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Estimation of Effective Doses and Lifetime Risk of Exposure-induced Cancer Death in Pediatric CT Scans

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Abstract

Background: The increasing frequency of computed tomography (CT) scans for a range of purposes, particularly pediatrics, has raised concerns regarding the population's radiation exposure and subsequent chances of cancers. This study aimed to estimate the effective doses of pediatrics radiation and induced cancer risks from five most common CT scan procedures in Yazd Province, Iran.

Methods: Data of pediatric patients from four age groups of ≤1, 1-5, 5-10, and 10-15 years old were retrospectively collected from 6 educational institutions located in diverse areas of Yazd Province. For each participant, the effective doses and REID (risk of exposure-induced death) rate were estimated by Impact Dose and PCXMC software, respectively. Then, the findings were reported by categorizing the patients regarding their effective diameter.

Results: The effective doses and REID values did not show any significant differences among the studied age groups. The highest mean of effective dose was recorded for the scan of abdomen-pelvis (average ± standard deviation, 5.24±3.19 mSv) followed by chest (3.76±2.28 mSv), brain (1.25±1.07 mSv), and sinus (0.65±0.4 mSv) examinations. The highest REID was documented for chest scan (490±314 excess deaths in one million scans) followed by abdomen-pelvis procedure (404±280).

Conclusion: The radiation doses delivered to the pediatric patients and the associated fatal cancer risk with common CT procedures were comparably in the same range of the previous studies. Our findings can represent an estimation of the radiation-induced risks of CT scans and can be used for extending the knowledge of clinicians and researchers.

Key Words: Cancer risk, CT scan, Effective dose, Impact dose, PCXMC software, Pediatrics.

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1- INTRODUCTION

Computed Tomography (CT) is a non-invasive imaging modality first introduced by Hounsfield in the United Kingdom in 1972, and its applications are growing with a significant high rate in medical diagnostics all over the world (1). CT scans provide medical images having high spatial resolution presenting superior-anatomical details compared to other imaging modalities, while there are still concerns about the side effects of ionizing radiations used in CT scanners on patients, particularly for children (2).

It is well known that the lifetime risk of radiation-associated cancer tends to be higher for children, due to their higher radio sensitivity and longer lifetime (3-5). Moreover, it has been estimated that CT examinations have an annual growth rate of 10 percent, with pediatric scans rising faster than CT growth rate for adults (6, 7). The increase in annually performed CT scans in the United States was 1.15 million per year which resulted in 20 million CT scans in 1995 compared to 2.8 million in 1981 (8).

The benefits of a CT scan performed on symptomatic patients predominantly outweigh the induced cancer risks; however, it must be justified and compared with other diagnostic protocols. Furthermore, in several studies, it has been reported that there is no clinical rationale for up to one-third of CT scans (4, 5). This may partly emerge from the fact that medical specialists, particularly physicians, appear to be unaware of the risks associated with these tests (6, 9). Therefore, there is a need for estimating the risks of CT scans for different patients, protocols and geographical regions.

This study was designed to estimate the effective doses delivered to the pediatric patients and broaden our knowledge regarding the cancer risks attributed to the most common CT scans performed in Yazd Province, Iran.

2- MATERIALS AND METHODS

2-1. The studied institutions

Data were retrospectively collected from six general hospitals located in different geographical regions of Yazd Province, Iran, including A) Shahid Sadoughi Hospital, B) Shahid Rahnemoon Hospital, C) Imam Sadegh Hospital, D) Ziaee Hospital, E) Shahid Beheshti Hospital, and F) Shohadaye Kargar Hospital. Except for the hospital F, all the institutions are affiliated to Shahid Sadoughi University of Medical Sciences and Health Services. The data were collected from February 2019 to June 2020. The characteristics of the involved CT scanners are presented in **Table 1**.

2-2. Data Collection

Overall, 765 patients aged under 15 years undergoing CT examinations of brain, sinus, chest, and abdomen–pelvis were included in our study. It is notable that 61% of the patients (467 patients) were male and 39% (268 patients) were female. Furthermore, 35% underwent a CT scan of the brain followed by abdomen-pelvis (24% of patients), routine chest (22%), and sinus (19%) examinations. These procedures were chosen since they are highly prescribed by physicians, based on the hospital information system (HIS) of our studied institutions in 2018 (the procedures with a frequency of at least 5% (**Fig. 1**)).

For each patient, data including the demographics of age, gender, anterior-posterior (AP) thickness, and lateral (LAT) thickness, as well as the scan parameters (section thickness, detector rows, kVp (peak kilovoltage), mAs (current-time product), automatic exposure control implementation, dose data reported by the console (computed tomography dose index ($CTDI_{vol}$) and dose length product (DLP)

were recorded from the picture archiving and communication system (PACS).

