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ARTICLE

Paediatric cancer risks associated with chest computed tomography (CT) scans: comparison of routine chest and COVID-19 diagnosis CT protocols

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Abstract – The aim of this study is to compare the radiation dose and cancer incidence risk associated with two chest Computed Tomography (CT) protocols: routine chest CT (RC-CT) and COVID-19 Diagnosis CT protocol (CD-CT). The study included 254 pediatric patients divided into three age groups: G1 (<5), G2 (5–<10), and G3 (10–15). The effective diameter, volumetric CT dose index ($CTDI_{vol}$), dose length product (DLP), size specific dose estimate (SSDE), organ doses, and cancer incidence risk were calculated for the two protocols. Organ doses (mSv) and effective dose (mSv) were estimated using the National Cancer Institute dosimetry system for CT (NCICT) software. Estimation of cancer incidence risks were conducted according to the Biological Effects of Ionizing Radiation (BEIR) VII report. The oldest group (G3) in two protocols exhibited the greatest values for $CTDI_{vol}$, DLP, effective dose and SSDE. The results showed that CD-CT protocol resulted in statistically significant ($p < 0.05$) lower organ doses and cancer incidence risk. The cancer incidence risk for both protocols did not exceed the reference levels reported in literature surveys on pediatric CT chest radiation dose for all age groups. It can be concluded that the choice of CT protocol can significantly impact the radiation dose received by pediatric patients during CT imaging, highlighting the importance of carefully selecting the appropriate protocol to minimize radiation exposure.

Keywords: Computed tomography / chest CT / paediatric / cancer risk

1 Introduction

COVID-19, caused by the SARS-CoV-2 virus, initially emerged as a respiratory illness primarily affecting adults, but it has also been observed in pediatric populations (Zimmermann and Curtis, 2020). Although children generally experience milder symptoms compared to adults, severe cases and complications, including Multisystem Inflammatory Syndrome in Children (MIS-C), have been reported (Hennon *et al.*, 2020). Studies have shown that children can contract and transmit the virus, even if they are often asymptomatic or exhibit mild symptoms (Adeyinka *et al.*, 2021). It is crucial to closely monitor and understand the impact of COVID-19 on pediatric patients to guide appropriate public health measures and medical interventions (Howard-Jones *et al.*, 2022).

Computed Tomography (CT) scans have become an indispensable tool in pediatric diagnostic imaging due to their ability to provide detailed cross-sectional images of the body (Hussain *et al.*, 2022). CT scans offer valuable information for the evaluation of various conditions in children, including trauma, neurological disorders, pulmonary diseases, abdominal pathologies, and recently COVID-19 diagnosis (Biagas *et al.*, 2019; Kaufman *et al.*, 2020; Li *et al.*, 2020; Lin and Lin, 2016).

However, it is important to use CT scans judiciously in pediatric patients due to the potential risks associated with ionizing radiation exposure (Garg *et al.*, 2021). The use of CT scans in pediatric patients is associated with potential long-term risks, particularly in terms of radiation-induced cancer (Marcu *et al.*, 2021).

Ionizing radiation from diagnostic imaging, including CT scans, has been found to increase the lifetime risk of cancer (Garg *et al.*, 2021; Marcu *et al.*, 2021). Several studies have investigated this risk, emphasizing the importance of minimizing radiation exposure in children (Berrington de Gonzalez *et al.*, 2021). A population-based cohort study by Mathews *et al.* found that pediatric patients who underwent CT scans had a small but statistically significant increase in their risk of developing solid cancers later in life (Mathews *et al.*, 2013). Another study by Pearce *et al.* estimated that exposure to radiation from two to three CT scans in childhood might lead

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to a doubling of the risk of leukemia (Pearce *et al.*, 2012). Also, Meulepas *et al.* conducted a retrospective cohort study on 168,394 children nationwide and discovered a link between exposure to radiation from CT scans and an elevated risk of brain tumors (Meulepas *et al.*, 2019).

Given these findings, it is crucial to adopt radiation dose reduction techniques and follow evidence-based imaging guidelines to minimize unnecessary radiation exposure and ensure the clinical benefits of CT scans outweigh the associated cancer risks in pediatric populations.

