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Radiation dose in cardiac CT for preoperative diagnosis of children with congenital heart disease

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Abstract

Background One of the most common congenital conditions detected globally, congenital heart diseases, and CT techniques provide a high-quality and thorough presentation of heart anatomy, thoracic vasculature, and extracardiac structures, and hence, it is becoming a more popular non-invasive diagnostic imaging method for congenital heart disease. The drawbacks with CT imaging are the radiation exposure from repeated scans is also rising, especially in young patients. The present study is aimed to evaluate the radiation dose in gated and non-gated cardiac CT for preoperative diagnosis of pediatric patients with congenital heart diseases.

Results A total of 111 pediatric patients with mean age of 7.47 years were prospectively included in the study. The mean value of "Effective dose (E)" for gated CT at 100 kV_p was found to be 4.71 mSv which is higher than mean "E" of 3.95 mSv observed for gated CT at 80 kV_p. The average value of "E" for non-gated technique was observed less than that of gated technique at both 100 kV_p and 80 kV_p. The multiple regression analysis shows that "E" is significantly dependent on DLP(mGy cm) for both gated and non-gated techniques at 95% level of significance ($p < 0.05$). The Student's *t-test* verifies that the mean value of "E" for both the techniques at 100 kV_p and 80 kV_p are significantly different at 95% level of significance ($p < 0.05$).

Conclusions The effective dose received by pediatric patients is much higher when using ECG-gated acquisition with an average value of 4.71 mSv and 3.95 mSv at 100 kV_p, and at 80 kV_p respectively. Because low-voltage X-rays are more sensitive to high atomic number iodinated contrast media, the mean "E" for non-gated cardiac CT imaging at 80 kV_p is 2.26 mSv, and results in significant reduction of effective dose.

Keywords Congenital heart disease, Gated, Non-gated cardiac CT, Effective dose, Multiple regression analysis

Background

One of the most common congenital conditions detected globally, congenital heart diseases (CHD) affects 0.8–1.2% of live births [1, 2]. While the incidence of CHD rose in many industrialized nations, the incidence of CHD remained constant worldwide. Countries with higher incidence of CHD were shown to have a relatively high risk of CHD death. Researchers have also discovered a global decline in the death rate from cardiovascular disease, independent of gender, age, or location. The developed world had the sharpest fall in CHD-related deaths. Infant growth and development are severely hampered, and early diagnosis is crucial for both prognosis and therapy. It is associated with severe morbidity and mortality. Children with CHD die at a rate highest during the 1st year of life [3, 4]. The prompt and precise diagnosis is crucial to initiate the appropriate treatment. Thus, non-invasive and repeatable

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imaging is vital for patients with better prognoses, and longer life spans [5]. For primary pediatric cardiac diagnosis, the most widely utilized imaging modality is echocardiography. The three main modalities used to evaluate CHD are cardiac magnetic resonance imaging (MRI), computed tomography (CT), and echocardiography. Echocardiography is widely utilized as screening imaging tool for initial diagnosis and identify the hemodynamic alterations. It can be used for follow up and to monitor the effectiveness of surgical or interventional therapy. But, it has limitations in terms of poor acoustic window, spatial resolution, and lack in precise and thorough detection of complex intracardiac shunts or extracardiac vascular structures [6, 7]. While MRI is ionization radiation-free and provides excellent resolution for soft tissues, it is a time-consuming procedure that requires lengthy anesthesia, making it unsuitable for newborns exhibiting severe clinical complaints and higher cost and lack of widespread availability are its limitations [8]. CT can reveal good anatomical details because of its spatial and temporal resolution. However, given that pediatric patients are more sensitive to radiation, there are worries regarding how radiation may affect them [9]. Furthermore, Iodinated contrast media (CM), which is frequently used to diagnose congenital heart disease (CHD), has a potential risk of acute renal failure [10]. New CT techniques, on the other hand, allow for the highly detailed, high-quality presentation of cardiac anatomy, thoracic vasculature, and extracardiac structures, even in children with very short examination times and low radiation doses. Additionally, neonatal intubation anesthesia is no longer required because the examination can occur during the patient's postprandial sleep phase, avoiding the risks associated with anesthesia. On the other hand, modern CT methods allow for the detailed and high-quality display of images with reduced radiation doses. Nevertheless, modern CT techniques provide optimal appearance of heart structure, with very short examination times, a lower radiation dosage, and neonatal intubation. For this reason, they are becoming a more popular non-invasive diagnostic imaging method for congenital heart disease, even in young patients who are clinically unstable and fragile [11, 12].