Table-1: Characteristics of the involved CT scanners

Institution	Vendor	Model	# Detector Rows	Acquisition Type	Max Power (kVA)	Max kVp	Max mA	Max FOV (mm)
A	Toshiba	ALEXION	16	Spiral/Sequential	100	135	300	500
B	Siemens	SOMATION EMOTION	16	Spiral/Sequential	70	130	345	700
C	Siemens	SOMATOM SENSATION	4	Spiral/Sequential	50	140	500	500
D	Toshiba	ACTIVISION	16	Spiral/Sequential	75	135	300	500
E	Siemens	SOMATOM EMOTION	16	Spiral/Sequential	70	130	345	700
F	Siemens	SOMATOM EMOTION	16	Spiral/Sequential	70	130	345	700

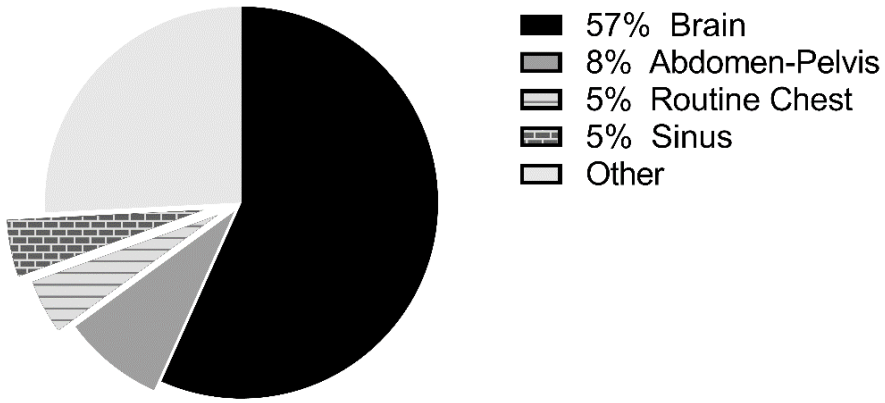

Fig. 1: Contribution of the procedures to all CT scans performed on pediatrics in 2018 in Yazd Province.

2-3. Categorization of the Patients

Since according to ICRP recommendations in publication 135 (10), the dose received by an individual is highly affected by patient size, the participants were also categorized based on their effective diameter. Supposing a cylindrical circumference for the body, effective diameter represents the radius of the body and is calculated as the square root of multiplying anterior-posterior (AP) and lateral (LAT) dimensions of the patient (equation 1) (11).

Equation 1: $$Effective\ diameter = \sqrt{Thickness_{AP} \times Thickness_{LAT}}$$

The group of the patients with different effective body diameters were divided by an equivalent age, recommended by the International Commission on Radiation Units and Measurements (ICRU) report 74 (12). **Table** 2 illustrates the categorizations and the corresponding ages.

Table-2: Effective diameter classifications (in cm) and their equivalent ages (in years) in both trunk and head regions

Trunk Region		Head Region	
Effective Diameter	Equivalent Age	Effective Diameter	Equivalent Age
≤15.1	≤ 1	≤13.9	≤ 1
(15.1,18.5]	(1,5]	(13.9,16.1]	(1,5]
(18.5,21.6]	(5,10]	(16.1,16.7]	(5,10]
(21.6,26.0]	(10,15]	(16.7,17.4]	(10,15]
>26.0	> 15	>17.4	> 15

2-4. Quality Control

To ensure that the CT-system displayed dose data are accurate enough to be directly implemented in the study, dose measurements in a CTDI phantom were performed under various exposure settings. The $CTDI_{100}$ was measured by a Barracuda package using a 100-mm-long pencil ionization chamber (RTI Electronics, Sweden) at central and peripheral holes of both head CTDI phantom (16 cm in diameter) and body CTDI phantom (32 cm in diameter). Subsequently, the weighted-CTDI ($CTDI_w$) and volume-CTDI ($CTDI_{vol}$) were calculated by the following equations:

Equation 2: $$CTDI_w = \frac{1}{3}CTDI_c + \frac{2}{3}CTDI_p$$

Equation 3: $$CTDI_{vol} = \frac{CTDI_w}{pitch}$$

The subscripts refer to central (*c*) or peripheral (*p*) holes, and *pitch* is the table increment per rotation divided by beam width (13-15). Thereafter, the percentage tolerance between the measured and displayed doses was calculated as follows:

Equation 4:

$$Tolerance = \frac{Measured - Displayed}{Displayed} \times 100\%$$

2-5. Dose Calculation

For each participant, effective dose and organ doses were estimated by Impact Dose software (CT Imaging GmbH, Erlangen Germany). In this regard, examination data as well as patient demographics (age and effective diameter) were given as inputs to the software, and then patient-specific doses were calculated by the software and recorded for further analysis. Impact Dose estimates the dose delivered to each patient by taking advantage of a more sophisticated Oak Ridge National Laboratory (ORNL) phantom (16) and tabulated pre-calculated Monte Carlo data. Several investigators have assessed the validity of this software package, and the findings of almost all of these investigations had shown that in parallel with fast calculations, dose estimations are adequately accurate (17-20).

2-6. Risk Evaluation

To investigate the cancer induced risks from CT scans, the risk of exposure-induced death (REID) (21) was estimated using the personal computer-based Monte Carlo (PCXMC) software (STUK, Helsinki, Finland); the risk was introduced as the probability that an exposed individual will die after radiation-induced

cancer. The input parameters for PCXMC consisted of the size of the radiation field, the coordinates of the location, beam angle, focus-reference point distance, age, gender, kVp (peak kilovoltage), organ dose, and finally effective dose. The parameters were quantified for each patient. PCXMC benefits from the risk models developed by the Committee on the Biological Effects of Ionizing Radiation (BEIR-VII) report (22) and combines this model with the epidemiological data published in ICRP 103 (23).

