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Estimation of Effective Dose in Monte Carlo Simulation Method for CT Coronary Angiography Patients

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Abstract: Computed tomography (CT) scans of Coronary Angiography have significantly aided in the diagnosis of disorders of the coronary artery. In contrast to other radiological examinations, the patient's radiation exposure is notably higher. This study aimed to optimize the radiation dose and estimate the adequate amount in computed tomography (CT) for coronary angiography. A total of 380 patients were referred to the Primus Diagnostic Centre and Heath City Hospital, Guwahati Assam, during the study with coronary artery disturbances. Data on the technical parameters used in CT procedures were taken in 2022. The aim and study's objective was Organ and surface dose to specific radiosensitive organs (Chest) estimation using software imPACT 1.0.4 from National Radiological Protection Board (NRPB) SR250 Monte Carlo dataset. The study population (n = 380) comprised 190 men and 190 women with an average age of 29 to 75 years. The Mean ± SD of BMI and ED are 22.42±1.06 and 21.57±4.27 respectively. The mean DLP is 854.67, and the mean ED is 21.57. The effective doses for males (13-27) mSv were in females (13-29) mSv. This study was a pioneer in presenting actual amounts of CT examinations in Assam because other countries have already started with more advanced CT procedures, such as dosages for paediatrics, coronary angiography and CT fluoroscopy. 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. The high precision with minimum risk, the current study can be considered as the need of the hour.

Keywords: Radiation, Computed Tomography, Effective Dose, Angiography, Monte Carlo Simulation

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1. INTRODUCTION

In 1971, Computed Tomography (CT) was introduced into clinical practice by G.N. Hounsfield and J. Ambrose, who conducted the first clinical CT examination based on two contiguous axial images of a patient's head. A few years earlier, Cormack had described a technique for calculating the x-ray attenuation distribution inside the body and derived a mathematical theory for image reconstruction. Hounsfield and Cormack were awarded the Nobel Prize for Physiology and Medicine in 1979, recognizing their pioneering work in CT[1,2]. 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 in the volume coverage speed. Besides, the spatial and low-contrast resolution in the CT images has significantly improved over the years. 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 the heart or lungs, reducing the movement artifacts[2,3]. 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 Protection (ICRP) to assess risk[4,5]. Applications for CT imaging have recently expanded from cancer diagnosis to trauma screening [6]. Even though CT imaging has significantly improved healthcare, worries about the cancer risks of the X-rays used to create CT images have persisted[7,8]. This study aimed to optimize the radiation dose and estimate the effective dose in computed tomography (CT) for coronary angiography patients.

2. MATERIALS & METHODS:

This study aimed to assess the patient's effective dose during Coronary CT examinations and to recommend establishing local DRL. One hospital(X) and One Diagnostic Centre(Y) in the Kamrup (Guwahati) district of Assam state provided the data for this study. Data from two CT scanners were gathered for this investigation. There were two private Radiological departments equipped with these devices. Prior to any data gathering, the equipment performed all quality control tests. As a result, every set of information from the data came within an acceptable range. In CT scans, to achieve the accuracy of the data, data were gathered using a data sheet for each patient (Appendix). A CT dosimetry unit was included with every CT machine. A data collecting sheet was created to assess the patient doses and the radiation-related factor. Gender, age, tube potential (mA), tube current-time product settings (mAs), pitch, slice thickness, and the 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. Each of these variables directly impacted the radiation dosage.

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

Table 1 depicts the study population and the classification of Hospitals and Diagnostic Centres for CT Coronary Angiography Examination. Using the ImPACT (Imaging Performance Assessment of Computed Tomography Scanners) CT Patient Dosimetry Calculator, it was calculated DLP-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, and E for a typical hermaphrodite phantom after the 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

The kVp was set to 120, and the collimation field to the largest beam width possible in the ImPACT spreadsheet. It used a tube current of 90 to 100 mA, a scan period of 0.8 to 1 second, and a pitch value of 0.27 to 1. For the chest area, use a 32 cm diameter CTDI phantom. The ImPACT spreadsheet calculated the E and the DLP, and their conversion factor could be calculated as a result. Each scanner model's DLP-to-E conversion factors were computed and averaged across all scanner models. Their standard deviations and most significant deviations from the Mean were also calculated. Figure 1 illustrates the start and end locations of the patient's cardiac scans on the ImPACT spreadsheet.

