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Pediatric dose references levels estimation for routine computed tomography examinations in Great Khorasan province, Iran

H. Akbari-Zadeh, S.S. Seyedi, Z. Ganji, H. Sherkat, A.R. Montazerabadi, M.T. Bahreyni Toossi*

Medical Physics Research Center, Mashhad University of Medical Sciences , Mashhad, Iran

▸ ***Original article***

***Corresponding author:**
M. Taghi Bahreyni Toossi, Ph.D.,
E-mail:
BahreyniMT@mums.ac.ir

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ABSTRACT

Background: This study was performed to assess pediatric dose reference level for routine computed tomography (CT) examination (head, chest and abdomen-pelvic) along with its corresponding risks in Great Khorasan province, Iran. ***Martial and Methods:*** For this purpose, different CT scan parameters of patients in 1-5, 6-10, and 11-15 years old were collected from 23 public hospitals. The total and main organ effective dose (ED), and DLP was estimated by Impact Dose software for each age group. In addition, the cancer risk of each CT examination was calculated according to the BEIR VII model and ICRP 103 data with PCMX software. ***Results:*** The results of the estimated values of dosimetric quantities indicated that the range of changes of these quantities is very wide (3 to almost 10 times) even in a certain age group. In common CT scans, the highest value for the average dose received by the patient was 27.14 mGy for the brain, 11.41 mGy for the lung, and 9.88 mGy for the bladder, respectively. Also the highest amount of REID in men and women are caused by abdominal-pelvic and breast CT scan, respectively. ***Conclusion:*** Although the values of studied quantities are not significantly different from similar reports, however, this does not reduce the important and necessity of the present study, as knowing the real amount dosimetric quantities in each area can help local authorities in revising and optimizing protocols to reduce patients' dose.

INTRODUCTION

Today, computed tomography (CT) is considered an inevitable technique when detailed, accurate information is required rapidly in diagnosis of complicated illnesses. It's rapid and high quality 3D image production, increased its use in various medical specialties [1]. However, CT is a high dose technique compared to other X-ray imaging modalities [2]. Although only 25% of all X-ray imaging is performed using this technique but 75% of patients dose from radiological examinations is caused by this technique [3]. For instance, radiation dose from a chest CT is more than hundred times higher than a typical chest X-ray [4]. Hence the compliance with the principle of justification becomes very important [5].

In conducting CT examination it is more important to pay attention to radiation protection of children compared to adults, because they are considerably more sensitive to radiation and have a long life expect [6]. A recent study has the result of a showed that a dose of 30 mGy or higher to active bone marrow from a CT scan raise the risk of leukemia up to 2.3 times in higher for a young compared with an adult exposed to an identical CT scan [7]. Furthermore, epidemiological studies have demonstrated that pediatric who have experienced only one CT scan have a higher chance of developing cancer [8]. As a result, increasing use of this X-ray modality in children causes concern about the harmful effects of radiation and it requires careful monitoring at radiation dose received by patients of this age group [9, 10].

There are several quantities for monitoring and calculating the radiation dose effect. Absorbed dose (D), equivalent dose (H) and effective dose (ED) are the three main quantities defined to express the adverse effect of radiation. Equivalent dose (H) is used when the same absorbed dose is delivered an organ or tissue when exposed to different types of radiation e.g. alpha, beta, gamma or neutron. The study of the effects of a certain dose and a certain type of ionizing radiation in different tissues has showed the sensitivity of different tissues to radiation is different. Therefore, ICRP has assigned a weighting factor to each tissue in its report (103). The value of this factor indicates the level of radiation sensitivity of the tissue. The effective dose considered the tissue sensitivity and obtained from the product of tissue weighting factor (W_t) in the equivalent dose [11]. Although, these metrics are useful indexes in modalities comparing, but they cannot predict specific individual risks [12]. Risk of exposure induced cancer death (REID) is a quantity which several studies have recommended to use REID which indicates the probability death of an individual due to cancer induced by exposure [13].