The BEIR-VII model proposed a linear no-threshold model as the most reasonable description of the relation between ionizing radiation exposure at low doses and the lifetime radiation induced cancer risks. In this model, gender, age at exposure, and time elapsed after exposure are considered the moderating factors for cancer type (22). A threshold-free linear model was used to estimate solid tumors, and a quadratic linear model was used to estimate the risk of leukemia. The report uses an exponential multiple-risk estimation model of the natural risk frequency in the community. In the expression of risk, the committee has finally presented the life attributed risks (22). These values are presented as the lifetime attributable risk of cancer incidence and lifetime attributable risk of cancer mortality for the various sites of cancers at different exposure ages. These values present the additional risk of different cancers and the total risk of all cancers for ages ranging from 0 to 80 years in both sexes for a dose of 0.1 Gy per 100,000 individuals. PCXMC integrates both models to obtain a lifetime risk of fatal cancer incidence, assuming a latent period of 2 years for solid cancers and 5 years for leukemia (22, 24).

2-7. Statistical Analysis

The statistical significance of discrepancies for scan parameters, effective dose and risks across equivalent age groups were examined by one-way ANOVA implementing Tukey post-hoc. All the statistical tests were performed using SPSS (v. 16, SPSS Inc., Chicago, IL). P-values lower than 0.05 were considered significant.

3- RESULTS

3-1. Patients' Characteristics

The number of participants, distribution of their age, and effective diameters are presented in **Table 3** by the type of procedure and equivalent age groups.

3-2. Accuracy of the Displayed Dose Data

Experimental dose measurements in the (CTDI) phantoms using a pencil dosimeter revealed that all the estimated CTDI values by the scanner software had small differences with measurements (tolerances<5%). The International Atomic Energy Agency (IAEA) recommended the acceptable tolerance in CTDI quality control dosimetry tests to be within ± 20% (25). Hence, it can be concluded that the displayed dose data are accurate enough for direct usages.

3-3. Exposure Parameters

Table 4 displays the scan parameters in various procedures and the equivalent age groups. For the procedures, no statistical differences were identified in kVp across equivalent age categories (*P*-values>0.05). The differences in mAs between equivalent age groups, except brain scans for newborn children (≤1 year and ≤1, 5 years groups with *P*-values = 0.029 and 0.036, respectively), were not statistically significant.

Table-3: Characteristics of the participants (M: male, F: female).

Procedures	Equivalent Age (years)	# Patients			Age (years)		Effective diameter (cm)	
		F	M	Total	F	M	F	M
Abdomen-Pelvis	Overall	80	109	189	9 ± 5	10 ± 5	18.40 ± 3.95	19.49 ± 3.89
	≤ 1	15	14	29	2 ± 2	2 ± 2	12.78 ± 2.31	13.29 ± 2.08
	(1,5]	24	32	56	7 ± 3	7 ± 3	16.54 ± 0.98	16.89 ± 0.94
	(5,10]	23	28	51	12 ± 3	11 ± 3	20.02 ± 1.00	19.84 ± 0.89
	(10,15]	18	35	53	14 ± 2	15 ± 2	23.49 ± 1.29	24.07 ± 1.02
Chest	Overall	64	103	167	9 ± 6	9 ± 5	17.49 ± 3.88	17.98 ± 4.00
	≤ 1	22	25	47	3 ± 4	3 ± 3	13.22 ± 1.38	13.03 ± 2.30
	(1,5]	16	31	47	9 ± 4	7 ± 4	16.90 ± 1.13	16.49 ± 0.85
	(5,10]	15	27	42	14 ± 2	12 ± 3	20.23 ± 0.93	20.10 ± 0.92
	(10,15]	11	20	31	15 ± 2	13 ± 5	23.12 ± 1.03	23.62 ± 1.17
Brain	Overall	106	162	268	7 ± 5	8 ± 5	14.24 ± 1.82	14.72 ± 1.54
	≤ 1	39	43	82	3 ± 4	4 ± 4	12.40 ± 1.51	12.67 ± 1.00
	(1,5]	50	88	138	9 ± 4	9 ± 4	14.90 ± 0.63	15.07 ± 0.64
	(5,10]	11	20	31	13 ± 4	13 ± 4	16.37 ± 0.19	16.34 ± 0.17
	(10,15]	6	11	17	15 ± 2	14 ± 3	16.79 ± 0.08	17.03 ± 0.15
Sinus	Overall	44	97	141	10 ± 4	13 ± 4	13.88 ± 1.73	14.73 ± 1.61
	≤ 1	21	33	54	8 ± 4	11 ± 4	12.34 ± 1.07	12.81 ± 0.90
	(1,5]	19	42	61	12 ± 4	12 ± 4	14.92 ± 0.58	15.25 ± 0.54
	(5,10]	4	15	19	13 ± 2	15 ± 3	16.31 ± 0.19	16.45 ± 0.19
	(10,15]	-	7	8	-	16± 1	-	16.91 ± 0.18
Overall		294	471	765	9 ± 5	10 ± 5	16.02 ± 3.59	16.54 ± 3.55

3-4. Patient Doses

Table 5 indicates the calculated effective doses delivered to the patients who underwent a CT scan of abdomen-pelvis, chest, brain, and sinus at the six participating institutions in Yazd Province. Among the equivalent age groups, the highest average of the effective dose is related to the abdomen-pelvis scans. In the chest and brain scans, the highest average dose was allocated to the patients' ≤1-year-old group (4.22 ± 3.15 and 1.63 ± 1.59 mSv, respectively). Likewise, for abdomen-pelvis and sinus procedures, the highest mean dose was recorded for the 1-5-year-old (5.44 ± 3.24 mSv) and 10-15-years-old (0.75 ± 0.18 mSv) patients, respectively.

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Table 5 displays the variations in effective doses among the patients for each procedure and equivalent age group via the coefficient of variation (CV). Generally, the coefficient of variation for all the procedures was the highest for the age group of ≤1 year, with the value of 78% for abdomen-pelvis, 75% for chest, 98% for brain, and 79% for sinus.