The worries about low-dose ionizing radiation exposure from CT scans have grown [13, 14]. Because of the early radiation mishaps and the atomic bombings in Japan, which increased the risk of cancer in the victims, the biological risks of ionizing radiation have long been recognized. About half of the annual medical radiation exposure is attributed to CT, whose ionizing radiation dose is 100–500 times higher than that of traditional radiography [15, 16]. Pediatric CT scans are linked to a higher incidence of leukemia and brain tumors, according to several epidemiological studies [17–22]. The bone marrow in practically every part of the body is exposed to radiation from CT scans, and leukemia has a shorter latency period than radiation-associated solid tumors [23]. The amount of pediatric CT scans performed was quantitatively linked to a lifelong cancer risk in 2001, as demonstrated by Brenner et al. [24]. USA Today's top page instantly featured the story. The general public developed a negative opinion of pediatric CT, and some parents even refused to let their kids get CT [25]. It is necessary to strike the right balance between child protection and CT use. Numerous epidemiological studies have assessed the risks of cancer that follow radiation exposure from children CT scans [26–29]. According to Pearce et al. [30], there is a positive correlation between radiation exposure from CT scans and brain tumors and leukemia in terms of excess relative risk [31]. It is still unknown if having a previous CT scan increases the chance of cancer in youngsters, or if getting another one increases the risk. Furthermore, it is unclear if pediatric CT exposure raises a child's cancer risk to a higher degree than it does for children who are not exposed. There is disagreement among epidemiological research; whereas some [28–31] found an elevated risk of cancer, others [31] did not. When it comes to assessing congenital heart disease, cardiac CT has a much more comprehensive radiation dosage range than non-cardiac CT. This is due to the many scan techniques, such as non-electrocardiographic (ECG)-synchronized spiral scan, prospectively ECG-triggered sequential scan, or retrospectively ECG-gated spiral scan [32–34].

To optimize pediatric cardiac CT protocols, it is critical to identify variations in pediatric cardiac CT dosage and potential influencing factors [32]. Because of insufficient pediatric imaging specialists, streamlined protocols, suitable training, or efficient radiation monitoring, approaches for lowering pediatric CT radiation exposure are not available. Recent developments in hardware and software have made low-tube voltage scans and iterative reconstruction (IR) algorithms among the currently available CT dose optimization techniques is regarded generally practical and recommended procedures for low-dose pediatric CT [33, 34]. A methodological approach and a cautious implementation plan are required to optimize the potential for dose reduction while maintaining diagnostic image quality. The present study is aimed to evaluate the radiation dose in gated and non-gated cardiac CT at different tube potentials for preoperative diagnosis of children with congenital heart disease and to verify the dependence of “E” on multidimensional variables for both gated and non-gated cardiac CT at different tube potentials.

Methods

Subject

The prospective study was conducted in a tertiary care hospital from June 2022 to March 2024. The data source includes pediatric patients aged less than 15 years undergoing cardiac CT for the diagnosis of congenital heart disease on GE Healthcare Revolution EVO CT installed in the department of radiodiagnosis as per the standard protocol. This prospective study was approved by the University’s Institutional Ethics Committee (Ref. No: IECJNMC/908, dated 26.10.2022). The guardian of the patient provided the written consent and software package installed in the control console and workstation of the unit generate the dose length product (DLP), and volume computed tomography dose index ($CTDI_{vol}$), and total mAs for each examination specific to a patient. All the patients above 15 years of age, non-cooperative patients that could not maintain the proper position while imaging and other patients with any contraindication to computed tomography imaging were excluded from the study.

Effective dose

According to ICRP report-60 [35, 36], the weighted average of organ dose values (H_T) for a number of designated organs is the effective dose (E):

$$E = \sum_i w_i H_{t,i} \tag{1}$$

“Effective dose (E)” is measured in millisieverts (mSv). The tissue weighting factor (w_i) assigned to each organ indicates its relative sensitivity to radiation-induced effects, which determines how much that organ contributes to "E". It is not possible to measure the effective dose *in-vivo*. Because the anthropomorphic phantom-based thermoluminescent dosimeter (TLD)-based measurements take a long time, are not ideal for everyday use. As a result, "E" is obtained by multiplying the age and site corrected conversion factor (K) by the $\text{DLP}(\text{mGy cm})$. Consequently, "E":

$$E = K \times \text{DLP} \tag{2}$$

where “*K*” is conversion factor: Normalized effective dose per DLP values for different body parts and (standard) patient age groups [37, 38]. Following every CT imaging study, the $\text{DLP}(\text{mGy cm})$ is shown as a dosage sheet, from which the value "E" is calculated with the help of Eq. (2).