During the COVID-19 pandemic, our hospital faced a large number of CT scans for the diagnosis, screening, and monitoring of COVID-19 paediatric patients. In order to reduce paediatric radiation dose, we implemented a new chest CT protocol called COVID-19 Diagnosis CT protocol (CD-CT).

The objective of this study is to compare the radiation dose and the risk of cancer incidence associated with ionizing radiation in two chest CT protocols: namely, the routine chest CT (RC-CT) protocol and the CD-CT protocol.

2 Materials and methods

The study received approval from our institution's ethics committee, and obtaining consent forms was not deemed necessary. This retrospective study recorded a total of 254 patients who underwent a chest CT examination with RC-CT protocol or CD-CT protocol from March 2020 to May 2022. The patients were divided into three age groups: G1 (<5), G2 (5–<10), and G3 (10–15). It should be noted that the CD-CT protocol was chosen for patients undergoing COVID-19 diagnosis, while the RC-CT protocol was used for other patients with the indications of mainly evaluation of infectious and lung diseases. Patient's demographic data were acquired through the picture archiving and communication system (PACS). The matching between the two groups (CD-CT protocol and RC-CT protocol for males and females separately) was conducted based on an equal number of patients and effective diameter. The patient selection between the two groups was carried out in a way to match the effective diameter in the two groups.

To calculate the effective diameter of the chest, the middle slice of the scanning region was used and the anterior-posterior (AP) and lateral (L) distances were measured. The equation recommended by AAPM 204 was then used to calculate the effective diameter (Medicine, 2011) as follow;

$$\textit{effective diameter} = \sqrt{\mathrm{A}P \times L}$$

2.1 Collection of CT dose parameters

All patients were imaged with a 16 slice CT scanner (Somatom Emotion, Siemens, Germany). The chest CT scanning range was set using a scout view from the lung apices to the lung bases. Table 1 shows CT scanning parameters of two protocols for three age groups. Slice thickness and nominal beam width were constant for all groups. Three tube potentials (kVp) were used: 80, 110, and 130, manually based on the CT technologist's experience. Lower tube current (mAs) was used for CD-CT protocol, and the CareDose 4D option was activated for all patients during CT scanning. All the radiologists working at our institution have approved the image quality of both protocols based on the assessment of image noise in the CTDI phantom.

The values of volumetric CT dose index (CTDIvol), dose length product (DLP) and the parameters of two chest CT protocols were extracted from dose report page by looking back at the PACS.

In this study also size specific dose estimate (SSDE) was calculated by multiplying $\mathrm{CTDI_{vol}}$ and a conversion factor provided in AAPM 204 report. The SSDE is a more accurate radiation dose metric for patients of different sizes compared to the CTDIvol alone, as it takes into account the patient's size, which can affect the effective dose received during the CT scan.

2.2 Estimation of organ dose and effective dose

Organ doses (mSv) and effective dose (mSv) were estimated using the National Cancer Institute dosimetry system for CT (NCICT) software version 3.0 (Lee *et al.*, 2015). Organ doses were calculated for organs in the field of scanning range such as thyroid, esophagus, lung, breast and stomach by employing a Monte Carlo simulation and an International Commission on Radiological Protection (ICRP) standard pediatric phantom (Lee *et al.*, 2015).

2.3 Estimation of cancer incidence risk

Estimation of cancer incidence risks were conducted according to the Biological Effects of Ionizing Radiation (BEIR) VII report (Council, 2006). The models presented in the BEIR VII report take into account a range of factors that can influence the risk of cancer, the age and gender of the exposed individual, and the dose. The report also provides estimates of the risks associated with different types of cancer, including solid tumors and leukemia.

Cancer risks were calculated for different organs, including thyroid, lung, and breast.

2.4 Statistical analysis

The statistical analysis was performed using SPSS software (version 23), with mean and standard deviation (SD) used to express all values. Furthermore, the Mann–Whitney test was employed to compare the means of continuous variables between the two groups due to the non-normality of the data, as assessed by the Kolmogorov–Smirnov test. Statistical significance was interpreted as differences with a p-value less than 0.05.