Table-4: Scan parameters of peak kilo voltage (kVp), mean mill ampere-second (mAs), pitch factor, section thickness, scan length, and gantry tilt.

Procedure	Equivalent Age	kVp		mAs		Pitch Factor		Section Thickness (mm)		Scan Length (cm)		Tilt (degree)	
		F	M	F	M	F	M	F	M	F	M	F	M
Abdomen-Pelvis	Overall	119±6	119±9	51±45	47±39	1.07±0.22	1.10±0.24	1.60±1.27	1.78±1.51	34.72±9.62	35.37±9.96	0±1	0±2
	≤ 1	117±9	117±9	32±12	30±16	1.00±0.16	1.10±0.26	1.68±1.23	1.48±1.44	24.41±7.29	24.50±6.65	1±2	0±0
	(1,5]	120±3	120±9	41±39	41±36	1.01±0.17	1.06±0.21	1.51±1.17	1.96±1.64	34.10±9.81	33.35±5.83	0±0	1±4
	(5,10]	120±5	116±12	45±34	58±49	1.09±0.24	1.05±0.20	1.73±1.65	1.63±1.40	38.96±5.36	34.62±11.69	0±0	0±0
	(10,15]	119±6	120±6	92±61	49±38	1.17±0.25	1.18±0.27	1.51±0.93	1.87±1.56	38.73±9.13	42.19±7.61	0±0	0±0
Chest	Overall	120±5	118±8	40±16	37±20	1.42±0.34	1.41±0.15	1.44±1.27	1.34±1.04	26.56±11.30	26.23±8.18	0±0	0±1
	≤ 1	118±8	116±8	34±6	30±8	1.42±0.11	1.42±0.10	1.21±0.92	1.11±0.62	19.41±5.52	21.77±5.89	0±0	0±0
	(1,5]	120±0	119±4	38±10	34±16	1.44±0.00	1.41±0.13	1.50±1.58	0.98±0.08	26.16±11.08	23.53±4.84	0±0	0±3
	(5,10]	121±4	117±8	42±21	42±26	1.35±0.21	1.44±0.11	1.81±1.38	1.41±1.14	29.87±10.86	26.89±5.32	0±0	0±0
	(10,15]	121±5	119±11	49±27	47±26	1.51±0.79	1.33±0.25	1.34±1.50	2.02±1.63	36.94±12.00	35.08±10.88	0±0	0±0
Brain	Overall	120±8	121±8	111±53	108±47	0.95±0.29	0.95±0.38	2.90±2.46	2.64±2.13	13.63±3.57	14.56±4.09	5±8	6±14
	≤ 1	117±8	120±10	123±57	127±52	1.01±0.50	1.03±0.72	3.47±2.67	2.89±1.88	12.75±3.07	12.41±3.21	6±9	5±9
	(1,5]	121±9	121±7	105±48	103±42	0.92±0.09	0.92±0.08	2.56±2.22	2.62±2.11	14.39±3.58	15.40±3.97	6±8	7±17
	(5,10]	123±6	119±4	102±48	103±49	0.93±0.10	0.93±0.06	2.64±2.60	2.69±2.90	13.67±3.48	15.11±4.82	2±5	8±10
	(10,15]	120±6	125±5	106±68	89±44	0.90±0.12	0.91±0.12	3.40±3.42	1.85±1.83	12.97±5.75	15.23±4.13	2±4	3±4
Sinus	Overall	122±7	120±7	80±46	92±45	0.81±0.15	0.80±0.14	0.98±0.51	1.12±0.91	12.10±3.93	12.11±4.71	2±8	2±7
	≤ 1	123±7	122±8	80±50	95±42	0.85±0.16	0.86±0.15	1.04±0.47	1.18±0.88	11.88±2.92	11.94±3.22	0±2	3±8
	(1,5]	121±7	118±7	75±42	89±51	0.75±0.09	0.75±0.12	0.74±0.21	1.02±0.88	12.94±4.76	12.65±6.18	3±8	1±5
	(5,10]	123±5	121±6	98±43	97±38	0.79±0.18	0.81±0.15	1.83±1.04	1.28±1.22	10.85±3.77	11.15±3.69	7±14	5±10
	(10,15]	-	120±6	-	80±29	-	0.77±0.13	-	1.03±0.37	-	11.71±1.35	-	1±4
Overall		120±7	119±8	75±53	76±51	1.09±0.34	1.08±0.34	1.92±1.86	1.85±1.69	21.92±12.16	21.42±11.49	2±6	3±9

Table-5: Distribution of effective doses in mSv delivered to patients by CT procedure and the patients' age group