Body mass index

Prior to imaging, each patient had their height and weight measured, and their body mass index (BMI) was computed using a specific, calibrated tool (Indosurgicals: weight and height measuring instrument). The patients were grouped according to the subcategories of the BMI data: underweight was defined as $\text{BMI} < 18.5\ \text{kg m}^{-2}$, normal weight as $18.5 \le \text{BMI} \le 24.9\ \text{kg m}^{-2}$, overweight as $25 \le \text{BMI} \le 29.9\ \text{kg m}^{-2}$, and obese as $\text{BMI} \ge 30\ \text{kg m}^{-2}$.

Statistical analysis

The statistical analysis was performed for both gated and non-gated cardiac CT datasets performed at $100\ \text{kV}_\text{p}$ and $80\ \text{kV}_\text{p}$ by using the Origin 6.0 (v6.1052[B232] Origin Lab Corporation, Northampton, MA 01060 USA) software. The 25th percentile, 50th percentile, and 75th percentile were computed in order to find where the given values fall within datasets (Tables 1, 2). The multivariate regression analysis was performed to verify the dependence of “E” on multidimensional variables for both gated and non-gated cardiac CT at different tube potentials (Tables 3, 4). Additionally, to test whether the difference between the doses received by patients during gated and non-gated pediatric cardiac CT is statistically significant or not, the Student’s *t-test* was performed at 95% level of significance ($p < 0.05$). The test verifies the variability of mean and standard deviation of the data (Table 5) [39].

Results

A total of 111 pediatric (Non-gated at $100\ \text{kV}_\text{p} = 25$, non-gated at $80\ \text{kV}_\text{p} = 36$, gated at $100\ \text{kV}_\text{p} = 25$, and gated at $80\ \text{kV}_\text{p} = 25$) with an average age of 7.47 years, and ranging from 0.74 to 15 years were prospectively included in the study for estimation of effective dose. Nearly 72.97% of patients were under weight, and height, 26.13% were normal, and only 0.9%(only one patient) patients was overweight. The statistical analysis of E, $\text{CTDI}_\text{vol}(\text{mGy})$, DLP, age, volume of the contrast agent (ml) injected, and heart rate for both gated and non-gated CT imaging at $100\ \text{kV}_\text{p}$ and $80\ \text{kV}_\text{p}$ is presented in Tables 1 and 2, respectively. Additionally, the whole data and mathematical calculations can be seen from the Additional file 1 (page 1 to 4). The mean value of effective dose for gated at $100\ \text{kV}_\text{p}$ was observed to be 4.71 mSv, with a minimum value of 2.79 mSv, and a maximum value 7.10 mSv. And for gated $80\ \text{kV}_\text{p}$ technique, the mean value of E was found to be 3.95 mSv with a minimum value of 2.31 mSv and maximumof 6.31 mSv, which is less than that of gated at $100\ \text{kV}_\text{p}$ technique. The $\text{CTDI}_\text{vol}(\text{mGy})$ and $\text{DLP}(\text{mGy cm})$ values for gated $100\ \text{kV}_\text{p}$ were also found

Table 1 The statistical analysis of gated pediatric cardiac CT at 100 kV_p and 80 kV_p

Parameter	Mean	Standard deviation	Minimum	Maximum	Range	Median	Percentile		
							25	50	75
Gated at 100 kV_p									
Age(y)	10.72	3.12	4.0	15.0	11	12	9.0	12.0	12
BMI(kg m^{-2})	15.48	3.34	9.50	20.60	11.1	14.5	13.1	14.5	18.6
$CTDI_{vol}$(mGy)	21.48	6.34	13.03	45.85	537.09	21.5	16.8	21.5	23.9
DLP(mGy cm)	316.36	93.83	214.3	507.09	292.79	295.89	230.6	285.9	376.4
E(mSv)	4.71	1.41	2.79	7.10	4.31	4.82	3.6	4.82	5.9
Volume of contrast (ml)	34.94	10.49	20.0	60.0	40.0	33.0	27.0	33.0	40.0
Heart rate (bpm)	96.16	6.03	88.0	112.0	24.0	96.0	92.0	96.0	100.0
Gated at 80 kV_p									
Age(y)	7.67	4.04	1.07	13.0	11.93	8.0	4.0	8.0	11.0
BMI(kg m^{-2})	14.48	3.66	10.20	25.0	14.80	14.2	11.5	14.2	16.4
$CTDI_{vol}$(mGy)	15.67	3.11	9.57	23.50	13.93	15.4	13.5	15.4	17.4
DLP(mGy cm)	225.93	24.73	177.81	278.0	100.19	225.0	210.3	225.0	242.5
E(mSv)	3.95	1.21	2.31	6.31	4.0	3.87	2.89	3.87	4.91
Volume of contrast (ml)	28.50	8.71	15.0	45.0	30.0	28.0	22.0	28.0	35
Heart rate (bpm)	116.20	7.02	105.0	132.0	27.0	118.0	110.0	118.0	120.0