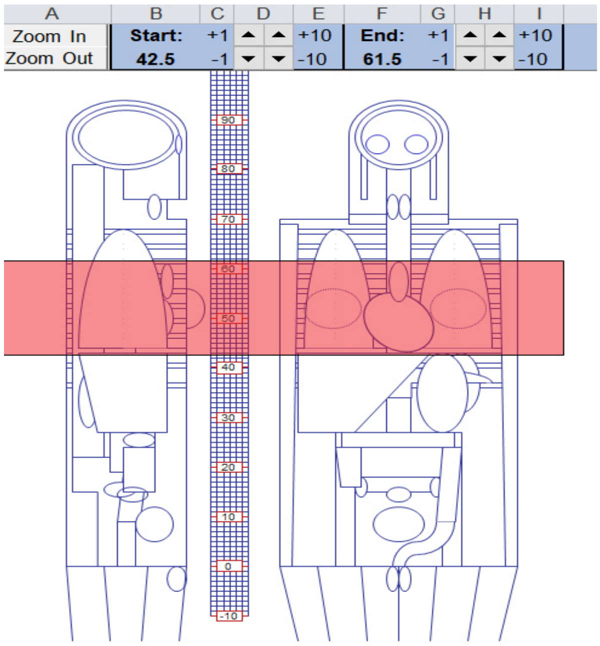

Fig 1: Imagining Performance Assessment of Computed Tomography Scanners (ImPACT). The scan range for the heart is displayed numerically by the CT Patient Dosimetry Calculator, starting at 42.5 cm and ending at 61.5 cm.

3. RESULTS

The results of this study were presented for dose measurements performed in two hospitals, hospital (X) with CT scanner Siemens model Definition 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 amounts. Though it represents the average absorbed dose in the scanned area (CTDIvol), the integrated absorbed dose for the entire CT scan along a perpendicular line to the radiation axis (DLP) and the adequate amount. The results were described in greater detail below.

Table 3: Depicts the statistical analysis of DLP and Effective Dose(ED) in both Male and Female Contrast Enhanced Coronary CT Angiography.

Parameters	Total No of Cases (N)	Mean±SD	Minimum Values	Median Value count	Maximum Values
DLP	380	854.67±170.42	506	879	1182
Effective Dose(ED)		21.57±4.26	12.73	22.12	29.74

Table 3 shows the statistical analysis data of 380 patients' correlation in DLP and Effective Dose for Contrast CT Coronary Angiography. The mean values of DLP and Effective dose were 854.67 and 21.57, respectively. The standard deviations of DLP and Effective quantity for those patients were 170.42 and 4.26, respectively, with a p-value at the significant level of <0.05. For both males and females, the value of R is 0.9471 and 1.0, respectively, where the p-value was <0.00001. The result is significant at p<0.05. This was a strong positive correlation, which means that high X variable scores go with high Y variable scores (and vice versa).

Table 4: Shows the statistical analysis of DLP and Effective Dose(ED) in Male Contrast Enhanced Coronary CT Angiography.

Parameters	Total No of Cases (N)	Mean±SD	Minimum Values	Median Value count	Maximum Values
DLP	190	840.45±153.25	521	876	1113
Effective Dose(ED)		21.29±3.816	13.1	22.115	27.99

Table 4 depicts the statistical analyzing data of 190 male patients' correlation in DLP and Effective Dose for Contrast CT Coronary Angiography. The mean values of DLP and Effective dose were 840.45 and 21.29, respectively. The standard deviations of DLP and Effective quantity for those 190 patients were 153.25 and 3.816 respectively.

Table 5: Shows the statistical analysis of DLP and Effective Dose(ED) in Female Contrast Enhanced Coronary CT Angiography.

Parameters	Total No of Cases (N)	Mean±SD	Minimum	Median	Maximum
DLP	190	868.894±185.337	506	914	1182
Effective Dose(ED)		21.849±4.668	12.73	22.99	29.74

Table 5 shows statistically analyzing data of 190 female patients' correlation in DLP and Effective Dose for Contrast CT Coronary Angiography. The mean values of DLP and Effective dose were 868.89 and 21.85, respectively. The DLP and Effective quantity standard deviations for those 190 patients were 185.34 and 4.67, respectively.