Procedure	Age	Median (Q1*-Q3*)		Mean ± SD*		CV*	
		F	M	F	M	F	M
Abdomen -Pelvis	Overall	4.89 (4.01,6.66)	4.54 (3.06,5.50)	5.88 ± 3.51	4.76 ± 2.86	60%	60%
	≤ 1	5.24 (3.95,7.16)	4.36 (2.22,4.75)	6.78 ± 5.20	3.90 ± 2.12	77%	54%
	(1,5]	4.83 (4.06,5.99)	4.69 (3.35,6.46)	5.81 ± 3.41	5.17 ± 3.13	59%	61%
	(5,10]	4.99 (4.02,5.59)	5.05 (3.64,5.68)	5.22 ± 2.45	5.12 ± 2.64	47%	52%
	(10,15]	4.57 (4.01,8.49)	4.06 (2.68,4.77)	6.07 ± 3.17	4.45 ± 3.03	52%	68%
Chest	Overall	3.75 (2.87,5.07)	3.26 (2.12,4.37)	4.08 ± 1.88	3.57 ± 2.49	46%	70%
	≤ 1	4.08 (2.76,5.50)	3.08 (2.25,5.15)	4.34 ± 1.93	4.11 ± 3.96	44%	96%
	(1,5]	3.51 (3.17,5.15)	3.58 (2.11,4.20)	4.12 ± 1.96	3.55 ± 1.92	48%	54%
	(5,10]	3.08 (2.49,3.81)	3.05 (1.86,3.95)	3.23 ± 1.10	3.23 ± 1.93	34%	60%
	(10,15]	4.34 (3.16,5.79)	3.27 (2.34,4.20)	4.67 ± 2.29	3.37 ± 1.43	49%	42%
Brain	Overall	1.03 (0.71,1.60)	1.07 (0.77,1.40)	1.21 ± 0.82	1.27 ± 1.21	68%	95%
	≤ 1	1.25 (0.74,2.34)	1.24 (0.74,1.86)	1.60 ± 1.07	1.64 ± 1.94	67%	118%
	(1,5]	0.91 (0.69,1.24)	1.06 (0.81,1.33)	1.04 ± 0.58	1.20 ± 0.80	56%	67%
	(5,10]	0.85 (0.76,1.05)	0.90 (0.65,0.95)	0.84 ± 0.27	0.92 ± 0.65	32%	71%
	(10,15]	0.85 (0.65,0.94)	0.83 (0.74,1.04)	0.76 ± 0.31	1.04 ± 0.62	41%	60%
Sinus	Overall	0.59 (0.46,0.78)	0.59 (0.43,0.74)	0.70 ± 0.51	0.63 ± 0.34	73%	54%
	≤ 1	0.61 (0.53,0.64)	0.51 (0.43,0.66)	0.77 ± 0.67	0.67 ± 0.48	87%	72%
	(1,5]	0.52 (0.33,0.91)	0.60 (0.39,0.79)	0.60 ± 0.32	0.59 ± 0.24	53%	41%
	(5,10]	0.84 (0.67,0.96)	0.63 (0.43,0.72)	0.79 ± 0.24	0.61 ± 0.21	30%	34%
	(10,15]	-	0.82 (0.72,0.87)	-	0.75 ± 0.19	-	24%
Grand Total		2.60 (2.04,3.60)	2.25 (1.53,2.86)	3.03 ± 2.97	2.45 ± 2.54	98%	104%

* Q1: First Quartile; Q3: Second Quartile; SD: Standard Deviation; CV: Coefficient of Variation

The differences between genders were not significant for different procedures and equivalent age categories, except for the patients in ≤1 and 10-15 year-old groups in abdomen-pelvis procedure which showed significant differences with P-values=0.021 and 0.013, respectively.

3-5. Induced Risks

The distribution of excess lifetime cancer risks arising from CT examinations is presented in **Table 6**. The higher risks were, respectively, attributed to the age groups of ≤1 year in chest scan (680 ± 410 excess deaths induced by a million scans), ≤1-year-old in abdomen-pelvis scan (504 ± 280), ≤1-year-old in brain scan (123 ± 101), and 10-15-year-old in sinus scan (40 ± 10).

Calculated variations in the distribution of risks among the patients in different age groups and procedures were presented in **Table 6**. The maximum value of CV in abdomen-pelvis, chest, brain, and sinus procedures was equal to 67% for children with the age of 5-10 years old, 60% for ≤1-year-old, 92% for children with the age of 10-15 years old, and 87% for children ≤1-years-old.

Statistical tests showed that the risks of effective doses and exposure induced cancer death were higher among females compared to males (P<0.04), excluding the patients aged 1-5-year-old who had undergone a CT scan of the brain.

Table 7 presents the risks of radiation-induced solid cancers and leukemia in different procedures and age groups. The distribution of REID across genders were significantly different in the following groups: children with the age of 10-15 years in abdomen-pelvis procedure (*P*-value=0.030), as well as the ≤1 year olds, 1- 5 year olds, 5-10 year olds, and 10-15 year olds in chest procedure (*P*-values=0.003, 0.008, 0.012, 0.033, respectively). In the case of radiation-induced leukemia, however, the differences across genders were proved to be statistically significant only in the group of 5-10-year-old children who had undergone the chest CT procedure (*P*-value=0.020).

As illustrated in **Fig. 2**, among solid malignancies and by excluding other cancers, the highest risk in the abdomen-pelvis scans was attributed to stomach cancer. In contrast, in chest, brain, and sinus examinations, the highest risk was attributed to lung cancer. Interestingly, the colon, liver, stomach, bladder, and ovary cancers have all shown roughly no probability of occurrence in brain and sinus scans.

4- DISCUSSION

This study was performed to assess the risks attributed to frequent CT scans for pediatric patients, due to the delivered doses and the patient's age, by collecting the data related to 765 scans from six institutions in diverse areas of Yazd Province, Iran. For each patient, the effective dose was estimated by a Monte Carlo-based software, Impact Dose, and the risk of radiation-induced death was calculated according to the latest acknowledged models published by BEIR VII (22).

In the current study, the patients were categorized based on their effective diameter according to International Commission on Radiological Protection (ICRP) publication 135 (10), American Association of Physicists in Medicine (AAPM) report no. 204 (11), as well as the International Commission on Radiation Units and Measurements (ICRU) report no.74 (12) recommendations.