Table 2 The statistical analysis of non-gated pediatric cardiac CT at 100 kV_p and 80 kV_p

Parameter	Mean	Standard deviation	Minimum	Maximum	Range	Median	Percentile		
							25	50	75
Non-Gated at 100 kV_p									
Age(y)	5.27	3.19	0.74	13.0	12.26	3.50	2.0	3.50	7.50
BMI(kg m^{-2})	14.04	2.05	10.42	17.10	6.68	15.3	11.90	15.30	15.78
$CTDI_{vol}$(mGy)	23.08	4.52	14.68	31.57	16.89	23.88	21.88	23.88	26.72
DLP(mGy cm)	199.19	36.55	145.31	266.9	244.62	180.93	174.65	180.93	223.47
E(mSv)	4.14	0.60	3.15	5.95	2.79	4.12	3.78	4.12	4.54
Volume of contrast (ml)	23.56	9.03	10.0	40.0	30.0	24.0	16.0	24.0	29.0
Heart rate (bpm)	109.48	13.43	76.0	140.0	64.0	110.0	104.0	110.0	116.0
Non-Gated at 80 kV_p									
Age(y)	6.23	3.40	0.74	13.0	12.26	7.0	3.0	7.0	9.0
BMI(kg m^{-2})	15.33	3.52	11.11	27.3	16.19	14.56	13.25	14.58	15.86
$CTDI_{vol}$(mGy)	8.17	1.64	6.69	13.94	7.25	7.78	7.27	7.78	8.39
DLP(mGy cm)	116.16	23.44	85.57	205.72	120.15	118.85	95.16	118.86	124.59
E(mSv)	2.26	0.43	1.18	3.65	2.46	2.24	2.12	2.24	2.41
Volume of contrast (ml)	24.78	12.83	9.0	80.0	71.0	23.0	14.75	23.0	30
Heart rate (bpm)	106.47	8.88	92.0	132.0	40.0	108.0	99.5	108.0	110.0

higher than that of gated 80 kV_p technique. The 25 and 75 percentile of E for gated 100 kV_p technique values were found to be 3.6 mSv and 5.9 mSv , respectively, and for gated 80 kV_p, the 25 and 75 percentile values of E were 2.89 mSv and 4.91 mSv , respectively (Table 1). The average values of $CTDI_{vol}$, DLP, and E for non-gated techniques were found much less than that of the values seen in the gated technique for both 100 kV_p and 80 kV_p as shown in the Table 2. The mean value of "E" for non-gated at 80 kV_p is much less than that of the gated techniques as presented in Fig. 1. We compared the mean value of "E" with the literature published international studies (Table 6). Further, in case of non-gated cardiac CT at 80 kV_p , the mean value of "E" is

Table 3 Multivariate regression analysis of non-gated pediatric cardiac CT at 100 kV_p and 80 kV_p

Dependent variable	Independent variable	Regression coefficient	Standard error	*p*-value
Non-Gated at 100 kV_p				
E(mSv)	Age(y)	− 0.10	0.05	< 0.05
	BMI$\left(\text{kg m}^{-2}\right)$	− 0.03	0.05	< 0.05
	$CTDI_{vol}$(mGy)	0.026	0.02	> 0.05
	DLP(mGy cm)	0.018	0.0028	< 0.05
	Volume of contrast (ml)	− 0.02	0.014	< 0.05
	Heart rate (bpm)	− 0.006	0.008	> 0.05
Non-Gated at 80 kV_p				
E(mSv)	Age(y)	− 0.014	0.033	> 0.05
	BMI$\left(\text{kg m}^{-2}\right)$	0.0021	0.017	> 0.05
	$CTDI_{vol}$(mGy)	− 0.032	0.046	> 0.05
	DLP(mGy cm)	0.025	0.0053	< 0.05
	Volume of contrast (ml)	− 0.0092	0.0079	> 0.05
	Heart rate (bpm)	0.0063	0.0073	> 0.05

