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Estimation of Organ Doses in Pediatric Patients for Different Imaging Protocols and Examinations

Turan ŞAHMARAN[1*]

[1] Hatay Mustafa Kemal University, Kırıkhan Vocational School, Hatay, Türkiye

Keywords

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$CTDI_{vol}$

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Abstract

In this study, the Volume Computed Tomography Dose Index (CTDIvol) Dose Length Product (DLP), effective patient doses (ED), and organ doses were calculated for pediatric patients aged 0, 1, 5, and 10 years undergoing computed tomography (CT) examinations using the VirtualDose program, a software designed for reporting such doses. The study utilized a Toshiba Aquilion 16 CT scanner. Head, chest, and pelvis CT scans were simulated with commonly used kVp, mAs, and pitch values. The results indicated a significant difference in organ doses between standard and low-dose protocols. When kVp and mAs values were increased, ED and organ doses increased by an average of 2.5 times. Conversely, when kVp and mAs values were held constant and pitch value was increased, ED and organ doses decreased by an average of 2 times. Physicians requesting pediatric CT scans should continuously evaluate the requested examinations based on their benefits and risks. To reduce organ doses, scanning protocols should be reviewed, and low-dose protocols should be preferred. Additionally, newer generation devices that provide lower dose scanning should be utilized.

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Author ID (ORCID Number)

0000-0003-3708-6162 Turan ŞAHMARAN

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1. INTRODUCTION

Effective pediatric radiology necessitates proper equipment, specialized safety measures, and expertise in ionizing radiation. This poses significant challenges, particularly for developing countries, regarding the acquisition of equipment and implementation of precautions (Kamdem et al., 2021). Today, rapid and accurate imaging techniques are extremely important for the diagnosis and treatment of diseases. One of these techniques is computed tomography (CT). CT is an X-ray imaging method that visualizes the internal structure of the body in detail, facilitating the diagnosis of diseases and guiding treatment processes (AAPM, 2010; Çakmak et al., 2015). X-rays are absorbed at different intensities as they pass through body tissues. CT detects these differences in absorption to produce detailed cross-sectional images. This allows for a detailed map of organs, tissues, and even blood vessels. It is especially widely used for examining internal organs such as the head, chest, abdomen, and pelvis. CT is of vital importance in the diagnosis and monitoring of a wide range of conditions, from cancer diagnosis to post-trauma injuries, brain hemorrhages, and heart diseases. According to the NCRP (2009) report, data obtained in 2006 indicate that CT usage in the United States increased by 8-15% annually over the past 7-10 years. In 2006, approximately half of the total medical radiation exposure was attributed to CT scans (Zhang et al., 2012). During this process, body tissues are exposed to radiation, which can damage organs (Power et al., 2016; Gul et al., 2024). Children are at a higher risk than adults for developing radiation-induced malignancies due to their longer life expectancies and increased tissue radiosensitivity in certain organs (UNSCEAR, 2013; Kost et al., 2015; Power et al., 2016; Journy et al., 2017; Habib Geryes et al., 2019; Gul et al., 2022). Moreover, the lesser amount of fat between organs in children

*Corresponding Author, e-mail: tsahmaran@gmail.com

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results in a higher absorbed dose than in adults when using the same technical parameters (Malchair & Maccia, 2020). The UNSCEAR (2013) report recommends avoiding the use of generalized radiation risk estimates for children (UNSCEAR, 2013). Leukemia and brain tumors are among the most common radiation-induced malignancies in children (Pearce et al., 2012; Meulepas et al., 2019). More frequent use of CT scans raises the overall radiation dose (Tahmasebzadeh et al., 2022). Research indicates that pediatric exposed to CT scan radiation have a higher cancer risk compared to their who are not exposed to CT (Mathews et al., 2013; Huang et al., 2014). Therefore, the optimization of imaging parameters to obtain diagnostic information at the lowest possible dose has become a primary goal in pediatric CT imaging (Lee C. et al., 2016; Pace & Borg, 2018; Strauss et al., 2019). Dose optimization in pediatric CT imaging depends on many parameters, including the patient's age, weight, tube voltage (kVp), current (mAs), and pitch factor (Al Mahrooqi et al., 2015; Olgar & Şahmaran, 2017; Priyanka & Sukumar, 2024). The variation of these factors is an effort to balance image quality with radiation dose. To expedite the dose optimization process, it is necessary to continuously evaluate dose levels in hospitals and medical facilities. Therefore, the optimal pitch, kVp, and mAs values for each situation should be carefully adjusted according to the objectives of the scan and the patient's characteristics (Muhogora et al., 2010; Smith-Bindman et al., 2019; Ataç & İnal, 2020). In the literature, there are not many experimental studies on the organ doses that pediatric patients are exposed to during CT scans with different imaging protocols and examinations. The difficulties of working with pediatric patients and the requirement for special permissions are among the reasons for this.

The aim of this study is to calculate the doses received by organs by varying parameters such as pitch factor, kVp, and mAs during head, chest, and pelvis scans using the Virtual Dose (NIBIB, USA) program. Additionally, the Volume Computed Tomography Dose Index ($CTDI_{vol}$), Dose Length Product (DLP), and effective patient doses (ED) were calculated and compared with results from the literature.