The main exposure parameters that affected the patient dose were kVp and mAs. There were no significant differences in kVp and mAs between various age groups in almost all the procedures which consequently resulted in a non-statistically difference in doses delivered to patients of

various ages from a specific examination. This is an unwelcome finding, alarming that the exposure parameters were not optimized for different age groups, and the children with lower ages were receiving higher doses than the needed irradiation for CT imaging.

Table-6: Risk distribution of radiation exposure-induced death (REID) in one million CT examinations

Procedure	Age	Median (Q1*-Q3*)		Mean ± SD*		CV*	
		F	M	F	M	F	M
Abdomen-Pelvis	Overall	425 (289,546)	335 (203,479)	448 ± 277	372 ± 279	62%	75%
	≤ 1	551 (325,718)	512 (275,733)	524 ± 290	481 ± 278	55%	58%
	(1,5]	471 (332,584)	437 (272,601)	531 ± 312	482 ± 328	59%	68%
	(5,10]	389 (270,496)	345 (213,399)	421 ± 279	377 ± 256	66%	68%
	(10,15]	303 (226,415)	162 (102,329)	306 ± 132	224 ± 170	43%	76%
Chest	Overall	630 (420,786)	361 (269,500)	611 ± 322	415 ± 286	53%	69%
	≤ 1	863 (579,1100)	468 (286,675)	841 ± 390	538 ± 379	46%	70%
	(1,5]	558 (306,655)	373 (297,490)	516 ± 227	431 ± 281	44%	65%
	(5,10]	452 (330,543)	314 (241,387)	439 ± 128	333 ± 205	29%	62%
	(10,15]	513 (392,679)	273 (243,450)	522 ± 224	346 ± 201	43%	58%
Brain	Overall	68 (52,117)	74 (49,101)	94 ± 81	88 ± 72	86%	82%
	≤ 1	87 (59,186)	100 (47,140)	130 ± 104	117 ± 99	80%	85%
	(1,5]	56 (48,80)	70 (54,96)	75 ± 52	84 ± 60	69%	71%
	(5,10]	56 (48,65)	48 (40,57)	57 ± 22	56 ± 44	39%	79%
	(10,15]	62 (45,68)	52 (38,77)	92 ± 107	64 ± 37	116%	58%
Sinus	Overall	31 (24,42)	30 (23,37)	39 ± 29	34 ± 22	74%	65%
	≤ 1	30 (25,33)	28 (23,33)	41 ± 36	37 ± 32	88%	86%
	(1,5]	29 (19,50)	29 (21,38)	37 ± 25	30 ± 15	68%	50%
	(5,10]	42 (32,51)	33 (21,40)	42 ± 14	32 ± 12	33%	38%
	(10,15]	-	41 (39,46)	-	40 ± 10	-	25%
Grand Total		281 (192,367)	188 (127,263)	294 ± 313	214 ± 254	106%	119%

* Q1: First Quartile; Q3: Second Quartile; SD: Standard Deviation; CV: Coefficient of Variation

Table-7: Distribution of all solid cancers and leukemia per a million CT scans

Procedure	Age	Solid cancer (per million)		Leukemia (per million)	
		F	M	F	M
Abdomen-Pelvis	Overall	418 (281,534)	329 (193,466)	7 (5,12)	8 (5,12)
	≤ 1	545 (312,701)	501 (266,710)	8 (6,15)	11 (5,14)
	(1,5]	464 (328,577)	430 (261,581)	7 (5,10)	8 (5,11)
	(5,10]	382 (266,487)	339 (210,392)	7 (4,10)	7 (5,15)
	(10,15]	297 (210,400)	159 (88,323)	8 (5,15)	7 (5,10)
Chest	Overall	626 (418,780)	357 (266,493)	3 (2,5)	4 (3,6)
	≤ 1	857 (577,1091)	463 (283,664)	4 (3,6)	5 (4,9)
	(1,5]	553 (304,651)	369 (293,483)	4 (2,4)	4 (3,6)
	(5,10]	450 (329,540)	310 (238,382)	2 (2,3)	3 (2,5)
	(10,15]	510 (388,675)	270 (240,443)	3 (2,5)	3 (3,4)
Brain	Overall	62 (47,109)	69 (44,95)	6 (4,9)	5 (4,8)
	≤ 1	77 (53,173)	93 (42,129)	9 (6,15)	8 (5,12)
	(1,5]	53 (44,76)	65 (48,90)	4 (3,7)	5 (3,7)
	(5,10]	53 (44,60)	44 (34,53)	4 (3,4)	3 (3,5)
	(10,15]	56 (42,63)	48 (36,72)	3 (2,4)	3 (3,4)
Sinus	Overall	29 (22,39)	29 (21,35)	2 (1,3)	2 (1,2)
	≤ 1	28 (24,31)	26 (21,31)	2 (1,3)	1 (1,3)
	(1,5]	27 (18,46)	27 (20,36)	1 (1,3)	2 (1,2)
	(5,10]	39 (31,48)	31 (19,39)	2 (2,3)	1 (1,2)
	(10,15]	-	40 (37,44)	-	2 (2,2)
Grand Total		276 (187,359)	184 (122,256)	5 (4,8)	5 (3,7)

Note: The data were reported as median (first quartile, third quartile).