3 Results

Table 2 shows demographic data and values of effective diameter for the two groups of the patients. The number of patients in the two protocols according to gender was equal to facilitate a better matching process. The age of patients ranged from 2.7 ± 0.9 years in the male CD-CT protocol group to 13.0 ± 1.7 years in the female CD-CT protocol group. There were no statistical differences in terms of effective diameter between the two protocols for all age groups ($P > 0.05$).

Table 1. CT scanning parameters of two protocols for three age groups.

Group age (years)	Protocol	CT protocol parameters				
		Tube potential (kVp)	Tube current (mAs)	Slice thickness (mm)	Nominal beam width (mm)	pitch
<5	RC-CT	80, 110	52.8 ± 12.9	5	16 × 1.2	1.25–1.5
	CD-CT	80, 110	27.8 ± 9.7	5	16 × 1.2	1.25–1.5
5–<10	RC-CT	110, 130	59.7 ± 10.5	5	16 × 1.2	1–1.5
	CD-CT	110, 130	31.4 ± 11.1	5	16 × 1.2	1–1.5
10–15	RC-CT	110, 130	67.8 ± 14.7	5	16 × 1.2	1–1.5
	CD-CT	110, 130	35.7 ± 13.5	5	16 × 1.2	1–1.5

Table 2. Demographic data and values of effective diameter.

Group age (years)	Sex	CT protocol	Number	Age (years)	Effective diameter (cm)	*P* value
G1 (<5)	Male	RC-CT	13	2.9 ± 1.0	15.1 ± 2.6	0.594
		CD-CT	13	2.7 ± 0.9	15.3 ± 2.3	
	Female	RC-CT	14	3.1 ± 1.1	13.9 ± 1.2	0.841
		CD-CT	14	2.9 ± 1.0	14.2 ± 0.9	
G2 (5–<10)	Male	RC-CT	23	7.7 ± 1.3	19.9 ± 1.9	0.332
		CD-CT	23	7.6 ± 1.2	20.5 ± 2.1	
	Female	RC-CT	21	7.1 ± 1.4	17.9 ± 1.8	0.117
		CD-CT	21	7.3 ± 1.1	17.3 ± 1.7	
G3 (10–15)	Male	RC-CT	29	13.1 ± 1.8	23.8 ± 2.3	0.117
		CD-CT	29	13.0 ± 1.5	24.2 ± 2.6	
	Female	RC-CT	27	12.8 ± 1.7	20.4 ± 2.3	0.472
		CD-CT	27	13.0 ± 1.7	19.1 ± 1.7	

Table 3. Data on CTDIvol, DLP, effective dose and SSDE.

Group age (years)	Dose descriptors (Mean ± SD)							
	$CTDI_{vol}$ (mGy)		DLP (mGy.cm)		Effective dose (mSv)		SSDE (mGy)	
	RC-CT	CD-CT	RC-CT	CD-CT	RC-CT	CD-CT	RC-CT	CD-CT
G1 (<5)	2.4 ± 0.6	1.1 ± 0.4	58.7 ± 14.3	26.7 ± 12.2	1.4 ± 0.6	0.9 ± 0.2	4.5 ± 1.2	2.1 ± 0.5
G2 (5–<10)	2.9 ± 0.4	1.3 ± 0.3	75.9 ± 11.8	34.5 ± 9.8	1.8 ± 0.8	1.1 ± 0.2	5.5 ± 1.2	2.5 ± 0.6
G3 (10–15)	3.3 ± 0.9	1.5 ± 0.3	87.1 ± 15.3	39.6 ± 12.7	1.9 ± 2.3	1.2 ± 0.3	5.7 ± 2.1	2.6 ± 0.5

Data on dose descriptors such as CTDIvol, DLP, effective dose and SSDE are summarized in Table 3. The lowest values of $CTDI_{vol}$ were 2.4 ± 0.6 mGy and 1.1 ± 0.4 mGy for RC-CT and CD-CT protocols in the G1 group, respectively. The highest values of $CTDI_{vol}$ were 3.3 ± 0.9 mGy and 1.5 ± 0.3 mGy for RC-CT and CD-CT protocols in the G3 group, respectively.