2. MATERIAL AND METHOD

Using the Virtual Dose program (Albany, New York, USA), the organ dose, $CTDI_{vol}$, DLP, and ED values for pediatric patients in four different age groups (0 years, 1 year, 5 years, and 10 years) were calculated. Funded by a grant from the National Institute of Biomedical Imaging and Bioengineering (NIBIB), Virtual Dose is designed to improve existing software packages by incorporating validated CT scanner models, scanner-specific correction factors, and the latest ICRP recommendations. It is a program that includes a series of voxel phantoms and 25 anatomically accurate patient phantoms (Ding et al., 2015). VirtualDose™CT is advanced radiation dose simulation software designed for radiologists, radiologic technologists, medical physicists, regulators, manufacturers, and researchers. By utilizing a well-tested anatomically accurate phantom family, revolutionary GPU-based Monte Carlo simulation, and innovative SaaS programming techniques, it enables radiation health professionals to achieve highly accurate images with significantly enhanced patient safety. VirtualDoseCT allows users to assess organ doses in addition to the $CTDI_{vol}$ and DLP data provided by the CT scanner. It can differentiate for individuals outside the "average" population body habitus. It is compatible with the latest CT scanners and adheres to the latest effective dose recommendations from ICRP-60 and ICRP-103. In this study, measurements were taken using a Toshiba Aquilion 16 CT scanner. The Toshiba Aquilion 16 CT scanner has a 16-slice detector with 896 channels, a slice width of 0.5mm, and can reconstruct images at 12 frames per second. It has a large aperture, slip-ring gantry, and extra-wide patient couch. The scanner provides high resolution imaging and has advanced capabilities such as ECG gating and cardiac function analysis. The relationship between $CTDI_{vol}$, DLP, and ED parameters used in dose calculation in CT systems is given below.

$$\mathrm{CTDI_{vol}} = \left(\frac{1}{3}\cdot \mathrm{CTDI_{Center}} + \frac{2}{3}\cdot \mathrm{CTDI_{Periphery}}\right)/\mathrm{pitch}$$
$$\mathrm{DLP} = \mathrm{CTDI_{vol}} \times \text{lenght of scan (cm)} \tag{1}$$

$$\mathrm{ED} = \mathrm{DLP} \times \mathrm{k}$$
$$\mathrm{CTDI_{vol}} = \mathrm{CTDI}_w/pitch \tag{2}$$

$$H_E = \sum w_T \, H_T$$
$$H_T = Q \, D_T \tag{3}$$

where, k is a conversion factor (mSv mGy^{-1} cm^{-1}). Pitch is the ratio of the table speed during a 360-degree rotation of the gantry to the thickness of the X-ray beam (collimation). Following the k-factors for adult patients, k-factors for pediatric patients, including newborns and those aged 1, 5, 10, and 15 years, have also been introduced for head and body CT examinations. The k-factors for extended scan regions have been published in the updated EC report, as adopted in the American Association of Physicists in Medicine (AAPM) Report (Shrimpton & Wall, 2000; EC, 2000; McCollough, 2012). w_T is the weighting coefficient for each tissue (T) or organ and H_T is the tissue equivalent dose. Q represents the quality factor of the radiation type, while D_T refers to the absorbed dose at a specific point within a given tissue (ICRP, 1977). Table 1 shows the CT scan parameters. Figure 1 displays the calculation screen in the virtual dose program.

Table 1. *Irradiation conditions of CT scan protocols*

	Head scan	Chest scan	Pelvis scan
Tube voltage (kVp)	80/100/120	80/100/120	80/100/120
Tube current (mAs)	80/90/100	80/90/100	80/90/100
Pitch factor	0.75/1/1.5	0.75/1/1.5	0.75/1/1.25
CT Manufacturer	Toshiba Aquilion 16	Toshiba Aquilion 16	Toshiba Aquilion 16