ICRP has not defined dose limitation for exposure to ionizing radiation from medical application, but at the same time has emphasized that any such exposure should be in compliance with the ALARA principle. ALARA principle states that ionizing radiation should be as low as reasonably achievable [14-17] and awareness of the overall conditions of the patient's exposure is the first step to accomplish ALARA. This is particularly more important when the target population are children, as they are more sensitive to harmful effects of ionizing radiation. DRL is a practical and useful quantity to represent the optimization achieved in a radiological center. The greater Khorasan (including Khorasan Razavi, North Khorasan and South Khorasan) has a total population of more than 8 million people as in 2016 [18]. To our knowledge of the time this study was carried out and tils now, no other study has been conducted in this field. The results of this study would provide the area health managers do this region, how significant is the risk of routine CT examination compared to other studies.

MATERIAL AND METHODS

Data collection

This study was approved by our Institutional Review Board and informed consent was IR.MUMS.MEDICAL.REC.1402.039. For this purpose, a questionnaire containing the required information was prepared. The data needed to carry out this research project were collected from 23 active government hospitals and 30 CT scanners in the three provinces of the Great Khorasan for the period of Oct 2020 to June 2022. Brain, chest, abdomen-pelvic were the most common CT scans performed in these centers. The collected data included scanner name, model, number, detector rows, tube current (mA), kilo voltage at peak (kVp), pitch, scan range and slice thickness and information related to the patient included age and sex.

Estimation of different dose quantity

In this study the ImpactDose software (version 2.3, Germany) was used to calculate total body EDs, main organ EDs, CT dose index ($CTDI_{vol}$) and dose-length product (DLP). First, CT scan parameters such as scan type, kVp, mA, rotation time, number of detector rows, slice thickness and pitch were entered into the software. Also, the tube current modulation option in software was used in each CT scan that used this method. In addition, to the scan parameters, variables related to the patients such as age range, sex, lateral and anterior-posterior diameter, and scan length were recorded in the software. The calculations performed with this software are based on the use of the ORNL mathematical phantom. Since the patient's body dimensions are used in the calculations, the values obtained for the patient's EDs are close to reality. In calculating the effective dose W_t values were used as recommended in ICRP report 103.

Cancer risk estimation

In this study, PCXMC software (v. 2, STUK, Helsinki, Finland) [19] was used to calculate REID for patients aged 1 to 15 years. The software was developed for Asian men and women. Patient was divided into age group with a two-year interval. This software uses Biological Effects of Ionizing Radiation VII (BEIR VII) model to estimate REID [20]. The BEIR VII model estimate the risk of leukemia and solid cancers, including breast, colon, liver, lung, ovary, stomach, bladder, and other solid cancers combined, assuming a latent period of 2 and 5 years, respectively [21]. PCXMC adopts the sex- and age-specific mortality and cancer incidence data from ICRP publication 103 [11].

Statistical analysis

GraphPad Prism software (v7.01, La Jolla, CA, USA) was used for statistical analysis of the result. For each of the desired dosimetric quantities in this study, mean and standard deviation were calculated. The mean value of $CTDI_{vol}$ and DLP were selected as dose reference level (DRL). The significance of differences genders and our results compared to other studies were evaluated by t-test ($p<0.05$).

RESULT

Patient and CT scan characteristics

In this study, the scan information of 460 people was used. Table 1 shows the number of people studied in each age group and gender. In all scans, the patients are first prepared and all metallic objects such as earrings and dental prosthetics in head scan, are removed from them. Then, they were positioned head first and in supine position. Their arms are placed on their side in the head scan and elevated in the chest and abdomen-pelvic scan. CT scan parameters including kVp, mAs, slice thickness, pitch, and scan length for common CT examination protocols for all age groups of pediatrics are summarized in table 2.

Table 1. Demographics of our study group.