The lowest values of DLP (mGy.cm) were 58.7 ± 14.3 and 26.7 ± 12.2 for RC-CT and CD-CT protocols in the G1 group, respectively. The highest values of DLP (mGy.cm) were 87.1 ± 15.3 and 39.6 ± 12.7 for RC-CT and CD-CT protocols in the G3 group, respectively.

The lowest values of effective dose were 1.4 ± 0.6 mSv and 0.9 ± 0.2 mSv for RC-CT and CD-CT protocols in the G1 group, respectively. The highest values of effective dose were 1.9 ± 2.3 mSv and 1.2 ± 0.3 mSv for RC-CT and CD-CT protocols in the G3 group, respectively.

The lowest values of SSDE were 4.5 ± 1.2 mGy and 2.1 ± 0.5 mGy for RC-CT and CD-CT protocols in the G1 group, respectively. The highest values of SSDE were 5.7 ± 2.1 mGy and 2.6 ± 0.5 mGy for RC-CT and CD-CT protocols in the G3 group, respectively. The statistical analysis showed that the SSDE was lower in the CD-CT protocol group compared to the RC-CT protocol group for all three age groups ($P < 0.05$).

Figure 1 presents organ doses for G1, G2, and G3. For the males, the lungs received the highest organ dose (4.27 ± 1.4 mGy) in the RC-CT protocol of the G3 age group. Also, for the females, the lungs received the highest organ dose (3.90 ± 1.23 mGy) in the RC-CT protocol of the G3 age group.

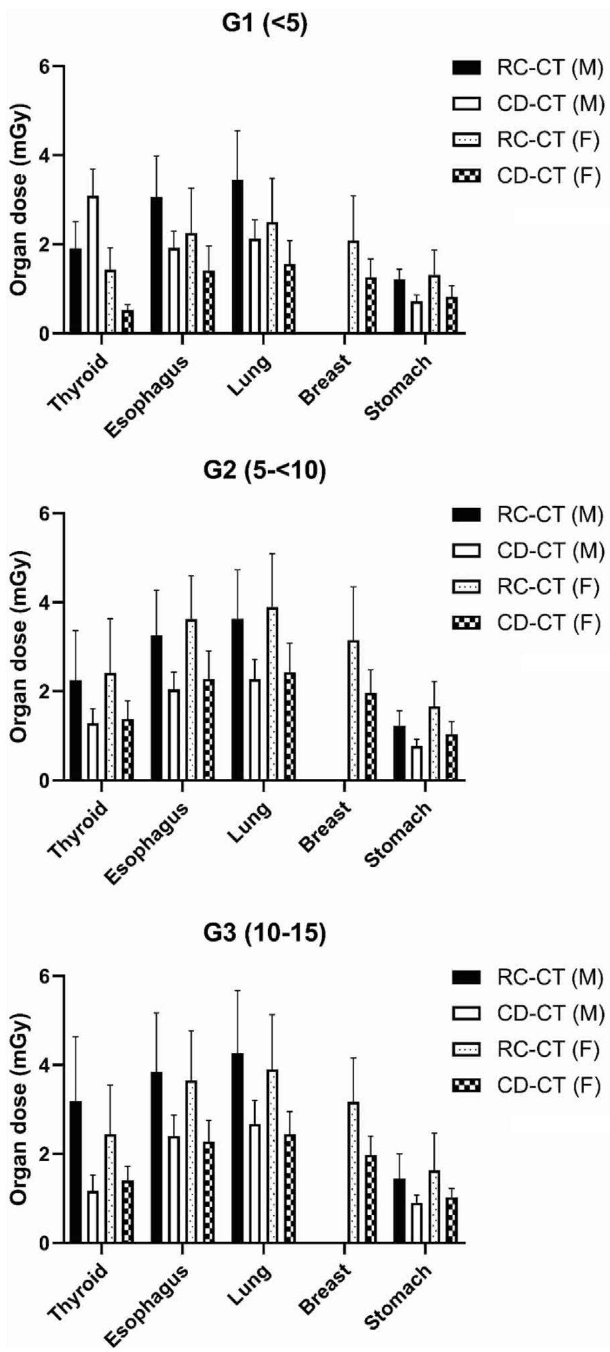

Figure 1. Organ dose of different organs for three age groups.