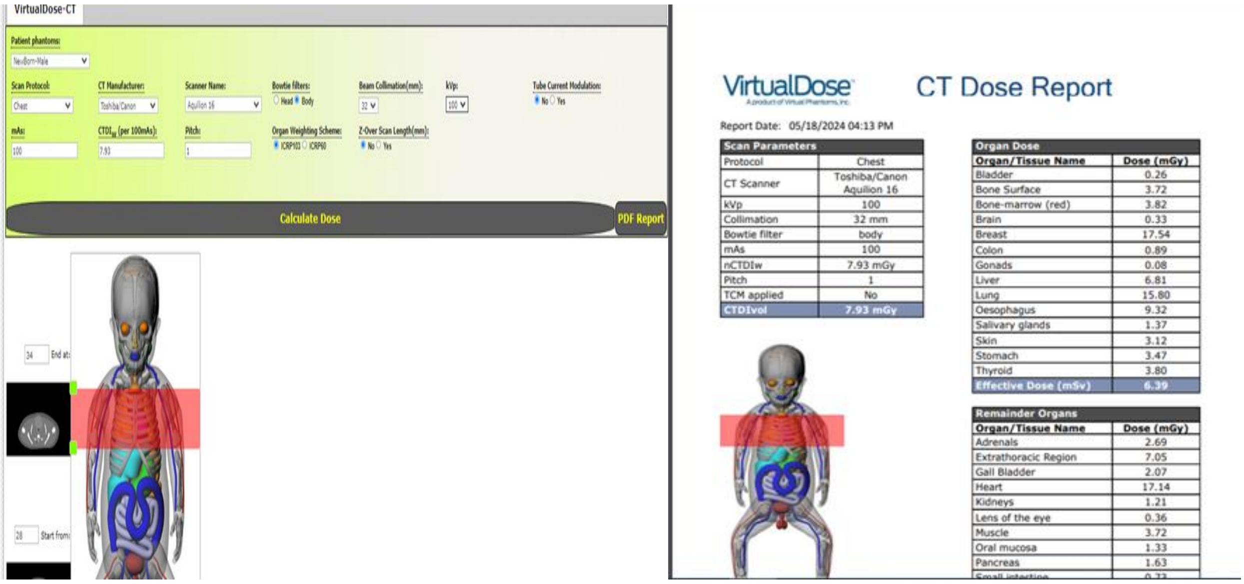

Figure 1. *The calculation screen in the virtual dose program.*

3. RESULTS AND DISCUSSION

The changes in $CTDI_{vol}$, DLP, and ED values for the head, chest, and pelvis phantoms in the 0-year-old, 1-year-old, 5-year-old, and 10-year-old groups are shown in Tables 2, 3, and 4. In Table 2, in the head_a section, when the mAs and pitch values are kept constant, the ED value obtained at 80 kVp for the 0-year-old is calculated as 1.05 mSv, while at 120 kVp, this value is calculated as 3.05 mSv. An increase of 190.48% is found in the ED value when increased from 80 kVp to 120 kVp. For the 1-year-old, 5-year-old, and 10-year-old groups, when increased from 80 kVp to 120 kVp, the increase in the ED value is found to be 205.31%, 201.01%, and 222.08%, respectively. In Table 2, in the head_b section, when the kVp and pitch values are kept constant, the ED value obtained at 90 mAs for the 0-year-old is found to be 0.75 mSv, while at 110 mAs, this value is found to be 0.92 mSv. An increase of 22.67% is found in the ED value when increased from 90 mAs to 110 mAs. For the 1-year-old, 5-year-old, and 10-year-old groups, when increased from 90 mAs to 110 mAs, the increase in the ED value is found to be 22.22%, 22.35%, and 21.92%, respectively. In Table 2, in the head_c section, a decrease in $CTDI_{vol}$, DLP, and ED values is observed when the pitch value is increased and the kVp and mAs values are kept constant. In Table 1, in the head_c section, when the kVp and mAs values are kept constant, the ED value obtained at a pitch factor of 0.75 for the 0-year-old is found to be 0.52 mSv, while at a pitch of 1.5, this value is found to be 0.26 mSv. When the pitch factor is increased from 0.75 to 1.5, a 50.00% decrease in the ED value is observed. For the 1-year-old, 5-year-old, and 10-year-old groups, when the pitch value is increased from 0.75 to 1.5, the decrease in the ED value is found to be 51.02%, 50.88%, and 48.94%, respectively. There is a linear inverse relationship between the pitch factor and radiation dose. As the pitch factor increases, the dose decreases, and as it decreases, the dose increases.

In Table 2, in the Head_a section, the DLP value has shown an increase with the change in kVp. When increased from 80 kVp to 120 kVp, the DLP value has increased by 174.82%, 174.05%, 174.06%, and 174.06% for the 0-year-old, 1-year-old, 5-year-old, and 10-year-old groups, respectively. In Table 2, in the Head_b section, the DLP value has increased with the change in tube current. When increased from 90 mAs to 110 mAs, the DLP value has increased by 22.23%, 22.24%, 22.21%, and 22.24% for the 0-year-old, 1-year-old, 5-year-old, and 10-year-old groups, respectively. In Table 1, in the Head_c section, the DLP value has decreased as the pitch factor decreased. When the pitch factor increased from 0.75 to 1.5, the DLP value has decreased by 39.17%, 50.00%, 50.00%, and 50.00% for the 0-year-old, 1-year-old, 5-year-old, and 10-year-old groups, respectively.

Table 2. *Comparison of $CTDI_{vol}$ (mGy), DLP (mGy cm), and ED (mSv) values at different kVp, mAs, and pitch values in head scans*

		80 kVp-80mAs-1 pitch			100 kVp-80 mAs-1 pitch			120 kVp-80 mAs-1 pitch		
	Age	**$CTDI_{vol}$**	**DLP**	**ED**	**$CTDI_{vol}$**	**DLP**	**ED**	**$CTDI_{vol}$**	**DLP**	**ED**
Head_a	**0**	6.40	46.72	1.05	11.35	82.85	1.93	17.54	128.04	3.05
	1		71.68	1.13		127.12	2.14		196.44	3.45
	5		81.92	0.99		145.28	1.85		224.51	2.98
	10		85.76	0.77		152.09	1.51		235.03	2.48
		100 kVp-90mAs-1 pitch			**100 kVp-100 mAs-1 pitch**			**100 kVp-110 mAs-1 pitch**		
	Age	**$CTDI_{vol}$**	**DLP**	**ED**	**$CTDI_{vol}$**	**DLP**	**ED**	**$CTDI_{vol}$**	**DLP**	**ED**
Head_b	**0**	12.77	93.22	0.75	14.19	103.58	0.84	15.61	113.95	0.92
	1		143.02	0.72		158.92	0.80		174.83	0.88
	5		163.45	0.85		181.63	0.94		199.80	1.04
	10		171.11	0.73		190.14	0.81		209.17	0.89
		80 kVp-90mAs-0.75 pitch			**80 kVp-90 mAs-1 pitch**			**80 kVp-90 mAs-1.50 pitch**		
	Age	**$CTDI_{vol}$**	**DLP**	**ED**	**$CTDI_{vol}$**	**DLP**	**ED**	**$CTDI_{vol}$**	**DLP**	**ED**
Head_c	**0**	9.60	57.60	0.52	7.20	52.56	0.39	4.80	35.04	0.26
	1		107.52	0.49		80.64	0.36		53.76	0.24
	5		122.88	0.57		92.16	0.43		61.44	0.28
	10		128.64	0.47		114.48	0.36		64.32	0.24

In Table 3, in the chest_a section, when the mAs and pitch values are kept constant, the ED value obtained at 80 kVp for the 0-year-old is calculated as 2.53 mSv, while at 120 kVp, this value is calculated as 7.19 mSv. An increase of 184.19% is found in the ED value when increased from 80 kVp to 120 kVp. For the 1-year-old, 5-year-old, and 10-year-old groups, when increased from 80 kVp to 120 kVp, the increase in the ED value is found to be 197.85%, 202.65%, and 211.11%, respectively.

In Table 3, in the chest_b section, when the kVp and pitch values are kept constant, the ED value obtained at 90 mAs for the 0-year-old is found to be 5.15 mSv, while at 110 mAs, this value is found to be 6.29 mSv. An increase of 22.14% is found in the ED value when increased from 90 mAs to 110 mAs. For the 1-year-old, 5-year-old, and 10-year-old groups, when increased from 90 mAs to 110 mAs, the increase in the ED value is found to be 22.13%, 22.18%, and 21.22%, respectively.