Table 4 Multivariate Regression analysis of Gated pediatric cardiac CT at 100 kV_p and 80 kV_p

Dependent variable	Independent variable	Regression coefficient	Standard error	*p*-value
Gated at 100 kV_p				
E(mSv)	Age(y)	− 0.24	0.061	> 0.05
	BMI$\left(\text{kg m}^{-2}\right)$	− 0.012	0.048	> 0.05
	$CTDI_{vol}$(mGy)	− 0.024	0.035	> 0.05
	DLP(mGy cm)	0.016	0.002	< 0.05
	Volume of contrast (ml)	0.013	0.019	> 0.05
	Heart Rate (bpm)	− 0.016	0.032	> 0.05
Gated at 80 kV_p				
E(mSv)	Age(y)	− 0.23	0.047	> 0.05
	BMI$\left(\text{kg m}^{-2}\right)$	− 0.006	0.05	> 0.05
	$CTDI_{vol}$(mGy)	− 0.022	0.064	> 0.05
	DLP(mGy cm)	0.013	0.008	< 0.05
	Volume of contrast (ml)	− 0.018	0.019	> 0.05
	Heart rate (bpm)	− 0.038	0.022	> 0.05

Table 5 Student's $t - test$ comparison for "E" in gated and non-gated pediatric cardiac imaging at 100 kV_p and 80 kV_p

Technique	No. of Patients	Mean Dose (mSv)	*t*-value	*p*-value
Gated at 100 kV_p	25	4.71	1.85	$0.035465 < 0.05$ Significant
Non-Gated at 100 kV_p	25	4.14		
Gated at 80 kV_p	25	3.95	7.76	$0.00001 < 0.05$ Significant
Non-Gated at 80 kV_p	36	2.26		

found less than the mean values of "E" presented in the published literature across the globe.

In order to unfold the relation between "E" and multidimensional variables in pediatric cardiac CT imaging, multivariate regression analysis was performed. Multivariate regression analysis is strong statistical tool to verify the degree up to which the various dependent variables are linearly related to each other.

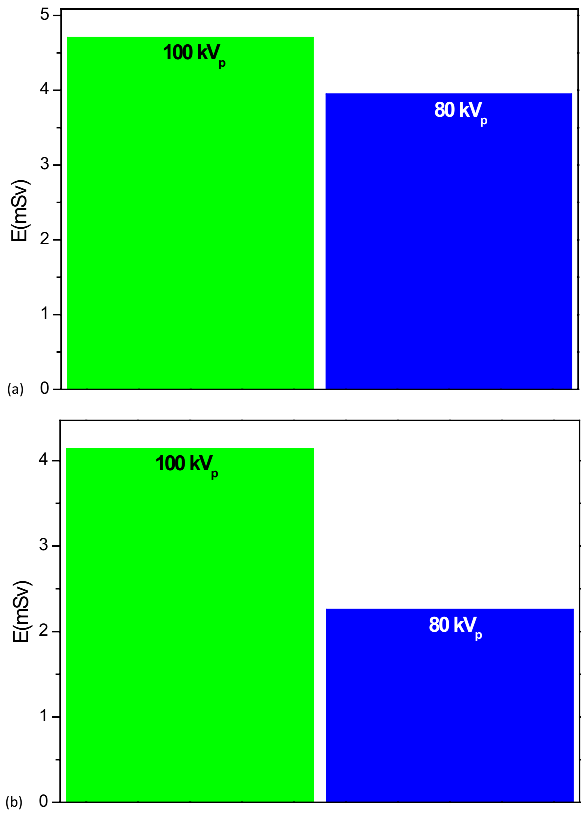

Fig. 1 Effective dose for **a** gated and **b** non-gated pediatric cardiac CT at 100 kV_p and 80 kV_p

The multivariate analysis shows that "E" is significant dependent on DLP for both gated and non-gated techniques at 95% level of significances with $p < 0.05$ as shown in Tables 3 and 4. Further, the "E" is found negatively correlated with age and BMI of the children undergoing non-gated cardiac CT at 100 kV_p with $p < 0.05$. For gated technique, the insignificant negative correlation of "E" with age and BMI is also observed both at 100 kV_p and 80 kV_p. The student's *t-test* was performed to present the comparison of two mean values of "E" for the two imaging techniques both at 100 kV_p and 80 kV_p. As seen from the Table 5, the two means are significantly different at 95% level of significance with $p < 0.05$. The image quality was blindly assessed by experienced radiologists, and the Fig. 2 presents the transverse view of the quality of images for both gated and non-gated techniques. Additionally, out of 111 patients, nearly 50% were operated and imaging findings of patients were compared with the surgical results.