For the breast in females, the highest dose (3.17 ± 0.99 mGy) was in the RC-CT protocol of the G3 age group, and the lowest dose (1.96 ± 0.52 mGy) was in the CD-CT protocol of the G1 age group. It should be noted that for all three age groups and for males and females, CD-CT groups received statistically lower organ dose ($P < 0.05$).

Figure 2 shows cancer incidence risk of some organs for G1, G2, and G3. Among the three age groups, the risk of cancer incidence of thyroid, lung, and breast was higher for the G1 age group. The risk of breast cancer incidence was highest (19.66 ± 6.14) in the females RC-CT of G1 age group and lowest (10.66 ± 2.71) in the females CD-CT of G3 age group. The risk of lung cancer incidence was highest (16.41 ± 4.92) in the females RC-CT of G1 age group and lowest (8.83 ± 2.36) in the females CD-CT of G3 age group. The lowest cancer risk was for thyroid in all three age groups for males and females.

It should be noted that for all three age groups and for males and females, CD-CT groups had statistically lower risk of cancer incidence ($P < 0.05$).

4 Discussion

Several studies emphasize the importance of minimizing radiation dose in children undergoing CT scans, particularly by employing pediatric-specific imaging protocols and dose reduction techniques (Miglioretti *et al.*, 2013). Adhering to these guidelines helps to strike a balance between diagnostic accuracy and reducing radiation-related risks in the pediatric population. In this study, we compared the organ dose and cancer risk associated with RC-CT and CD-CT protocols that were implemented in our institution.

Based on Table 2, the *p*-values related to effective diameter for the comparison of the two protocols for all age groups was above 0.05, indicating a good match between the two protocols. In other study (Bagherzadeh *et al.*, 2021), body mass index (BMI) was used to match two groups. However, in this study, we did not have access to BMI data, so we could not use it for matching. Instead, the matching between the two groups (CD-CT protocol and RC-CT protocol for males and females separately) was conducted based on an equal number of patients and effective diameter. As expected, the maximum effective diameter was for the oldest group, which is in line with the study by Karim *et al.* (2021) study. This is because effective diameter is a measure of the size of the body part being imaged, and older individuals tend to have larger body parts due to factors such as growth, and weight gain. Other factors such as gender and anatomical region can also affect effective diameter, as can be seen from Table 1, where it is shown that the effective diameter of males is slightly higher than that of females, which is in line with the study by Franck *et al.* (2016) and Karim *et al.* (2021).

It can be observed that the tube current utilized for CD-CT was lower than that used for RC-CT. The use of a lower tube current can help to reduce the radiation dose to the patient, while the CareDose 4D option can further optimize the radiation dose based on the patient's size and shape. These techniques are in line with current best practices for radiation dose reduction in medical imaging, which aim to balance the need for high-quality diagnostic images with the need to minimize potential risks associated with radiation exposure (Wang *et al.*, 2019).

It was also observed that a higher pitch factor was utilized for the younger age group, which can help to reduce the radiation dose to the patient (Kalra *et al.*, 2020).

All dose descriptors had lowest values for youngest age group (G1) and highest values for oldest age group (G3). Also, Karim *et al.* (2021), Gao *et al.* (2018), Galanski *et al.* (2005), and Mohammadbeigi *et al.* (2019) reported that $CTDI_{vol}$ and DLP had lowest values in youngest pediatric group and highest values in oldest pediatric group. In Admontree *et al.* (2019) study, the oldest age group did not have the highest values of $CTDI_{vol}$. Instead, they found that the highest $CTDI_{vol}$ value