In Table 3, in the chest_c section, when the kVp and mAs values are kept constant, the ED value obtained at a pitch factor of 0.75 for the 0-year-old is found to be 3.80 mSv, while at a pitch of 1.5, this value is found to be 1.90 mSv. A decrease of 50.00% in the ED value is observed when the pitch factor is increased from 0.75 to 1.5. For the 1-year-old, 5-year-old, and 10-year-old groups, when the pitch value is increased from 0.75 to 1.5, the decrease in the ED value is found to be 50.00%, 50.15%, and 50.00%, respectively. In Table 3, in the chest_a section, when increased from 80 kVp to 120 kVp, the DLP value has increased by 174.06%, 174.05%, 174.06%, and 174.06% for the 0-year-old, 1-year-old, 5-year-old, and 10-year-old groups, respectively. In the chest_b section, the DLP value has increased as the tube current increased. When increased from 90 mAs to 110 mAs, the DLP value has increased by 22.24% for the 0-year-old, 1-year-old, 5-year-old, and 10-year-old groups. In the chest_c section, the DLP value has decreased as the pitch factor decreased. When the pitch factor increased from 0.75 to 1.5, the DLP value has decreased by 50.00% for the 0-year-old, 1-year-old, 5-year-old, and 10-year-old groups.

Table 3. *Comparison of $CTDI_{vol}$ (mGy), DLP (mGy cm), and ED (mSv) values at different kVp, mAs, and pitch values in chest scans*

		80 kVp-80mAs-1 pitch			**100 kVp-80 mAs-1 pitch**			**120 kVp-80 mAs-1 pitch**		
	Age	**$CTDI_{vol}$**	**DLP**	**ED**	**$CTDI_{vol}$**	**DLP**	**ED**	**$CTDI_{vol}$**	**DLP**	**ED**
Chest_a	**0**	6.40	38.40	2.53	11.35	68.10	4.58	17.54	105.24	7.19
	1		63.36	2.33		112.36	4.34		173.64	6.94
	5		83.20	2.26		147.55	4.25		228.02	6.84
	10		101.76	1.80		180.46	3.44		278.88	5.60
		100 kVp-90mAs-1 pitch			**100 kVp-100 mAs-1 pitch**			**100 kVp-110 mAs-1 pitch**		
	Age	**$CTDI_{vol}$**	**DLP**	**ED**	**$CTDI_{vol}$**	**DLP**	**ED**	**$CTDI_{vol}$**	**DLP**	**ED**
Chest_b	**0**	12.77	76.62	5.15	14.19	85.14	5.72	15.61	93.66	6.29
	1		126.42	4.88		140.48	5.42		154.53	5.96
	5		166.01	4.78		184.47	5.31		202.93	5.84
	10		203.04	3.87		225.62	4.30		248.19	4.73
		80 kVp-90mAs-0.75 pitch			**80 kVp-90 mAs-1 pitch**			**80 kVp-90 mAs-1.50 pitch**		
	Age	**$CTDI_{vol}$**	**DLP**	**ED**	**$CTDI_{vol}$**	**DLP**	**ED**	**$CTDI_{vol}$**	**DLP**	**ED**
Chest_c	**0**	9.60	57.6	3.80	7.20	43.2	2.85	4.80	28.8	1.90
	1		95.04	3.50		71.28	2.62		47.52	1.75
	5		124.80	3.39		93.6	2.54		62.4	1.69
	10		152.64	2.70		114.48	2.02		76.32	1.35

In Table 4, in the pelvis_a section, when the mAs and pitch values are kept constant, the ED value obtained at 80 kVp for the 0-year-old is calculated as 1.07 mSv, while at 120 kVp, this value is calculated as 3.08 mSv. An increase of 187.85% is found in the ED value when increased from 80 kVp to 120 kVp. For the 1-year-old, 5-year-old, and 10-year-old groups, when increased from 80 kVp to 120 kVp, the increase in the ED value is found to be 203.48%, 207.14%, and 218.99%, respectively.

In Table 4, in the pelvis_b section, when the kVp and pitch values were kept constant, the ED obtained at 90 mAs was found to be 2.17 mSv at the age of 0, while at 110 mAs, this value was found to be 2.65 mSv. When the mAs was increased from 90 to 110, an increase of 22.12% was observed in the ED value. For the age groups of 1, 5, and 10 years, when the mAs was increased from 90 to 110, the increase in the ED value was found to be 22.41%, 22.01%, and 21.76%, respectively.

In Table 4, in the pelvis_c section, when the pitch value was increased and the kVp and mAs values were kept constant, a decrease was observed in the $CDTI_{vol}$, DLP, and ED values. In Table 1, in the pelvis_c section, when the kVp and mAs values were kept constant, the ED value obtained at a pitch factor of 0.75 was found to be 1.58 mSv at the age of 0, while at a pitch of 1.5, this value was found to be 0.79 mSv. When the pitch factor was increased from 0.75 to 1.5, the decrease in the ED value was found to be 50.00% for each age group.

In Table 4, in the pelvis_a section, according to the variation in kVp, the DLP value increased as the kVp increased. When it increased from 80 kVp to 120 kVp, the DLP value showed an increase of 174.05%, 174.06%, 174.06%, and 174.06% in the age groups of 0, 1, 5, and 10 years, respectively. In Table 4, in the pelvis_b section, according to the variation in tube current, the DLP value increased as the current increased. When it increased from 90 mAs to 110 mAs, the DLP value showed an increase of 22.23%, 22.24%, 22.24%, and 22.24% in the age groups of 0, 1, 5, and 10 years, respectively. In Table 4, in the pelvis_c section, according to the variation in pitch factor, the DLP value showed a decrease as the pitch factor decreased. When the pitch factor was increased from 0.75 to 1.5, the decrease in the DLP value was found to be 50.00% for each age group.

In Tables 2, 3, and 4, the $CTDI_{vol}$ value increased as the kVp increased. When it increased from 80 kVp to 120 kVp, the $CTDI_{vol}$ value showed an increase of 174.06%. According to the variation in tube current, the $CTDI_{vol}$ value increased as the current increased. When it increased from 90 mAs to 110 mAs, the $CTDI_{vol}$ value showed an increase of 22.24%. Regarding the variation in pitch factor, the $CTDI_{vol}$ value showed a decrease as the pitch factor increased. When the pitch factor increased from 0.75 to 1.5, it was calculated that the $CTDI_{vol}$ value decreased by 50.00%.