Procedure	Age range	Gender	
		Male	Female
Brain	1-5	24	20
	6-10	25	23
	11-15	33	22
Chest	1-5	22	21
	6-10	27	23
	11-15	35	24
Abdomen-Pelvic	1-5	23	21
	6-10	28	27
	11-15	32	30

Table 2. Relevant to CT scan parameters in brain, chest, and abdomen-pelvis as routine examination for pediatric different age groups (1-5, 6-10, and 11-15 years old).

Procedure	Age range	kVp	mAs	Slice thickness (mm)	Pitch	Scan length (cm)
Brain	1-5	80-130	80-240	0.5-5	0.55-1.44	8-14.2
	6-10	80-130	80-260	0.5-5	0.55-1.44	8-17
	11-15	120-140	100-300	2-10	0.55-2	10-20
Chest	1-5	80-120	30-160	1-7	0.6-1.5	9-18.6
	6-10	80-120	40-160	1-7	0.6-1.5	15-25.8
	11-15	110-130	80-290	1-10	0.94-1.5	18-33.1
Abdomen-Pelvic	1-5	80-130	40-150	1-7	0.6-1.5	10.7-22.8
	6-10	80-130	40-160	1-7	0.5-1.5	15-28
	11-15	120-130	60-200	2-10	0.94-1.5	20-37

Estimation of radiation dose

Distribution of $CTDI_{vol}$ values resulting from head, chest and abdomen-pelvic scans for the three age groups considered in this study is shown in figure 1 and as group A, B and C. The comparison of these graphs is evident that $CTDI_{vol}$ is more uniformly distributed for all age groups in the head scan. Our result revealed that the mean value of $CTDI_{vol}$ for head is 24.72 ± 11.03, 27.54 ± 9.84 (mGy), 26.61 ± 8.79 at age groups (1-5, 6-10 and 11-15) respectively. Similar values for the three studied age groups and for chest and abdomen-pelvis CT are reported as follows: 4.72 ± 2.32, 5.37 ± 2.1, 7.38 ± 3.36 (mGy) and 7.19 ± 4.4, 8.23 ± 5.76, 9.35 ± 3.82 (mGy). The ratios of maximum to minimum value obtained for $CTDI_{vol}$ of chest for the studied age groups are as follows: 7.4, 8.4, 5.54-fold. Similar ratios for head and abdomen-pelvis for the three groups are 4.2, 3.1 and 3.0-fold and 5.58, 6.42 and 3.0-fold.

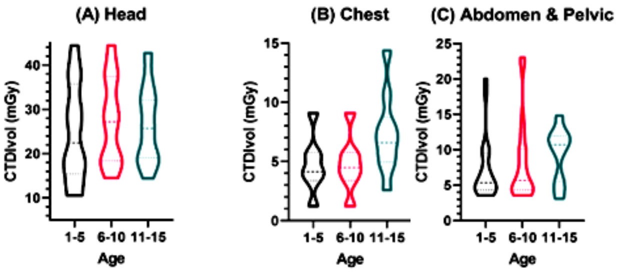

Figure 1. Violin plot of calculated   for brain, chest, and abdomen-pelvis as main examination protocols in pediatric different age's (1-5, 6-10, and 11-15 years old). The dashes drawn in the figure represent quartiles.

The distribution the DLP of head, chest and abdomen-pelvis examination are presented in figure 2. This result revealed that mean DLP value are 345.7 ± 145.1, 411.9 ± 178.8, 465.8 ± 198.9 (mGy.cm) for head of different ages' group respectively. These values are 137.1 ± 66.6, 143.3 ± 63.3, 273.5 ± 104.5 (mGy.cm) and 231.5 ± 124.7, 271.8 ± 174.4, 346.2 ± 150.5 (mGy.cm) for chest and abdomen-pelvic. The further analysis of DLP values indicate the ratio of the maximum to minimum value of this quantity for the age groups in question are for head 6.76, 5.9, 3.8 fold and for chest and abdomen-pelvis, respectively is 4.4, 3.8, 3.4-fold and 5.1, 6.5, 5.8-fold.