Discussion

Multislice CT is advantageous for congenital heart disease research because it offers advantages over earlier helical CT, such as faster acquisition times, thinner slices, and ECG-gated acquisition. Specifically, short-term sedation is needed for multislice CT tests instead of complete anesthesia. Even in young children who are clinically unstable and frail, cardiac CT is being used more and more for non-invasive diagnostic imaging of congenital heart disease due to its accessibility, speed, and ability to provide detailed anatomical information. It suffers from radiation exposure and the use of iodine-containing contrast agents. Modern CT techniques, on the other hand, enable the high-quality and detailed projections of images at lower radiation doses. Nevertheless, modern CT methods offer a comprehensive and high-quality representation of cardiac architecture, thoracic vasculature, and extracardiac structures with relatively short examination times, reduced radiation exposure, and neonatal intubation [44]. For this reason, computed tomography (CT) and magnetic resonance imaging (MRI) have been proposed. The task force report recommends MRI as a first-line approach for various CHD diseases because it has proven beneficial [45]. However, the spatial resolution of MRIs is lower than CT scans, which could be a significant problem when trying to see small anatomical structures like coronary arteries. Helical CT has been suggested more recently to see anatomy in three dimensions for individuals with congenital heart disease. Even in newborns or infants, helical technology enables high-quality three-dimensional vascular images in a short amount of time through volume capture. With the improved ability to synchronize images with the cardiac beat, multislice CT technology offers a possible reduction in heart motion and a considerably faster acquisition time that significantly minimizes respiratory artifacts [46]. Electrocardiogram (ECG)-gated acquisition, reduced slice thickness, and quicker acquisition times are all made possible by the multislice CT.

The distribution of radiation dose in CT is significantly different from the conventional radiographic techniques because of the three distinct radiation dosage characteristics. Firstly, the volume of tissue that is exposed to radiation from the primary X-ray beam during the acquisition of a single CT image is significantly smaller due to the highly collimated nature of the X-ray beam, secondly, during the rotating acquisition, the irradiated tissue volume is exposed to the X-ray beam from nearly every angle, which more uniformly distributes the radiation dosage to the tissues in the beam and lastly, high contrast resolution in CT acquisition needs a high signal to noise ratio (SNR), which greatly enhances, the radiation dose to the slice due to the higher kV and mAs approaches utilized. Further, there is a significant amount of scattered radiation, which at times exceeds the radiation dose from the primary beam. Since

Table 6 Comparison of mean value of effective dose (E) in cardiac CT for the diagnosis of CHD reported in the published literature

Mean Patient Age (Years)	Examination Type	CT Scanner Unit	Tube Potential (kV_p)	Mean Effective Dose (E mSv)	Range of E (mSv)	Reference
10.7 ± 6.2	Retrospective ECG-Gated Helical CT	Siemens 64 slice MDCT 64 slice DSCT 128 slice DSCT	80, 100, 120	6.1	2.5–10.6	[40]
0–3 3–8 -15 > 15	Prospective ECG-triggered High Pitch axial scan	Siemens 4 slice MDCT 4 slice DSCT 128 slice DSCT	80, 100, 120	2.2 4.7 2.5 2.6	0.4–4.9 0.8–14.4 .1–11.3 0.4–7.9	[41]
0.47 ± 0.31 (0.003 − 0.97)	ECG-gated	Single source 512 Slice MDCT	70	0.64 ± 0.16	0.32–1.12	[42]
0.36 (0.003 − 0.99)	Non-gated	DSCT Somatom, Definition, Siemen	80	0.5 ± 0.2	0.2–0.9	[43]
5.27	Non-gated	GE Healthcare Revolution EVO 128 Slice	100	4.41 ± 0.60	3.15- 5.95	Present Study
6.23	Non-gated	GE Healthcare Revolution EVO 128 Slice	80	2.26 ± 0.43	1.18–3.65	Present Study
10.72	ECG- Gated	GE Healthcare Revolution EVO 128 Slice	100	4.71 ± 1.41	2.79–7.10	Present Study
7.67	ECG- Gated	GE Healthcare Revolution EVO 128 Slice	80	3.95 ± 1.21	2.31–6.31	Present Study