In the study conducted by Ataç et al. (2015), for head scans, the $CTDI_{vol}$ values were found to be 31 mGy, 33.4 mGy, and 40.3 mGy for <1 year, 1-5 years, and 5-10 years age groups, respectively. For chest scans, the values were 13.6 mGy, 13.5 mGy, and 13.5 mGy, and for pelvis scans, they were 11.1 mGy, 12 mGy, and 13.3 mGy, respectively.

Table 4. *Comparison of $CTDI_{vol}$ (mGy), DLP (mGy cm), and ED (mSv) values at different kVp, mAs, and pitch values in pelvis scans*

		80 kVp-80mAs-1 pitch			**100 kVp-80 mAs-1 pitch**			**120 kVp-80 mAs-1 pitch**		
	Age	**$CTDI_{vol}$**	**DLP**	**ED**	**$CTDI_{vol}$**	**DLP**	**ED**	**$CTDI_{vol}$**	**DLP**	**ED**
Pelvis_a	**0**	6.40	35.84	1.07	11.35	63.56	1.93	17.54	98.22	3.08
	1		57.60	1.15		102.15	2.14		157.86	3.49
	5		67.84	0.98		120.31	1.85		185.92	3.01
	10		99.20	0.79		175.92	1.51		271.87	2.52
		100 kVp-90mAs-1 pitch			**100 kVp-100 mAs-1 pitch**			**100 kVp-110 mAs-1 pitch**		
	Age	**$CTDI_{vol}$**	**DLP**	**ED**	**$CTDI_{vol}$**	**DLP**	**ED**	**$CTDI_{vol}$**	**DLP**	**ED**
Pelvis_b	**0**	12.77	71.51	2.17	14.19	79.46	2.41	15.61	87.41	2.65
	1		114.93	2.41		127.71	2.68		140.49	2.95
	5		135.36	2.09		150.41	2.32		165.46	2.55
	10		197.93	1.70		219.94	1.88		241.95	2.07
		80 kVp-90mAs-0.75 pitch			**80 kVp-90 mAs-1 pitch**			**80 kVp-90 mAs-1.50 pitch**		
	Age	**$CTDI_{vol}$**	**DLP**	**ED**	**$CTDI_{vol}$**	**DLP**	**ED**	**$CTDI_{vol}$**	**DLP**	**ED**
Pelvis_c	**0**	9.60	53.76	1.58	7.20	40.32	1.58	4.80	26.88	0.79
	1		86.40	1.70		64.80	1.27		43.20	0.85
	5		101.76	1.48		76.32	1.11		50.88	0.74
	10		148.80	1.16		111.6	0.87		74.40	0.58

The organ dose values obtained from head CT examinations for each age group are summarized in Table 5. In head CT scans, the highest organ dose is associated with the brain (18.30 mGy). Following the brain, salivary glands (8.58 mGy), bone surface (5.80 mGy), and bone marrow (4.89 mGy) had the highest organ doses among all major and other organs. The results indicated that as the kVp and mAs values increased, the doses received by the organs also increased. When the pitch value was increased from 0.75 to 1.5, approximately a 50.00% decrease in organ doses was observed. Among the radiosensitive organs in childhood, the dose absorbed by the red bone marrow, which includes the highest dose, was found to be highest in the 10-year-old group (4.83 mGy). In the 0, 1, and 5-year-old groups, it was found to be 4.13 mGy, 4.33 mGy, and 4.70 mGy, respectively. The absorbed doses in the red bone marrow increased with age in pediatric patients.

Table 5. *The organ doses (mGy) obtained at different kVp, mAs, and pitch values in head scans*