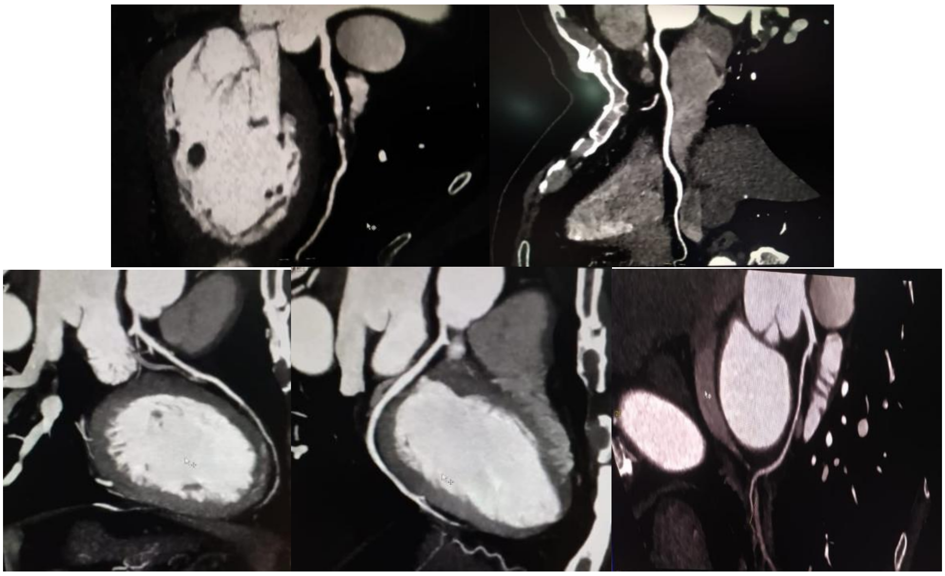

Fig 2: Reconstructed 3D CT images illustrate the coronary artery branches.

Table 6: 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 Table 6 shows the statistical analysis of 380 patients' correlation in BMI and Effective Dose for Contrast CT Coronary Angiography. The mean BMI and Effective dose values 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. Table 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 pitches (0.25 to 1). Accordingly, Table 3 presented the estimation of (mean, median, std, min and max) and DLP, E calculated by software imPACT 1.0.4 using data collection from CT scanner Siemens Somatom Definition AS (128 slices) model and Philips Ingenuity (128 pieces). The 380 cardiac angiography cases of CT scan where male and female patients are represented with different age groups. Similarly, Table 4 represents the estimation of (mean, median, std, min, max) DLP, E for 190 male patients with different age groups. Finally, Table 5 presents the estimation of (mean, median, std, min, max) and DLP, E for female contrast CT cardiac Angiography in both Siemens and Philips scanners. The estimation of DLP and E were calculated by imPACT1.0.4 software. This study was carried out for all age groups aged below 40 to above 60.

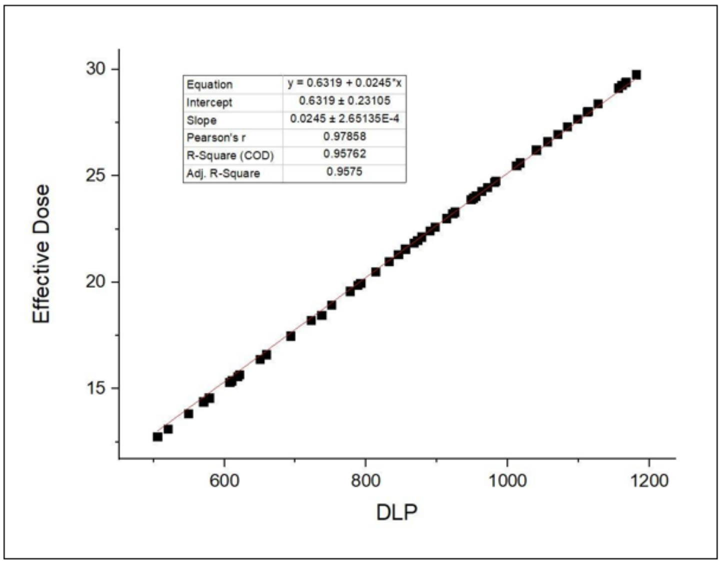

Fig 3: Shows the significant correlation between DLP and Effective Dose in both Male and Female Contrast Enhanced CT Coronary Angiography.

Figure 3 depicts the graphical representation of the relation between DLP and practical dose. There are highly significant p values between DLP and Effective amount, which makes the linear straight line. Pearson's r value was found to be 0.97858, where the equation of the graph is $Y=0.6319+0.0245^{*}X$.