scattered radiation is not restricted to the collimated beam profile as primary X-rays are, as a result significant dosage from scatter is delivered to surrounding tissues outside of the primary beam during the collection of a CT slice [47]. The radiation dose for a single CT scan of the organ under examination ranges from 15 mSv in adults to 30 mSv in neonates, depending on the machine settings. Two to three CT scans are routinely performed per study. Radiation-induced carcinogenesis is the most likely (though slight) risk at these dosages [47]. The concern is even more evident for youngsters, who are more at risk to radiation than adults are, both because of their natural radiosensitivity and the longer time span over which radiation-induced cancer is more likely to manifest itself. The first concern is whether ECG-gated acquisition should be used in patients with congenital heart disease (CHD); the second is the most appropriate protocol. To reduce radiation exposure, the radiation dosage supplied should be assessed for each procedure [48]. Therefore, patient dose management especially for pediatric patients during CT imaging is crucial ensuring that radiation safety precautions are appropriately followed [49].

The goal of the current investigation is to assess the radiation dosage levels and other relevant variables in cardiac CT in children with congenital heart disease. The DLP and "E" are excellent measures of radiation dose from CT and could be used to immediately improve the radiation safety standards by identifying when doses are much higher the reference values. The multiple regression analysis shows that "E" is significantly dependent on DLP at 95% level of significance with $p < 0.05$. The dependence of "E" on DLP obvious because the DLP is the measure of CT tube radiation output and scan length is also multiplicative factor for radiation dose. The reduction of scan length of 1 cm results nearly saving 1 mSv of radiation dose [50]. Our hospital is a central university medical college, which is a tertiary care referral center working as an apex center in the Western Uttar Pradesh, India, with the patients of all strata coming from a radius of nearly 150 km. Furthermore, the patients of staff, students from different parts of India, and many foreign students report for imaging. Approximately 72.97% of patients, we studied were under weight, and height, 26.13% was normal, and only 0.9% (only one patient) patients was overweight. The weak correlation between "E" and BMI is probable because the majority of the pediatric population we studied is under weight and height and negligible number of cases were overweight and none of the patients was obese. The negative correlation observed between "E" and age of the children may be attributed by the increase in