	80/100/120 kVp				**90/100/110 mAs**				**0.75/1/1.5 pitch**			
	0	**1**	**5**	**10**	**0**	**1**	**5**	**10**	**0**	**1**	**5**	**10**
Bladder	0.01 0.02 0.03	0.00 0.01 0.01	0.00 0.01 0.01	0.00 0.00 0.01	0.02 0.02 0.03	0.01 0.01 0.01	0.00 0.00 0.01	0.00 0.00 0.01	0.01 0.01 0.01	0.00 0.00 0.00	0.00 0.00 0.00	0.00 0.00 0.00
Bone surface	1.73 3.35 5.50	1.76 3.47 5.80	0.93 1.88 3.19	0.96 1.94 3.29	3.76 4.18 4.60	3.91 4.34 4.78	2.12 2.36 2.59	2.18 2.42 2.66	2.60 1.95 1.30	2.64 1.98 1.32	1.40 1.05 1.70	1.65 1.08 0.72
Red bone marrow	1.30 2.51 4.13	1.31 2.59 4.33	1.37 2.78 4.70	1.43 2.88 4.89	2.83 3.14 3.45	2.92 3.24 3.56	3.12 3.47 3.89	3.24 3.61 3.97	1.95 1.46 0.97	1.97 1.47 0.98	2.06 1.55 1.03	2.10 1.60 1.07
Brain	6.45 11.67 18.30	5.45 10.31 16.60	4.34 8.42 13.76	4.56 8.90 14.60	13.52 14.58 16.04	11.58 12.88 14.17	9.47 10.52 11.57	10.01 11.12 12.23	9.68 7.26 4.84	8.18 6.13 4.09	6.51 4.88 3.26	6.85 5.13 3.42
Breast	0.08 0.16 0.25	0.06 0.12 0.22	0.05 0.12 0.21	0.02 0.05 0.09	0.18 0.20 0.22	0.14 0.15 0.17	0.13 0.15 0.16	0.05 0.06 0.07	0.12 0.09 0.06	0.09 0.06 0.04	0.08 0.06 0.04	0.04 0.03 0.02
Colon	0.02 0.04 0.07	0.01 0.02 0.03	0.00 0.01 0.02	0.00 0.00 0.01	0.04 0.04 0.05	0.02 0.02 0.02	0.01 0.01 0.01	0.00 0.00 0.01	0.03 0.02 0.01	0.01 0.01 0.00	0.01 0.00 0.00	0.01 0.00 0.00
Gonads	0.00 0.01 0.02	0.01 0.00 0.02	0.00 0.01 0.01	0.00 0.00 0.01	0.01 0.01 0.02	0.00 0.00 0.00	0.00 0.00 0.01	0.00 0.00 0.01	0.01 0.01 0.00	0.00 0.00 0.00	0.00 0.00 0.00	0.00 0.00 0.00
Liver	0.05 0.11 0.19	0.03 0.06 0.11	0.02 0.06 0.10	0.01 0.02 0.04	0.13 0.14 0.15	0.07 0.08 0.09	0.06 0.07 0.08	0.03 0.03 0.04	0.08 0.06 0.04	0.04 0.03 0.02	0.04 0.03 0.02	0.03 0.01 0.01
Lung	0.14 0.29 0.47	0.11 0.22 0.38	0.15 0.30 0.51	0.06 0.13 0.22	0.32 0.36 0.39	0.25 0.28 0.31	0.34 0.38 0.42	0.14 0.16 0.17	0.22 0.16 0.11	0.16 0.12 0.08	0.22 0.17 0.11	0.15 0.07 0.04
Oesophagus	0.20 0.40 0.65	0.24 0.51 0.85	0.23 0.49 0.83	0.11 0.23 0.41	0.45 0.50 0.55	0.57 0.63 0.70	0.55 0.61 0.67	0.26 0.29 0.32	0.30 0.23 0.15	0.36 0.27 0.18	0.35 0.26 0.17	0.18 0.12 0.08
Salivary glands	1.26 2.35 3.74	1.00 1.98 3.27	4.32 8.04 7.33	2.48 4.71 8.58	2.65 2.94 3.24	2.23 2.48 2.73	9.05 10.06 11.06	5.29 5.88 6.47	1.90 1.42 0.95	1.50 1.12 0.75	6.47 4.85 3.24	3.54 2.79 1.86
Skin	1.24 2.17 3.35	1.07 1.91 3.27	0.80 1.44 2.27	0.55 0.99 1.56	2.44 2.71 2.98	2.15 2.39 2.63	1.62 1.81 1.99	1.12 1.24 1.37	1.86 1.39 0.93	1.61 1.21 0.80	1.21 0.90 0.60	0.84 0.62 0.41
Stomach	0.04 0.08 0.13	0.03 0.06 0.10	0.02 0.05 0.09	0.01 0.02 0.03	0.09 0.10 0.11	0.07 0.08 0.09	0.05 0.06 0.07	0.02 0.02 0.03	0.06 0.04 0.03	0.04 0.03 0.02	0.03 0.02 0.02	0.02 0.01 0.01
Thyroid	0.57 1.12 1.82	0.35 0.74 1.25	0.49 1.01 1.70	0.30 0.64 1.39	1.26 1.41 1.55	0.83 0.93 1.03	1.10 1.26 1.38	0.72 0.80 0.88	0.86 0.63 0.44	0.53 0.40 0.27	0.74 0.55 0.37	0.69 0.34 0.22

Table 6 displays the doses received by organs at different kVp, mAs, and pitch values in chest scans. In chest CT scans, the highest organ dose is received by the breast (20.00 mGy). Following the breast, the doses received by the lungs (18.01 mGy), oesophagus (11.68 mGy), and stomach (6.62 mGy) are observed. In chest scans, the dose values received by the gonads at 80 kVp are 0.03 mGy, 0.02 mGy, 0.01 mGy, and 0.01 mGy for the age groups of 0, 1, 5, and 10 years, respectively. When the kVp value is increased to 120, these values are found to be 0.09 mGy, 0.06 mGy, 0.03 mGy, and 0.02 mGy, respectively.

Table 6. *The organ doses (mGy) obtained at different kVp, mAs, and pitch values in chest scans*