Based on the comparison between the effective doses found in our study for each procedure and their equivalent age group (**Table 8)** are compared to the results of previous studies. Comparing effective doses estimated for the brain scan with those published by Gao et al. (26), Atac et al. (27), Galanski et al. (28), and Thomas et al. (29), it is clear that the amounts reported in our findings are significantly lower. The differences in exposure parameters may be the main reason for this discrepancy. For instance, the documented mAs in our study were around half of those published by Gao et al. (26). As for the abdomen-pelvis and chest procedures, our results regarding the effective doses are in the range of the aforementioned studies like those reported by Huda et al. (30) (**Table 8**). Various reasons including the differences in CT scan systems, exposure parameters, and different approaches implemented for effective dose estimation may clarify the discrepancies (31).

Comparing the findings with one of the most recent studies conducted by Masjedi et al. (31), to address the effective doses and radiation-induced cancer risk from adult CT scans in Yazd province, it is revealed that the pediatric effective doses arising from abdomen-pelvis, chest, and brain procedures are comparable with those of the adults; however, substantially higher doses were documented for pediatric sinus examinations.

All the included institutions were equipped with academic adult facilities in our study; therefore, the high variations in effective doses seem to be reasonable (32).

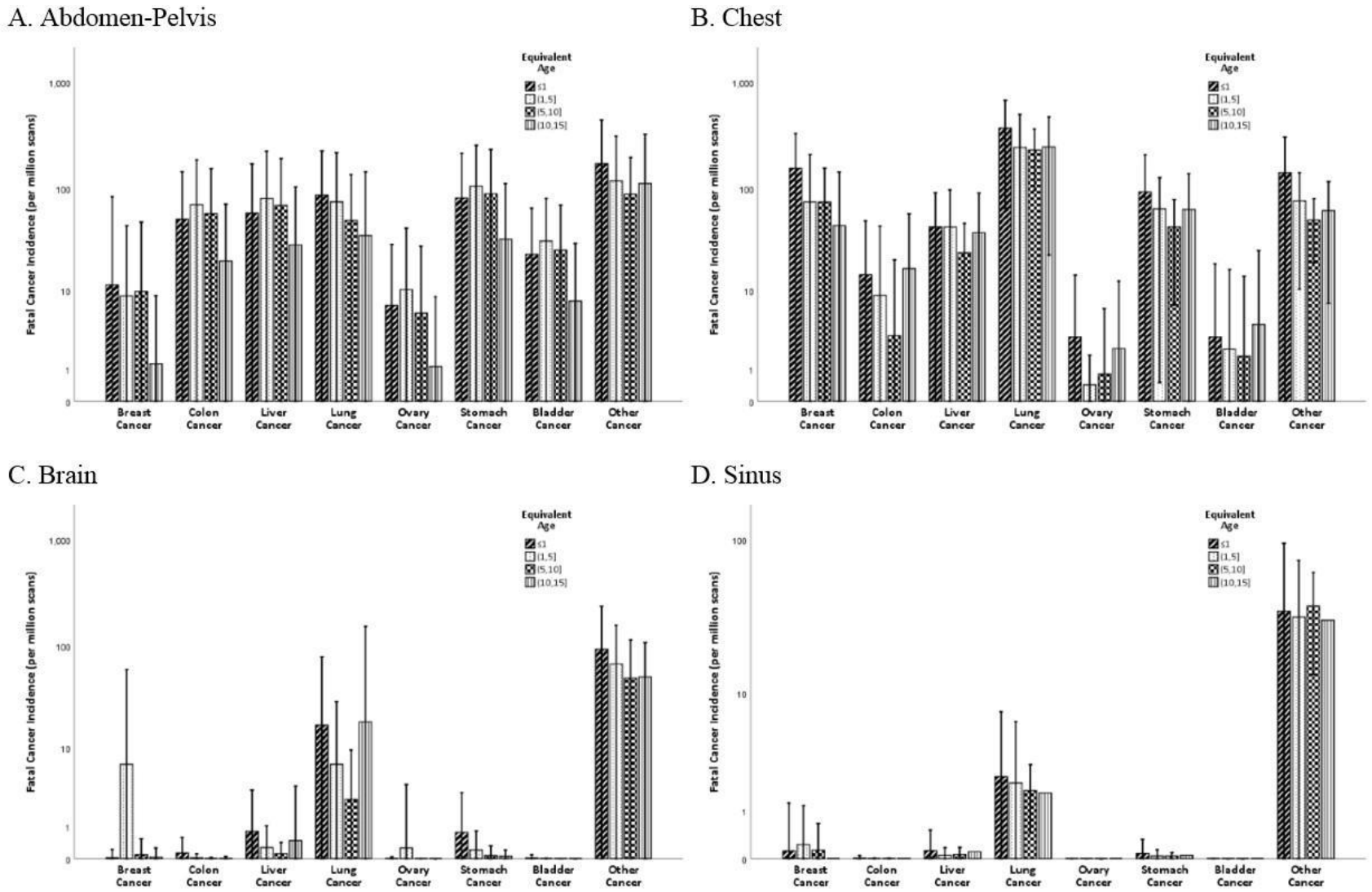

Fig. 2: The average of site-specific solid cancers per million scans induced by CT scans by procedure and patients' age.

