique of measuring absorbed dosage [20]. Comparing the DLP value (854.67±170.42 mGy.cm) found in this study with other values revealed that 854 was higher than 285 mGy.cm for France [21], 854 was higher than 361 mGy.cm for the UK [22], 854 was higher than 550 mGy.cm for the USA [23], and 854 was higher than 450 mGy.cm for Australia [24]. The use of various scan lengths could be a possible reason for these variations.

Furthermore, Roche et al.[21] demonstrated that dose-saving software was not installed on earlier CT scanners. In contrast to the latest scanners that have dose-saving software, they therefore give patients greater dosages. The calculated effective dosage for a chest CT scan (21.57± 4.26 mSv), using global standards. According to numerous international and national studies, the following values were established: 21.57 > 5.6mSv [25] **,**21.57 > 7.9mSv [26], 21.57 > 9.3mSv [27], and 21.57 > 5.7mSv. The use of different imaging parameters for the same protocol, as well as the type and age of the CT scanner employed, are likely to have had a significant impact on the variances. In our study we did not employ any dose saving software and may be of this the values of effective dose may more higher than other international values. Apart from that the scan length and demographics of people differ from one country to other, thus it influencing the scan length differently [28,29].

The BMI measurements rather than the constituent height and weights were available because author had mentioned in this study was retrospective in character. Additional evidence in support of this hypothesis may have emerged from data analysis of the interactions of these characteristics with BMI, body diameters, and radiation dose. The applicability of our findings may no longer be relevant to the small percentage of centres that now possess automated body diameter and SSDE measurement technology due to the advancement of these technologies. Current radiology practise emphasises dose optimization, particularly for CT where the right balance between radiation dose and image quality should be maintained. Any applied method of estimating patient exposure to radiation must be reproducible and user-friendly in order to be effective. According to latest research, effective diameter may be estimated using patient BMI rather than anteroposterior and lateral diameter measures, which removes the requirement to do so at the time of CT [30].

On the other hand a research showed that the radiation dose is inversely proportional to the patient's BMI and increases as BMI increases. As a consequence, it is suggested that BMI and other factors that affect the radiation dose, such as the kind of scan and other body measurements, be employed to estimate the radiation dose before to CT. For the purpose of optimising and explaining CT exams, this estimation might be taken into account. This study provided equations incorporating to BMI for each of the correlations, which can be used to estimate the effective dose and SSDE depending on the scan region and initial scan parameters. The evaluation of SSDE prior to CT is time-consuming and very complicated.

Organs nearer the scan region received higher radiation doses, whereas organs far away from the scan region received doses corresponding to their distance. The heart received a higher dose during in the abdomen-pelvis CT scan since it was close to the scanning's starting position.

CONCLUSION:

Our work, along with several other comparable national and international studies, highlights the requirement for an efficient dosage for coronary CT angiography. This is owing to the technique becoming increasingly widespread as cardiovascular disease-related mortality and morbidity grow. The large number of observations in our study that allowed us to calculate the effective dosage value suggests that a regional study for Guwahati, Assam, should be used. It was necessary to enhance CT scanning techniques since the organ doses and chance of cancer induction were both rather high. By carefully choosing the scanning settings depending on the study's indication, the body region of interest being scanned, and the patient's size, this may be accomplished. It is advised that the right methodologies and protocols should be maintained to lower the dose because the effective dose was shown to be substantially high in our study. It is advised to do more research and estimation of DRL on a national and worldwide level.

Ethical Approval: The study was conducted at Assam Down Town University with proper ethical clearance bearing ethical id: **AdtU/Ethics/PhD Scholar/2021/009**

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Conflict of Interest: Authors do not have any Conflict of Interest

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