	80/100/120 kVp				**90/100/110 mAs**				**0.75/1/1.5 pitch**			
	0	**1**	**5**	**10**	**0**	**1**	**5**	**10**	**0**	**1**	**5**	**10**
Bladder	0.08 0.17 0.28	0.04 0.09 0.16	0.02 0.05 0.10	0.01 0.02 0.03	0.19 0.21 0.23	0.10 0.11 0.12	0.06 0.07 0.07	0.02 0.02 0.02	0.13 0.10 0.06	0.06 0.04 0.03	0.03 0.02 0.02	0.01 0.01 0.00
Bone Surface	1.34 2.57 4.21	1.36 2.67 4.44	1.26 2.50 4.19	0.98 1.98 3.35	2.89 3.21 3.53	3.01 3.34 3.68	2.82 3.13 3.44	2.23 2.48 2.73	2.01 1.50 1.00	2.04 1.53 1.02	1.89 1.42 0.94	1.47 1.10 0.74
Bone-marrow	1.38 2.64 4.62	1.42 2.78 4.61	1.23 2.45 4.11	0.97 1.96 3.32	2.97 3.33 3.63	3.12 3.47 3.82	2.76 3.07 3.37	2.21 2.45 2.70	2.06 1.55 1.03	2.12 1.59 1.06	1.84 1.38 0.92	1.45 1.09 0.72
Brain	0.11 0.22 0.37	0.08 0.18 0.30	0.06 0.13 0.22	0.05 0.11 0.19	0.25 0.28 0.31	0.20 0.22 0.24	0.14 0.16 0.17	0.12 0.13 0.15	0.17 0.19 0.08	0.12 0.09 0.06	0.08 0.06 0.04	0.07 0.05 0.04
Breast	7.33 12.87 20.00	5.35 9.77 15.58	5.56 10.24 16.41	4.43 8.20 13.18	14.48 16.09 17.70	11.00 12.22 13.44	11.52 12.80 14.08	9.23 10.25 11.28	10.99 8.25 5.50	8.03 6.02 4.01	8.34 6.25 4.17	6.64 4.98 3.32
Colon	0.32 0.61 0.98	0.17 0.35 0.60	0.14 0.29 0.50	0.10 0.23 0.41	0.69 0.76 0.84	0.40 0.44 0.49	0.33 0.36 0.40	0.26 0.29 0.32	0.48 0.36 0.24	0.25 0.19 0.13	0.20 0.15 0.10	0.15 0.12 0.08
Gonads	0.03 0.06 0.09	0.02 0.03 0.06	0.01 0.02 0.03	0.01 0.01 0.02	0.06 0.07 0.08	0.04 0.04 0.05	0.02 0.02 0.02	0.01 0.01 0.01	0.04 0.03 0.02	0.02 0.01 0.01	0.02 0.01 0.01	0.00 0.00 0.00
Liver	2.65 4.82 7.56	1.74 3.30 5.30	2.71 5.17 8.36	2.12 4.13 6.76	5.42 6.03 6.43	3.71 4.13 4.54	5.82 6.47 7.11	4.64 5.16 5.68	3.97 2.98 1.99	2.61 1.96 1.31	4.07 3.05 2.03	3.18 2.38 1.59
Lung	6.25 11.29 17.71	6.22 11.39 18.01	5.41 10.03 15.97	4.85 9.15 14.74	12.70 14.11 15.52	12.81 14.23 15.66	11.28 12.53 13.79	10.30 11.44 12.59	9.38 7.03 4.69	9.33 7.00 4.66	8.11 6.08 4.06	7.28 5.46 3.59
Oesophagus	3.50 6.53 10.44	3.78 7.19 11.68	3.22 6.33 10.35	2.79 5.61 9.35	7.38 8.17 8.98	8.08 8.99 9.89	7.12 7.91 8.70	6.32 7.02 7.72	5.25 3.94 2.63	5.67 4.26 2.84	4.83 3.62 2.41	4.19 3.14 2.09
Salivary glands	0.50 0.94 1.51	0.51 0.99 1.63	0.26 0.54 0.90	0.21 0.43 0.74	1.06 1.18 1.29	1.12 1.24 1.37	0.60 0.67 0.74	0.49 0.54 0.59	0.76 0.57 0.38	0.76 0.55 0.35	0.39 0.30 0.29	0.31 0.23 0.15
Skin	1.31 2.29 3.53	1.17 2.08 3.23	1.00 1.81 2.80	0.86 1.55 2.44	2.58 2.86 3.15	2.34 2.59 2.85	2.02 2.25 2.47	1.75 1.94 2.13	1.96 1.47 0.98	1.75 1.31 0.88	1.50 1.13 0.75	1.29 0.97 0.65
Stomach	1.31 2.42 3.83	1.67 3.18 5.13	2.13 4.09 6.61	1.18 3.37 3.94	2.73 3.03 3.33	3.58 3.98 4.58	4.60 5.11 6.62	2.67 2.37 3.26	1.92 1.45 0.94	2.50 1.88 1.25	3.20 2.40 1.60	1.78 1.33 0.89
Thyroid	1.45 2.65 4.17	2.00 3.77 6.04	0.81 1.59 2.61	0.73 1.49 2.48	2.99 3.32 3.65	4.24 4.71 5.19	1.79 1.99 2.19	1.68 1.86 2.05	2.17 1.63 1.08	2.99 2.25 1.50	1.21 0.91 0.61	1.10 0.82 0.55

Table 7 presents the doses received by organs at different kVp, mAs, and pitch values in pelvis scans. In pelvic CT scans, the highest organ dose is received by the bladder (18.77 mGy). Following the bladder, the doses received by the gonads (14.29 mGy), colon (8.23 mGy), and skin (3.27 mGy) are observed. In pelvic scans, the dose values received by the gonads at 80 kVp are 1.18 mGy, 2.36 mGy, 5.09 mGy, and 3.39 mGy for the age groups of 0, 1, 5, and 10 years, respectively. When the kVp value is increased to 120, these values are found to be 3.33 mGy, 6.61 mGy, 14.29 mGy, and 9.68 mGy, respectively.

Table 7. *The organ doses (mGy) obtained at different kVp, mAs, and pitch values in pelvis scans*