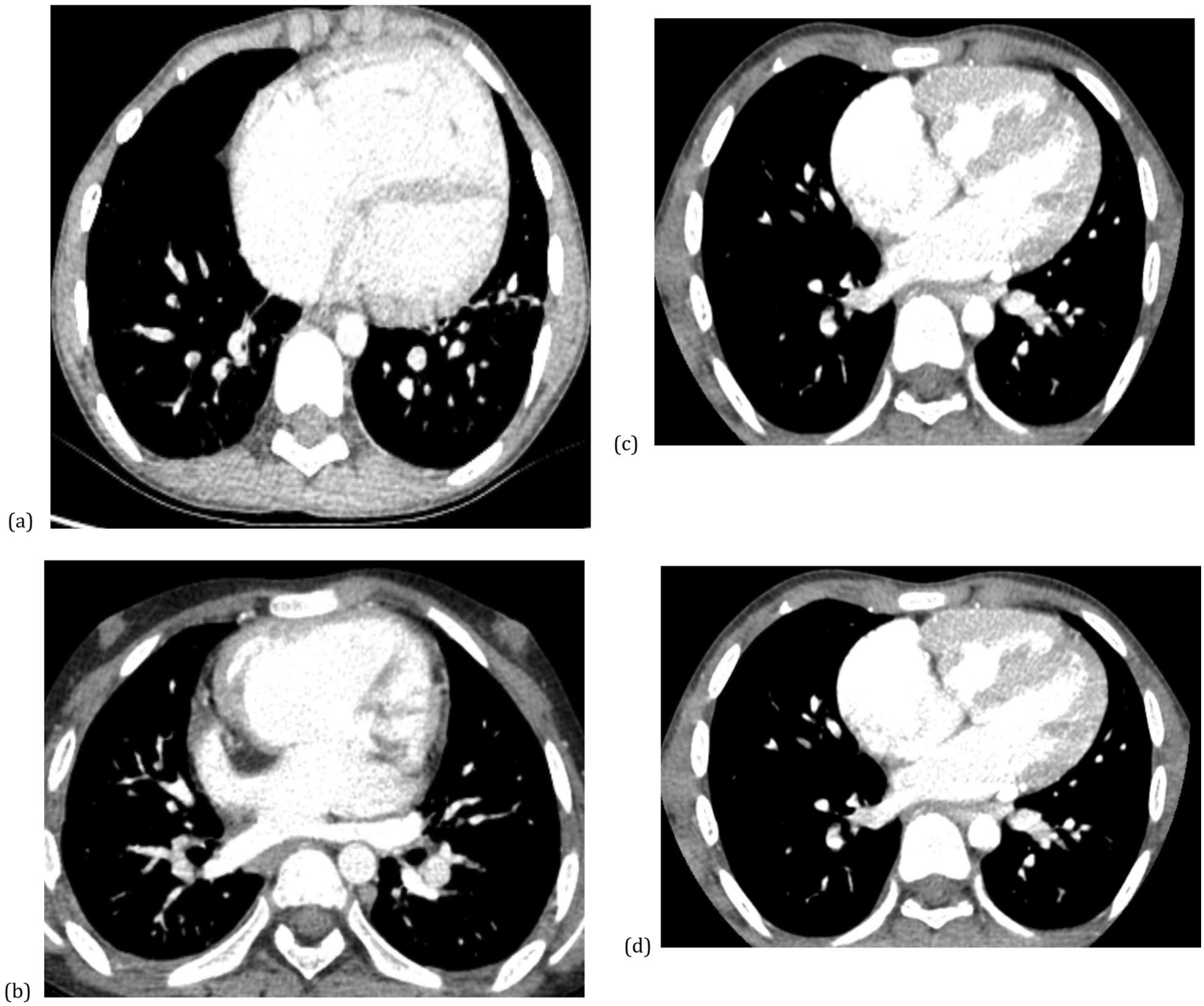

Fig. 2 Transverse views of images presenting the image quality for both gated and non-gated techniques at different tube potentials **a** gated at 100 kV_p, **b** non-gated at 100 kV_p, **c** gated at 80 kV_p, and **d** non-gated at 80 kV_p

age; the dimensions of the patient are increased and the radiation is distributed over a large volume of the patient while as the neonates and infants have very small size the distribution of radiation is over a smaller volume. The values of "E" are much higher for ECG-gated technique than non-gated CT imaging because in ECG-gated imaging only a part of the radiation dose is used in image formation. The statistically significant reduction of mean value of "E" in non-gated imaging techniques at 80 kV_p is obvious due to the reduction in the intensity of higher kilovoltage X-rays. Furthermore, the other advantages of using low kV_p is the possibility for reduction of contrast volume injection, because low kilovoltage X-rays are more sensitive to iodinated contrast material than standard 100 kV_p, 120 kV_p and 140 kV_p. Because of the iodine's *k-edge* (33.2 keV), the reduced tube potential enhances subject contrast, particularly when imaging contrast-enhanced arteries.

Conclusions

The "Effective dose (E)" received by children is much higher when using ECG-gated acquisition with an average value of 4.71 mSv and 3.95 mSv at 100 kV_p, and at 80 kV_p respectively. Because low-voltage X-rays are more sensitive to high atomic number iodinated contrast media, non-gated cardiac CT imaging at 80 kV_p the mean effective dose 2.26 mSv, and results significant reduction "Effective Dose (E)". The decrease in tube voltage results is significant reduction of "Effective dose (E)" without comprising the image quality. In conclusion, the non-gated cardiac CT at 80 kV_p significantly reduced the effective dose (E) and yields the image quality equivalent to retrospectively ECG-gated coronary CT. Hence, radiation professionals should always consider utilizing exposure settings tailored specifically for children in order to reduce exposure as low as reasonably attainable (ALARA).

Abbreviations

CHD	Congenital heart diseases
CT	Computed tomography
DLP	Dose length product
E	Effective dose
ECG	Electrocardiogram
MRI	Magnetic resonance Imaging
$CTDI_{vol}$	Computed tomography dose index volume
kV_p	Kilo-Voltage Peak

Supplementary Information

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Additional file 1

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Author contributions
The concept for the current study came from the corresponding author Mudasir Ashraf Shah. All the authors also cooperated on the work design, data collection, data interpretation, validation, and technique, as well as draft and revision writing. The final manuscript has been read and approved by all contributors.

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Availability of data and materials
The patient data for the present study are attached as supplementary file and can also be obtained from corresponding author upon justifiable request.

Declarations

Ethics approval and consent to participate
The study was approved by the Institutional Ethics Committee (Ref. No: IECJNMC/908, dated 26.10.2022), Aligarh Muslim University. The written consent was obtained from the guardian of the patients for the present study. The study was conducted from June 2023 to June 2024.

Consent for publication
All patients included in this study gave informed consent to publish the data contained within this study.

Competing interests
The authors declare that there is no potential competing interests.

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