Table-8: Comparison of mean effective doses with those published by other investigations

Procedure	Equivalent Age	This Study		Gao et al. 2019 (26)		Atac et al. 2015 (27)	Galanski M et al. 2001 (28)	Thomas et al. 2008 (29)	Huda et al. 2008 (30)
		F	M	F	M				
Abdomen-Pelvis	≤ 1	6.78 ± 5.20	3.90 ± 2.12	2.8 (0.001)	-	3.1 (0.037)	-	4.2 (0.971)	4.8 (0.371)
	(1,5]	5.81 ± 3.41	5.17 ± 3.13	7.5 (0.001)	5.5 (0.038)	2.5 (<0.0005)	-	3.7 (0.007)	5.3 (0.088)
	(5,10]	5.22 ± 2.45	5.12 ± 2.64	6.8 (0.001)	6.8 (0.001)	2.7 (<0.0005)	-	3.7 (0.004)	4.8 (0.531)
	(10,15]	6.07 ± 3.17	4.45 ± 3.03	7.9 (0.004)	8.5 (<0.0005)	3.1 (<0.0005)	-	3.6 (0.036)	3.3 (0.002)
Chest	≤ 1	4.34 ± 1.93	4.11 ± 3.96	1.3 (<0.0005)	1.4 (<0.0005)	7.1 (<0.0005)	3.4 (0.667)	1.8 (<0.0005)	7.0 (<0.0005)
	(1,5]	4.12 ± 1.96	3.55 ± 1.92	3.4 (0.447)	3.6 (0.142)	3.8 (0.071)	3.7 (0.148)	3.7 (0.148)	5.9 (<0.0005)
	(5,10]	3.23 ± 1.10	3.23 ± 1.93	3.9 (0.014)	4.1 (0.001)	3.6 (0.004)	4.1 (<0.0005)	3.7 (0.001)	6.1 (<0.0005)
	(10,15]	4.67 ± 2.29	3.37 ± 1.43	4.0 (0.979)	3.7 (0.080)	4.0 (0.091)	2.8 (0.048)	3.6 (0.539)	6.1 (<0.0005)
Brain	≤ 1	1.60 ± 1.07	1.64 ± 1.94	-	1.9 (<0.0005)	1.9 (<0.0005)	3.6 (<0.0005)	2.3 (<0.0005)	-
	(1,5]	1.04 ± 0.58	1.20 ± 0.80	2.6 (<0.0005)	2.3 (<0.0005)	1.5 (<0.0005)	2.4 (<0.0005)	1.5 (<0.0005)	-
	(5,10]	0.84 ± 0.27	0.92 ± 0.65	3.2 (<0.0005)	3.1 (<0.0005)	1.5 (<0.0005)	2.0 (<0.0005)	1.6 (<0.0005)	-
	(10,15]	0.76 ± 0.31	1.04 ± 0.62	3.4 (<0.0005)	3.5 (<0.0005)	1.3 (0.003)	1.4 (0.001)	-	-
Sinus	≤ 1	0.77 ± 0.67	0.67 ± 0.48	-	-	-	-	-	-
	(1,5]	0.60 ± 0.32	0.59 ± 0.24	-	-	-	-	-	-
	(5,10]	0.79 ± 0.24	0.61 ± 0.21	-	-	-	-	-	-
	(10,15]	-	0.75 ± 0.19	-	-	-	-	-	-

Note: The P-values regarding the significance of differences are reported in parenthesis.

The highest CV for effective dose was documented for pediatric cases younger than 1 year in all the procedures. Associations between the CV and the three parameters including patient age, effective diameter, and patient dose could be found in the results. This could explain the high variation in ≤1-year-old effective doses, since the patient dose is highly related to the patient size suggesting that subcategorization of these children to smaller groups based on their effective diameter may be required. In addition, the variation in doses among patients older than 1 year of age was also significant; the CV ranged between 24% and 63% for these subgroups.

The cancer risks of ionizing radiation are mainly found based on the information gathered from the life span study of atomic bomb survivors (33-35). However, the data substantially differ from the patients undergoing medical imaging due to their different backgrounds based on their predisposing history, and the kind and amount of radiation dose (36, 37). This controversy was the subject of various surveys, and very often, the conclusion was that linear no-threshold model should be considered for risk estimations. Some recent cohort studies have shown a linear association between diagnostic radiation exposure and lifetime cancer risks in children (38, 39).

Comparing the current results with the findings of Miglioretti et al. (40), the REID values obtained in our study against the patient's age follow similar trends; the higher risks were associated with younger patients, on account of the fact that they are intrinsically more radiosensitive and live for longer times (3). Averaged over the equivalent age subcategories, the highest REID values were approximately about 500 and 400 excess deaths in one million scans of chest and abdomen-pelvis, respectively, in the same order of magnitude as the adults (31), and around one-third of the findings of Brenner et al. (41). These relatively low risks are not promising since even one excess death due to an unjustified examination seems to be inadmissible. In addition, the wide ranges in the obtained attributed risks, demonstrated by high CVs (range, 25%-92%), leave space for further optimization processes, including but not limited to institutional-based auditing programs (42-44).

4-1. Limitations of the study

There are several limitations in this study. First and foremost, the image quality, playing a significant role in scanning parameter selection, was not assessed due to the limited time for conducting this study. Second, the number of the participants was limited to the time and effort of the investigators as the study was not financially supported by any institution.

4-2. Ethical considerations

The national ethics committee confirmed the study (Approval ID: IR.SSU.REC.1398.067). We did not perform any intervention in normal diagnostic or therapeutic procedures, and we just used the exposure parameters and images of the patients in this study. Therefore, gathering the consent forms was waived due to the prospective nature of this study.

5- CONCLUSION

The radiation doses delivered to the pediatric patients and the associated fatal cancer risk from common CT procedures were comparably in the range of previous studies but with wide ranges of variation. Further research needs to be carried out to achieve optimizations as well as better justifications for the patients at different ages. However, our findings can represent an estimation of the hazards from CT scans for the purpose of extending the

knowledge of physicians and those who are in charge of such procedures.

6- CONFLICT OF INTEREST

None.

7- FUNDING

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