	80/100/120 kVp				**90/100/110 mAs**				**0.75/1/1.5 pitch**			
	0	**1**	**5**	**10**	**0**	**1**	**5**	**10**	**0**	**1**	**5**	**10**
Bladder	6.70 12.03 18.77	5.57 10.49 16.83	5.84 10.84 17.26	4.69 9.17 15.03	13.53 15.03 16.54	11.80 13.11 14.42	12.20 13.55 14.91	10.31 11.46 12.61	10.05 7.54 5.02	8.36 6.27 4.18	8.76 6.57 4.38	7.04 5.28 3.52
Bone Surface	0.53 1.04 1.73	0.47 0.69 1.62	0.69 1.42 2.42	0.75 1.57 2.70	1.17 1.33 1.43	1.08 1.20 1.32	1.60 1.77 1.95	1.76 1.96 2.15	0.80 0.60 0.40	0.70 0.53 0.35	1.04 0.78 0.52	1.13 0.84 0.56
Bone-marrow	0.06 1.17 1.93	0.52 1.02 1.80	0.51 1.17 2.00	0.61 1.27 2.18	1.31 1.46 1.60	1.19 1.33 1.46	1.32 1.47 1.62	1.42 1.58 1.74	0.89 0.67 0.47	0.78 0.59 0.39	0.86 0.65 0.43	0.91 0.68 0.46
Brain	0.01 0.02 0.03	0.01 0.01 0.01	0.01 0.00 0.01	0.01 0.00 0.00	0.02 0.02 0.03	0.01 0.01 0.01	0.01 0.01 0.01	0.01 0.00 0.01	0.01 0.01 0.01	0.01 0.00 0.00	0.01 0.00 0.00	0.01 0.00 0.00
Breast	0.05 0.11 0.18	0.02 0.04 0.08	0.01 0.02 0.03	0.00 0.01 0.02	0.12 0.13 0.15	0.05 0.06 0.07	0.02 0.02 0.02	0.01 0.01 0.02	0.08 0.06 0.04	0.03 0.02 0.01	0.01 0.01 0.00	0.01 0.00 0.00
Colon	1.73 3.10 4.83	2.74 5.13 8.23	1.37 2.59 4.16	0.82 1.63 2.70	3.48 3.87 4.27	5.77 6.41 7.06	2.92 3.23 3.56	1.84 2.04 2.25	2.59 1.89 1.30	4.11 3.08 2.05	2.06 1.55 1.03	1.23 0.92 0.61
Gonads	1.18 2.15 3.33	2.36 4.25 6.61	5.09 9.13 14.29	3.39 6.16 9.68	2.41 2.68 2.95	4.78 5.31 5.84	10.48 11.42 12.56	6.93 7.71 8.48	1.77 1.33 0.89	3.54 2.65 1.77	7.64 5.73 3.82	5.09 3.82 2.54
Liver	0.32 0.60 0.96	0.26 0.53 0.89	0.06 0.14 0.25	0.04 0.10 0.18	0.67 0.75 0.82	0.59 0.66 0.73	0.16 0.18 0.21	0.11 0.12 0.13	0.47 0.35 0.24	0.38 0.29 0.19	0.09 0.07 0.05	0.06 0.05 0.03
Lung	0.09 0.18 0.30	0.06 0.14 0.29	0.02 0.04 0.06	0.01 0.03 0.05	0.20 0.23 0.25	0.16 0.17 0.19	0.03 0.04 0.05	0.02 0.02 0.04	0.14 0.10 0.07	0.10 0.07 0.05	0.02 0.02 0.01	0.02 0.01 0.01
Oesophagus	0.07 0.19 0.32	0.04 0.08 0.14	0.01 0.03 0.05	0.01 0.04 0.05	0.21 0.24 0.26	0.09 0.11 0.13	0.03 0.04 0.05	0.02 0.03 0.04	0.13 0.09 0.06	0.05 0.04 0.03	0.02 0.01 0.01	0.01 0.01 0.00
Salivary glands	0.02 0.04 0.06	0.01 0.02 0.03	0.00 0.01 0.01	0.00 0.00 0.01	0.04 0.04 0.05	0.02 0.02 0.03	0.01 0.01 0.01	0.01 0.01 0.02	0.03 0.02 0.01	0.02 0.01 0.01	0.01 0.01 0.00	0.01 0.01 0.00
Skin	1.22 2.12 3.27	1.09 1.94 3.02	0.83 1.48 2.31	0.82 1.47 2.31	2.35 2.39 2.45	2.19 2.43 2.67	1.66 1.85 2.03	1.66 1.84 2.03	1.82 1.37 0.91	1.64 1.23 0.82	1.24 0.93 0.62	1.23 0.92 0.61
Stomach	0.38 0.73 1.17	0.32 0.65 1.09	0.07 0.16 0.28	0.05 0.13 0.24	0.82 0.95 1.00	0.73 0.82 0.90	0.18 0.20 0.22	0.15 0.17 0.19	0.57 0.43 0.28	0.47 0.35 0.24	0.11 0.08 0.05	0.08 0.06 0.04
Thyroid	0.03 0.06 0.11	0.02 0.04 0.07	0.01 0.01 0.02	0.00 0.00 0.01	0.07 0.08 0.09	0.05 0.06 0.07	0.01 0.01 0.01	0.01 0.01 0.02	0.04 0.03 0.02	0.03 0.02 0.01	0.01 0.00 0.00	0.01 0.00 0.00

In many studies, reducing the kVp value has a greater impact on the dose received by organs than reducing the mAs value. To reduce patient dose, it is necessary to reduce the kVp value (Szucs-Farkas et al., 2009; Lee S. M. et al., 2013; Li et al., 2013; Sarpün et al., 2019). In these studies, contrast-enhanced scans recommend lower kVp values for children and thin patients, while higher kVp values are recommended for obese patients (Schimmöller et al., 2014). In our study, as well, the changes in organ doses due to variations in kVp values in head, chest, and pelvic scans are higher compared to changes in mAs values. Similarly to adults, pediatric CT scans have been reported to use kVp values between 120 and 140 in recent years, whereas these values have decreased to between 80 kVp and 120 kVp (Frush et al., 2003). In their study, Shah et al. (2005) stated that there was no significant change in image quality as a result of reducing the mAs value in pediatric patients. Kamel et al. (1994) mentioned in their study that there was no significant difference in image quality or diagnostic accuracy in imaging protocols ranging from 80 mAs to 240 mAs. In our study as well, an increase in organ doses was observed with an increase in the mAs value.

4. CONCLUSION

CT is an important tool for pediatric diagnosis. However, minimizing the radiation dose given to children and preventing unnecessary scans are even more crucial. Physicians and technicians can significantly reduce exposure to children by using special imaging protocols. The brain received the highest organ dose in head CT scans, the breast received the highest organ dose in chest scans and the bladder received the highest organ dose in pelvis scans. As kVp and mAs values increased, $CTDI_{vol}$, ED and DLP values also increased. In addition, $CTDI_{vol}$ and DLP values decreased linearly as the pitch value increased. All clinicians requesting pediatric CT scans should continually assess the benefits and risks of the requested examination. Many studies have shown that high kVp or mAs values are not necessary for a good CT scan. Children, pregnant women, and patients undergoing repeated scans are particularly at risk. Exposure to high radiation doses can lead to serious health problems such as cancer. There are several strategies for reducing organ doses. Firstly, screening protocols should be reviewed, and low-dose protocols should be preferred. Secondly, devices that provide lower dose scanning due to technological advancements should be used. Additionally, regular calibration and adjustments are important for reducing radiation doses.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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