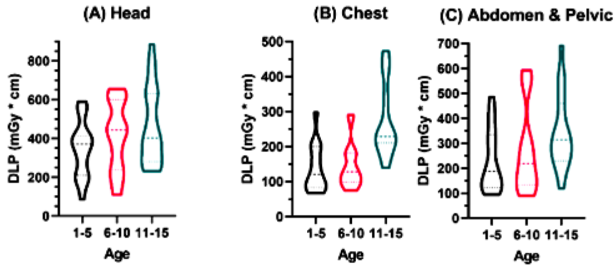

Figure 2. Violin plot of calculated DLP for brain, chest, and abdomen-pelvis as main examination protocols in pediatric different age's (1-5, 6-10, and 11-15 years old). The dashes drawn in the figure represent quartiles.

Estimated organ doses

The Violin plot of EDs are shown in figure 3. This figure shows that the mean value of EDs of 1-5, 6-10 and 11-15 years old are 1.57 ± 0.88, 1.44 ± 0.78, 1.54 ± 0.82 (mGy) respectively in the head CT examination. These values are 6.63 ± 3.79, 5.81 ± 3.42, 6.85 ± 3.71 (mGy) for chest and are 9.74 ± 3.29, 8.54 ± 3.18, 10.12 ± 4.17 (mGy) for abdomen-pelvic. The ratio of maximum to minimum of EDs are 11.7, 9.46, 12.2-folds for head scan in various ages. Also by further examination of figure 4, it is clear which of the main organs in the CT image of the age groups in question received the highest dose. As it is expected the organ location in the radiation field have received a higher dose brain, lung and bladder received the highest dose in head, chest and abdomen-pelvis CT examinations (27.14 ± 4.55, 11.41 ± 3.42, 9.88 ± 2.34 mGy), respectively.

Risk Prediction

The total REID of each CT scan procedure as a function of ages are illustrated in figure 5 for women and men. According to this figure, the chest scan in women and abdomen-pelvic scan in men has the highest risk of induced cancers. In general, REID seems to be higher for women than men, the only significant difference was observed in chest scan. The risk of lung cancer in men and lung and breast cancer in women has the largest share in chest scan as one of the high-risk scans. BEIR IIV models predicted that colon, liver, stomach and bladder are main cancer risk in the abdomen-pelvic CT examination in both genders.

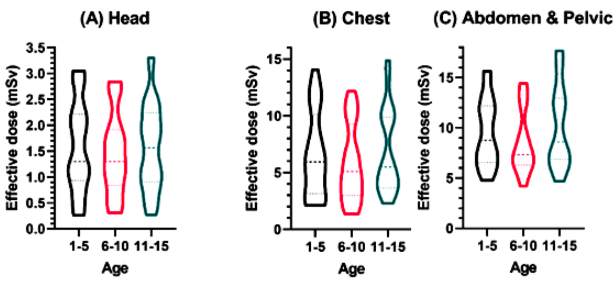

Figure 3. Violin plot of calculated effective dose for brain, chest, and abdomen-pelvis as main examination protocols in pediatric different age's (1-5, 6-10, and 11-15 years old). The dashes drawn in the figure represent quartiles.