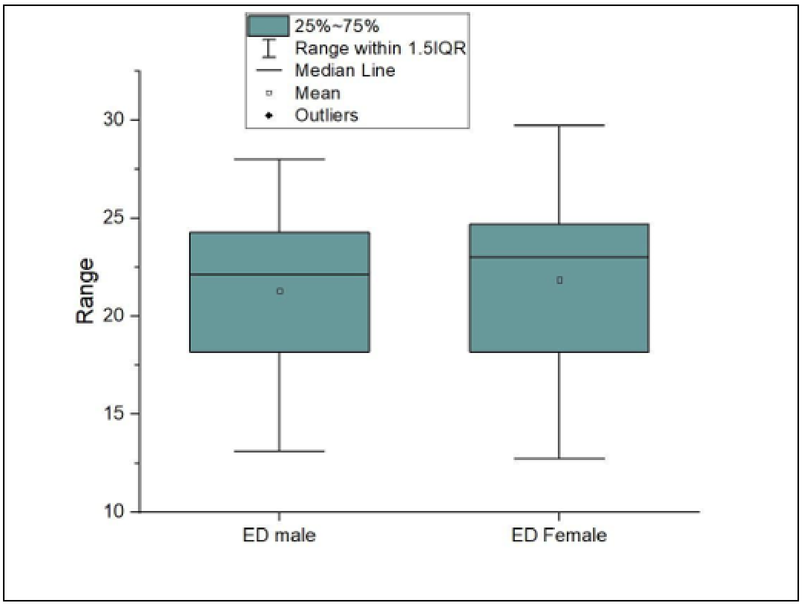

Fig 4: Shows the graphical representation of effective dose for both male and female Contrast Enhanced CT Coronary Angiography patients.

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

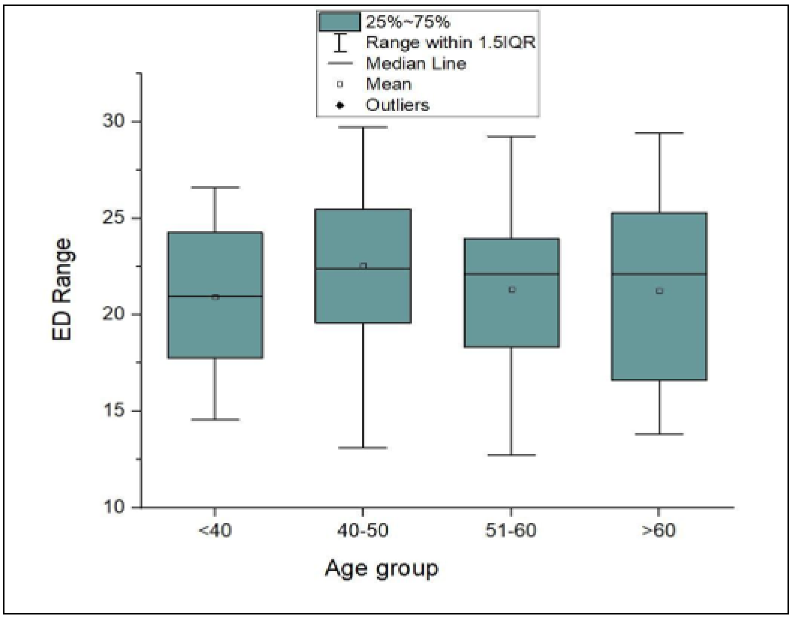

Fig 5: Shows the graphical representation of effective dose in both Male and Female Contrast Enhanced CT Coronary Angiography concerning age variations.

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

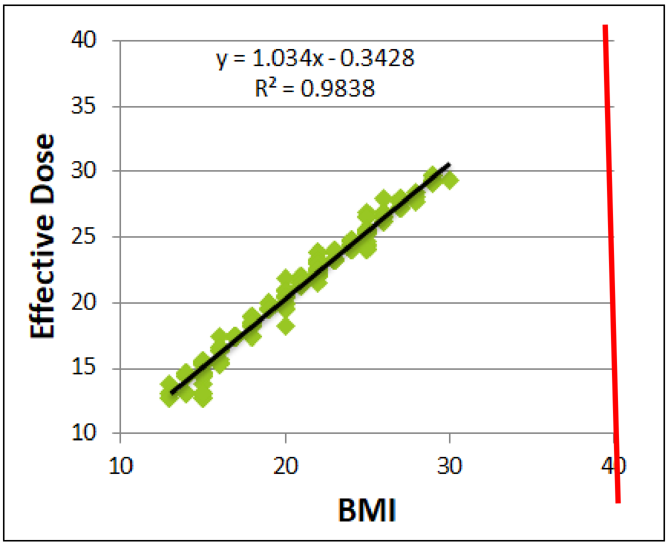

Fig 6: Correlation between BMI and Effective Dose in both sexes of Contrast-Enhanced Coronary CT Angiography.