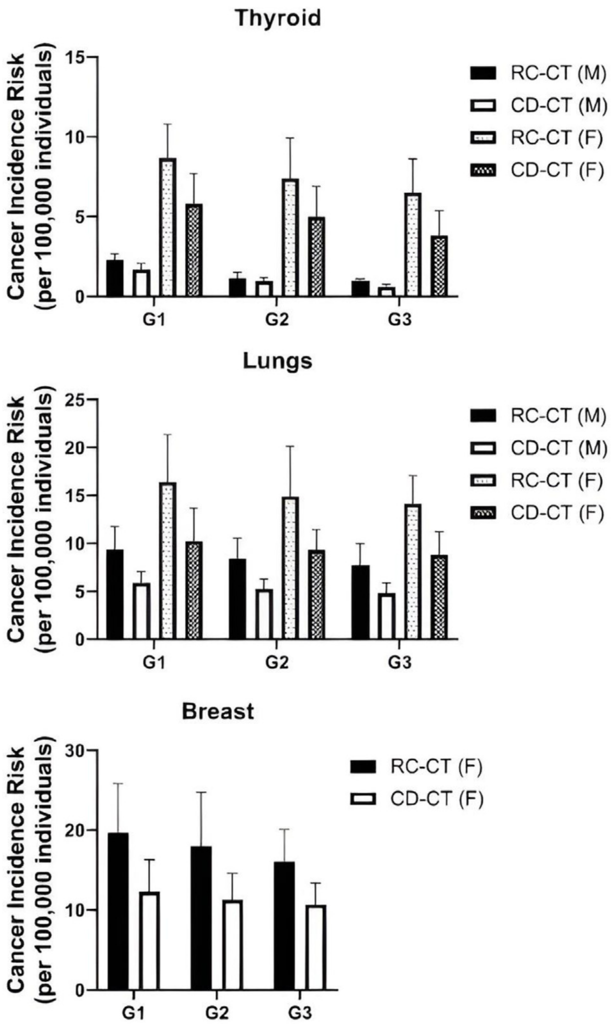

Figure 2. Cancer incidence risk (per 100,000 individuals) of different organs for three age groups.

was observed in group 2 (5–<10). The $CTDI_{vol}$ and DLP measured in this study did not exceed the reference levels reported in literature surveys on paediatric CT chest radiation dose for all age groups (Gao *et al.*, 2018; Radiology, 2016; Shrimpton *et al.*, 2006; Verdun *et al.*, 2008).

The calculation of SSDE in this study also took into account the patient's effective diameter as a crucial factor in estimating the absorbed dose during the CT scan. By considering the effective diameter, which represents the average cross-sectional dimension of the patient, the SSDE calculation provides a more accurate estimation of the absorbed dose specific to the patient undergoing the CT scan. The mean values of SSDE (mGy) in the CD-CT protocol group were 2.1 ± 0.5, 2.5 ± 0.6, and 2.6 ± 0.5 for G1, G2, and G3, respectively. Also, the corresponding values in the RC-CT protocol group were 4.5 ± 1.2, 5.5 ± 1.2, and 5.7 ± 2.1 for G1, G2, and G3, respectively. These findings show that the radiation doses in terms of SSDE were statistically lower in the CD-CT protocol group compared to the RC-CT protocol group for all three age groups. Specifically, the mean SSDE values in the CD-CT group were roughly half of those observed in the RC-CT group for each age group. These results demonstrate that the choice of CT protocol can significantly impact the radiation dose received by pediatric patients during CT imaging, highlighting the importance of carefully selecting the appropriate protocol to minimize radiation exposure.

The SSDE values for the two chest CT protocols used in our study's G1 age group were lower than those reported in previous studies by Karim *et al.* (4.6 mGy), Admontree *et al.* (5.2 mGy) and Mohammadbeigi *et al.* (7.4 mGy). Similarly, the SSDE values for the two chest CT protocols used in our study's G2 age group were lower than those reported in previous studies by Karim *et al.* (6.7 mGy), Admontree *et al.* (6.1 mGy), Mohammadbeigi *et al.* (11.1 mGy), and Strauss *et al.* (5.1 mGy). Additionally, the SSDE values for the two chest CT protocols used in our study's G3 age group were lower than those reported in previous studies by Karim *et al.* (7.6 mGy), Admontree *et al.* (6.3 mGy), Mohammadbeigi *et al.* (10.4 mGy), and Strauss *et al.* (6.6 mGy).