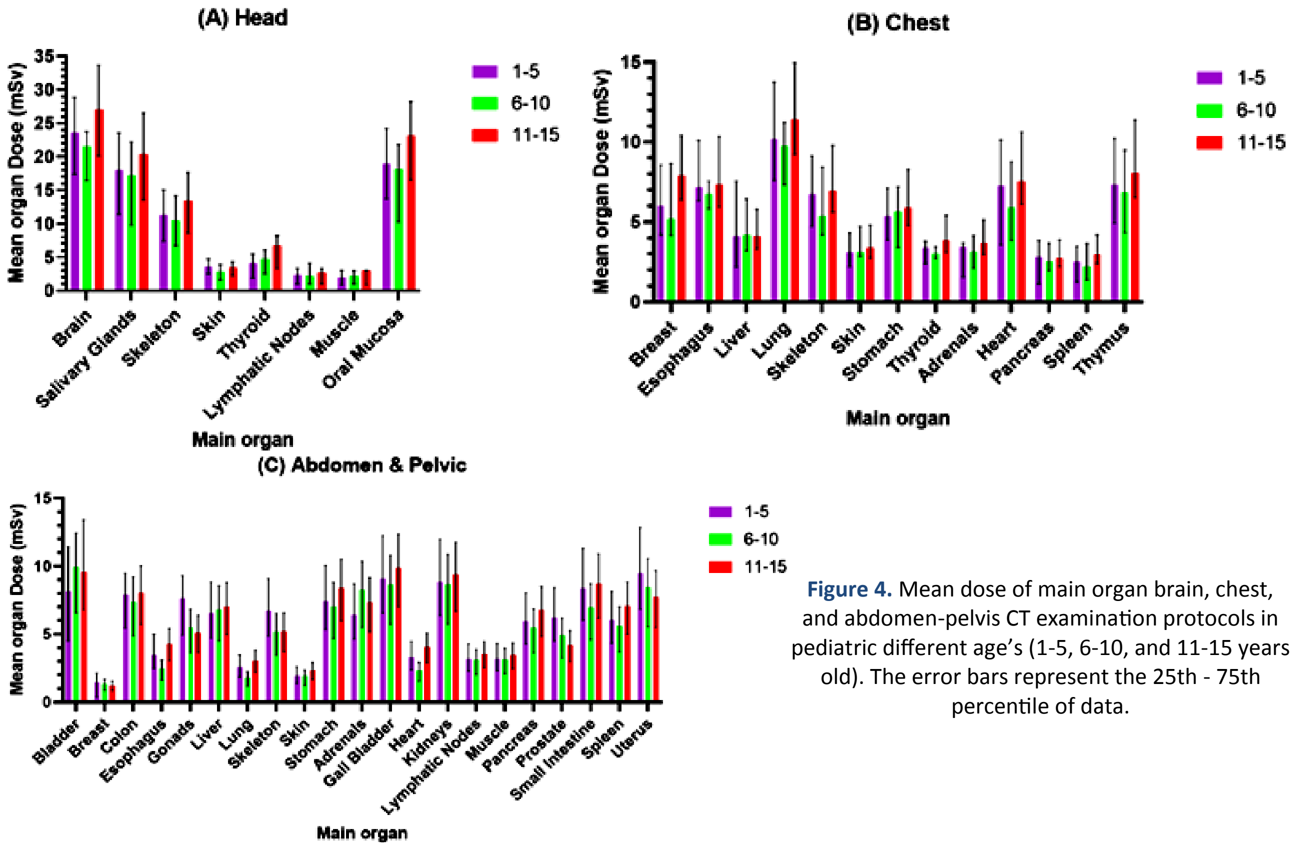

Figure 4. Mean dose of main organ brain, chest, and abdomen-pelvis CT examination protocols in pediatric different age's (1-5, 6-10, and 11-15 years old). The error bars represent the 25th - 75th percentile of data.