The above graph (Figure-6) shows the relation between BMI and practical dose. There was a highly significant correlation between BMI and Effective amount, and the values were found to be linear. Pearson's r value is 0.09838, and the equation of the graph is *Y=1.034X-0.3428*.

4. 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 using the 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 revealed radiation dose values ranging from 7 to 9 mSv [13]. In this study, when it represented the effective dose graphically for the two hospitals, it found that the effective doses for males (13-27) mSv were lower than females (13-29) mSv; this result was presented in Figure-3 for both the hospitals (X) and (Y). This difference in effective doses for males and females may be due to differences in tissue composition and weight. That means the Body Mass Index (BMI) can also be a factor for variations in effective dose. Accordingly, the relation between DLP and effective doses was found to be significant at p-value <0.05 and graphically representing the straight line in Figure -3. Figure -5 presented the effective dose concerning different ages for male and female patients. The mean effective doses were more at the age of 40-50 years in the 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 patient's heart rates, and monitoring the R-R interval during exposure, it is possible to optimize 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 this study has some flaws and must 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 various 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, 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 two years for prospective ECG-gated acquisitions with tube current padding[17].The application of patient size-specific protocols is essential to good CT imaging practice. These should be customized based on the patient's size, age, imaging region, and frequent clinical indication. Patient-specific methods reduce the patient dose without compromising the ability to diagnose from obtained images[18]. Clinical professionals who prescribe ionizing radiation should educate patients on its risks and benefits before exposing them to it for medicinal purposes, according to European 2014 Council Directive 2013/59/EURATOM [19].A DLP value measures a patient's total radiation exposure 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.[25] demonstrated that dose-saving software was not installed on earlier CT scanners. In contrast to the latest scanners that have dose-saving software, they give patients greater dosages. The calculated effective dosage for a chest CT scan (21.57± 4.26 mSv), using global standards. Numerous international and national studies established the following values: 21.57 > 5.6mSv[26], 21.57 >

7.9mSv[27], 21.57 > 9.3mSv[28], and 21.57 > 5.7mSv. The use of different imaging parameters for the same protocol and the type and age of the CT scanner is likely to have had a significant impact on the variances. This study did not employ any dose-saving software, and the values of effective dose may be higher than other international values. Apart from that, the scan length and demographics of people differ from country to country. Thus it influences the scan length differently[29,30].

5. LIMITATIONS

The use of the phantom to quantify CT dosage was the study's principal flaw. Since it takes into account both controllable (imaging technique, tube voltage, tube current) and uncontrollable (patient orientation, collimation, and distance) factors, the use of the patient may have been preferable. Even though using phantom produces almost identical exposures, it only addresses elements under our control.

6. CONCLUSION

Like many other similar national and international studies, this study emphasizes the need for an effective dose for coronary CT angiography. This is because the procedure is becoming more and more common due to the rise in cardiovascular disease-related mortality and morbidity. A regional study should be adopted for Guwahati, Assam, as a result of the significant number of observations in this study that allowed us to determine the practical dose value. The organ dosages and likelihood of cancer induction were both relatively high, requiring the improvement of CT scanning methods. Considering the DLP values, focusing on dose length product values is essential to reduce the radiation dose. This can be done by selecting the scanning parameters carefully based on the study's indication, the body region of interest being scanned, and the patient's size. As this study found the effective dose was significantly high, the proper techniques and protocols should be maintained to reduce the amount.Further study and estimation of DRL are advisable at national and international levels. The present study highlights the dose at which an appropriate amount can be initiated for a particular investigation to benefit the user and the organization. It will be helpful for the organizations to do a self-audit of the patient doses, which is essential and modify the exposure factors to lower the dose value to DRLs value without compromising the image quality.

7. ETHICAL APPROVAL STATEMENT

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

8. ACKNOWLEDGEMENT

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9. AUTHORS CONTRIBUTION STATEMENT

MKS & ADS conceived and planned the study. AJS, JS and MPK were responsible for data collection and analysis. AJS, MKS and JS were responsible for manuscript writing. AJS took the lead in writing the manuscript. MKS, AJS and JS were responsible for research design and manuscript revision. All authors provided critical feedback and helped shape the research, analysis and manuscript.

10. CONFLICT OF INTEREST

Conflict of Interest declared none.

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