The results of the organ dose analysis in chest CT imaging revealed that the lung received the highest radiation dose, followed by the esophagus, breast, thyroid, and stomach. These results are consistent with the study by Karim *et al.* (2021), with the exception that they reported a higher radiation dose to the breast than to the thyroid gland, which may be related to difference in setting the upper border of scanning range. Therefore, exact setting of the scanning range during chest CT scanning may be necessary to reduce the radiation dose to the thyroid. It is worth noting that they also used the NCICT software to calculate the organ doses. In line with previous comparison studies (Karim *et al.*, 2021), our results showed a pattern of increasing organ doses with age, with the lowest values observed in the youngest age group and a gradual increase in doses with increasing age. The results of the organ dose analysis in our study were lower than those reported in other comparable studies (Giansante *et al.*, 2019; Karim *et al.*, 2021).The organ doses in CD-CT protocol are significantly lower than the RC-CT protocol, indicating that the use of CD-CT protocol may be a more favorable option for reducing radiation exposure in pediatric patients undergoing CT imaging.

The most current researches suggest compelling evidence linking the occurrence of cancer to low-level radiation exposure from CT examinations (Alkhorayef, 2018; Hong *et al.*, 2019). The results of the cancer incidence risk analysis indicated that the lung had the highest risk for males, while the breast had the highest risk for females across all age groups. Even though the lung received the highest radiation dose in females, the breast had a higher cancer risk than the lung across all age groups, which is in line with Tahmasebzadeh *et al.* (2021) study. This is because, according to Table 12D-1 in the BEIR VII report, the breast has a higher cancer risk than the lung up to 20 years of age.

Furthermore, the results showed that the incidence risk of thyroid and lung cancer is higher in females than in males. According to Table 12D-1 in the BEIR VII report, females have a higher cancer risk than males for both types of cancer across all age groups.

In contrast to our findings, Karim *et al.* (2021) reported the highest cancer risk in the thyroid for females. This may be related to the different used reports for estimating cancer risk, where they utilized ICRP 103 publication report. Based on the ICRP 103 publication report, the nominal risk coefficient value was zero for the esophagus and breast in children aged between 0 and 15 years, and thyroid have highest risk value.

Our study, as depicted in Figure 2, revealed a decreasing trend in cancer risk with increasing age, which is in line with Tahmasebzadeh *et al.* (2021) study. However, this trend is not in agreement with the findings of Karim *et al.* (2021). This difference may be attributed to the use of different reports for estimating cancer risk in the two studies.

Moreover, the cancer incidence risks per 100,000 individuals in this study were higher than those reported by Karim *et al.* (2021). However, the SSDE values in their study were higher than those in this study. This may be related to the fact that the BEIR VII report used in this study for estimating cancer risk represents a conservative approach to estimating radiation risks.

The cancer risks associated with the CD-CT protocol are significantly lower than those of the RC-CT protocol, suggesting that the use of CD-CT protocol may be a safer and more effective option for reducing radiation exposure in pediatric patients undergoing CT imaging.

According to the provided CT scan parameters and results, it can be proposed to optimize the radiation dose by reducing the tube current-time product. One limitation of this study is presenting radiation dose results without providing image quality parameters, which should be addressed in future studies.

5 Conclusion

The study found that the CD-CT protocol resulted in lower cancer risks and organ doses. It can be concluded that the choice of CT protocol can significantly impact the radiation dose received by pediatric patients during CT imaging, highlighting the importance of carefully selecting the appropriate protocol to minimize radiation exposure. Overall, the findings suggest that the use of pediatric-specific imaging protocols such as CD-CT protocol and dose reduction techniques, can be a more favorable option for reducing radiation exposure in pediatric patients undergoing CT imaging.

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Conflicts of Interest

There is no conflict of interest.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Ethics approval

The study received ethical approval from ethics committee of Gonabad University of Medical Sciences.

Informed consent

Informed consent was not deemed necessary for this study.

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