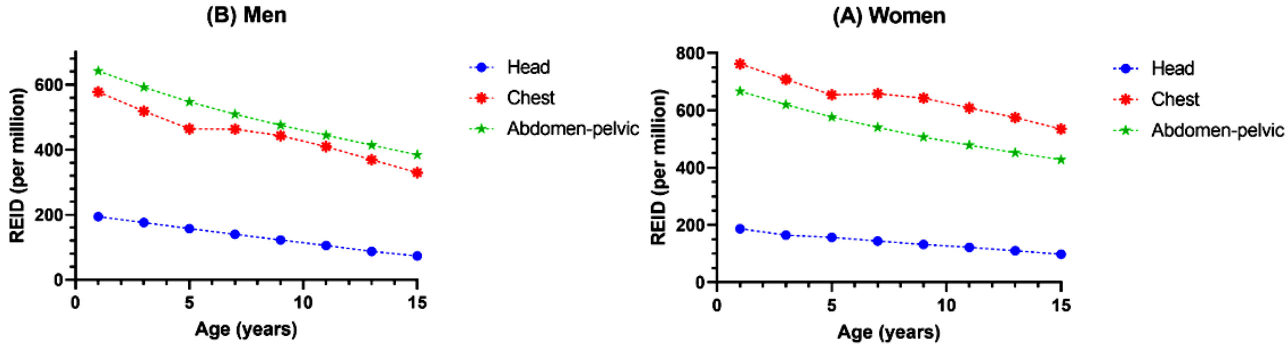

Figure 5. Total number of radiation exposure-induced deaths (REID) per million as an age function for **(A)** women and **(B)** men.

DISCUSSION

Today, advanced CT technology has provided fast and complex scans of patients [22]. Since children are known to be more sensitive to radiation and are expected to live longer following a CT examination, studying harmful effects of CT imaging has attracted the attention of researchers. The results of several studies have caused concerns about the consequence of the increasing use of this technique [22–26]. Pearce *et al.* [7] believe that an active bone marrow dose from CT of 30 mGy or higher would boost the risk of leukemia up to 2.3 times higher in children. In addition, Miglioretti *et al.* [9] stated that the risk of brain cancer were 2.8 times greater in the pediatrics who received a brain dose of 50 mGy or higher in CT examination.

The $CTDI_{vol}$ and DLP quantities are used as DRL metrics. Our result revealed that, the $CTDI_{vol}$ was increased with age (figure 1). This may be due to the increasing irradiated volume of patients with age. The DLP quantity shows similar behavior with $CTDI_{vol}$ (figure 2). The value of these two quantities in head scan is more than other CT examinations (figures 1 and 2). The reason for this phenomenon may be due to higher absorption of X-ray in the skull [27]. Nevertheless, longer scan length in the abdomen-pelvic procedure makes its DLP value closer to the DLP of head scan. Table 3 represent summary of $CTDI_{vol}$ and DLP values of various CT scans for pediatric and adult in some countries [21, 27–33]. These are in agreement with our results. In table 4, the dose caused by CT scan imaging of head, chest and abdomen-pelvic is compared with the corresponding values from a simple chest X-ray and background equivalent radiation time. The dose from a CT scan of a particular organ or region of the body is much higher than imaging by common X-ray radiography.

Table 3. Summary of , DLP and effective dose values of various CT examination scan in some countries for pediatric and adult. The three numbers displayed in the pediatric section represent the 1-5, 6-10 and 11-15 years-old, respectively.

Parameters	Procedure	Pediatric					Adult					
		This study	Iran [27]	Portugal [28]	Switzerland [29]	UK [30]	Iran [31]	Iran [27]	Iran (Yazd) [21]	Germany [32]	Egypt [33]	Portugal [28]
$CTDI_{vol}$	Head	24.7 27.5 26.6	25.9 32.6 34.9	44.6 52.3 59.2	30 40 60	35 44 N.R	48.8	35.9	N.R	53	30	75
	Chest	4.7 5.4 7.4	5.5 5.6 7.4	3.89 5.26 6.27	8 10 12	16 19 N.R	9.41	7.8	N.R	12	22	14
	Abdomen - pelvic	7.2 8.2 9.4	7.3 8.8 9.2	N.R	9 13 16	N.R	11.8	9.9	N.R	11	31	18
DLP	Head	345.7 411.9 465.8	227.4 336.8 384.2	673.6 785.4 929.8	420 560 1000	380 510 N.R	555.7	521.1	N.R	740	1360	1010
	Chest	137.1 143.3 273.5	83.8 110.4 187.6	98.3 175.7 212.2	200 220 460	200 300 N.R	244.1	250.3	N.R	279	420	470
	Abdomen - pelvic	231.5 271.8 346.2	154.6 262.2 296.1	N.R	300 380 500	N.R	517.7	403.2	N.R	496	1325	800
Effective dose	Head	1.57 1.44 1.54	1.52 1.35 1.61	N.R	N.R	1.5 1.6 N.R	N.R	1.09	1.05	1.6	N.R	N.R
	Chest	6.63 5.81 6.85	4.79 4.37 5.36	N.R	N.R	3.6 3.9 N.R	N.R	7.70	3.64	5.1	N.R	N.R
	Abdomen - pelvic	9.74 8.54 10.12	10.20 11.53 9.76	N.R	N.R	N.R	N.R	13.29	5.79	7.9	N.R	N.R

Table 4. The equivalent effective dose of a CT scan with number of posteroanterior (PA) chest radiographies and natural background radiation in years for main CT examination. PA and natural background radiation dose assumed 0.022 and 2.4 (mSv), respectively at different age.

Procedure	# PA Chest Radiographs	Equivalent Duration of Natural Background Radiation (Years)	
		Great Khorasan	Yazd (Iran) [21]
Head	72 65 70	0.65 0.60 0.64	0.43
Chest	302 264 311	2.76 2.42 2.85	1.54
Abdomen-pelvic	442 388 460	4.05 3.55 4.21	2.41

The results of this study indicate that the risk of death due to induced cancer by radiation exposure is higher for young patients. It can be seen in figure 5 that the highest risk is induced by CT scan of abdominal-pelvic and chest regions. Our results are in agreement with those of Masjedi *et al.* [21]. Higher radiosensitivity as well as longer life span of elders would cause higher risk of serious harmful effects in these group of patients.

Nevertheless, there is no doubt that CT examinations have period an extremely useful imaging tool for a fast and accurate diagnostic techniques and has saved many lives on the other hand, but these values received by the patients as obtained in this study and similar works indicate that the importance of having sufficient knowledge of dose reduction techniques when this modality is used. In addition, according to the ALARA principle, we are obliged to deliver the lowest reasonably achievable dose [14-17]. In this context some strategies to adopt are: prescription CT only when really necessary, choosing alternative imaging technique, limiting field of view, and setting exposure parameters based on size of the child and region to be imaged [26]. The relationship between radiation dose and beam energy, tube current, and pitch are: nonlinear, linear, and inversely proportional, respectively. Zacharias *et al.* [24] stated that an energy increase in a beam from 80 to 100 kVp would alter the CTDI from 14 to 26 mGy in a head phantom. Also, scans with pitch 2 result in a 50% decrease in absorbed dose compared to scans with pitch 1. Iterative reconstruction methods and automatic exposure control (AEC) are beneficial for a decrease in patient doses. On the other hand, dose reduction leads to a decrease in image quality. Therefore, there should be a compromise between dose reduction and image quality to provide an image which lead to an accurate diagnosis. Regular reviewing CT protocols is necessary for the optimization of image quality and dose.

CONCLUSION

This study reported pediatrics' doses arising from routine CT examination of head, chest, and abdomen-pelvis. The data provided a practical estimation of ionizing radiation risk in the Greater Khorasan region, which could be used as an exposure guideline or DRL for dose optimization and assessment of exposure parameters in clinical CT scans. Our result revealed that the doses delivered to patients in the Greater Khorasan are not significant difference to global values. However, given the wide distribution of doses observed, the need to optimize protocols and train personnel in this vast region seems necessary.

Ethical consideration

For this article no studies with human participants or animals were performed by any of the authors. Written informed consent was waived by the Institutional Review Board. Institutional Review Board approval was obtained.

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Author contribution: H.A., Writing original draft, investigation, calculation. S.S.S., Data collection, investigation. Z.G., H.S., Investigation & calculation. A.M., Review & editing. M.T.B.T.**,** Supervision, project administration, funding acquisition, final reviewing.

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