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Estimating the risks of exposure-induced death associated with common computed tomography procedures

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► ***Original article***

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ABSTRACT

Background: This study aimed to assess the risks of exposure-induced death (REID) in patients and embryos during CT examinations in Yazd province (Iran). ***Materials and Methods:*** Data on the exposure parameters were retrospectively collected from six imaging institutions. In total, 932 patients were included in this study and for each patient, organ doses were then estimated using ImpactDose software. The REIDs were calculated by BEIR VII risk model and using PCXMC software. In the case of gestational irradiation, excess cancer risk of 0.006% per mSv was taken into account in terms of the ICRP 84 recommendations, to calculate the excess childhood cancer risk imposed on the embryo. ***Results:*** The highest estimated organ doses for abdomen-pelvis, routine chest, chest HRCT, brain, and sinus examinations were obtained as 12.82 mSv for kidneys, 12.09 mSv for thymus, 13.16 mSv for thymus, 29.71 mSv for brain, and 11.70 mSv for oral mucosa, respectively. Across all procedures, abdomen-pelvis CT scan induced the highest excess REID to the patients (240 deaths per million). The highest delivered dose to the fetus was roughly 35 mSv, which was lower than the threshold dose proposed by ICRP (100 mSv) for the induction of malformations. However, the associated excess fatal childhood cancer risk of 2122 incidence per million scans can be a subject of concern for public health experts. ***Conclusion:*** Based on the results, although death risks related to induced cancer from CT scans were negligible, this risk can be relatively significant for children exposed during the fetal period.

INTRODUCTION

Computed tomography (CT) is one of the imaging tools with high applications in the diagnosis of various diseases and medical problems [1–3]. Significant improvements have occurred in quality and time of scanning in CT modalities [4]. Moreover, there has been a growing tendency for its clinical implementation; the increase in the annual number of CT scans in the United States from 3 to 70 million in less than three decades stands as a good example of this reality [5, 6].

Ionizing radiation from X-ray exposures produced by CT scanners increases the probability of adverse health effects. Also, it leads to breakage in DNA molecular bonding in human cells and affects chromosome to induce different cancers [7, 8]. In addition, medical specialists, particularly physicians, are commonly unacquainted with the possible risks of CT exposures to patients. A recent study of physicians' knowledge in medical imaging has demonstrated that 26% of physicians fail to categorize the modalities into ionization and non-ionization radiation types [9]. A survey in Australia in 2013 found that 78% of medical professionals underestimated patient exposures undergoing CT scans [10]. This issue in combination with the increasing number of CT scans gives rise to concerns about public health problems resulted from medical ionization radiations.

International Commission on Radiological Protection (ICRP) has identified the effects of ionization radiation falling into two distinct groups, which are known today as tissue reactions and stochastic effects [7]. Thus, ICRP has elaborated on two principles for public health protection against ionization radiation to eliminate tissue reactions and diminish the risk of stochastic effects to a reasonably achievable level [11].

Estimating the risk of lifetime cancer and mortality risks induced by diagnostic ionizing radiations could be important for having a perspective on future problems and preparing ways to reduce health problems. In diagnostic radiology examinations, the organ-absorbed dose is used to estimate the cancer risk and hereditary effects to provide effective protection for the patients [12,13]. Each organ tends to show different sensitivity to ionization radiation, and this issue must be considered in evaluating the radiation effects [4, 11].

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To provide an estimate of individual risk resulting from exposure, it has been recommended to use the risk of exposure-induced death (REID), which specifically addresses the risks emerging from ionization radiation, instead of effective dose [11, 14]. REID is defined as the probability that an individual will die from exposure-related cancer [15].

Evaluating the cancer risk and mortalities for every diagnostic imaging modality such as CT scans for every geographical region is essential [16, 17]. This information can be useful for the patients' radiation safety in the medical imaging process. There have been several studies investigating the patients' effective dose and cancer risk from CT procedures [5, 7, 18–22]. Also, some studies have evaluated the patients' effective dose alone or with image quality parameters [18, 23–25].

There are several models for predicting cancer risk and mortalities in low dose exposure situations like diagnostic radiology or CT examinations [26–28]. One of the most complete and reliable models is BEIR VII-phase2 (Biological Effects of Ionizing Radiation VII-phase2) provided by the national research council of the USA [27]. This model includes detailed risk estimates for cancer incidence as well as cancer mortality.

Based on our knowledge, there are just a few studies estimating the lifetime radiation-induced mortality risks for patients undergoing different CT examinations, and there has been no study on this issue in Yazd province, Iran. Therefore, this work was conducted to investigate the possible cancer mortality risks caused by irradiation of patients and specifically embryos to ionization radiation during various CT examinations.

MATERIALS AND METHODS

Data collection

Data were collected retrospectively from six CT scanner machines installed in major public hospitals located in four counties in Yazd province. The characteristics of CT scanners studied are summarized in table 1. The center selection was based on the high rate of patients' referrals, different areas in Yazd province, and availability of picture archiving and communication systems (PACS). The institutional review and ethical board at each facility confirmed this study.

At each institution, the data was collected on more than 20 consecutive patients. The mean age of patients from the six institutions was 36.4 years and ranging between 18-57 years. Patient's data including age, gender, anteroposterior (AP) and lateral (LAT) thickness, along with technical exposure parameters including section thickness, detector rows, kVp, and mean mAs (current-time product) were recorded. Furthermore, volume CT dose index ($CTDI_{vol}$) and dose-length product (DLP) were collected from PACS for each patient.

By extracting the hospital information system (HIS) data from all participating institutions except hospital F where the HIS data was not available for 2018, a total of 5 procedures with frequencies above 1% were identified as the most common CT scans and were included in this survey (figure 1). The five most common procedures are brain (comprising 40% of total CT scans), abdomen-pelvis (17%), routine chest (11%), sinus (7%), and chest high-resolution (chest HRCT) (3%), which cover more than three-fourths of all performed CT scans in Yazd province in 2018.

Dose estimation

For each patient, to estimate the organ doses and effective doses, the exposure parameters were imported to ImpactDose software (v. 2.2, CT Imaging GmbH, Erlangen, Germany). This software estimates patient dose through adjustment of pre-calculated Monte Carlo dose data for an improved version of the Oak Ridge National Laboratory (ORNL) mathematical phantom based on user-input patient characteristics, scanner specifications, and scan parameters [29, 30]. The effective dose for each patient was calculated by conversion factors retrieved from the American Association of Physicists in Medicine (AAPM) Task Group (TG) 23 [31] and compared with estimated doses resulted from ImpactDose software (table 2).

Table 1. Vendor, model, # detector rows, maximum kilovoltage (kVp), maximum milliamperage (mA), and maximum field of view (FOV) of the CT scanners.

Institution	Vendor	Model	#Detector rows	Type	Max kVp	Max mA	Max FOV (mm)
A	Toshiba	ALEXION	16	Spiral/ Sequential	135	300	500
B	Siemens	SOMATION EMOTION	16	Spiral/ Sequential	130	345	700
C	Siemens	SOMATOM SENSATION	4	Spiral/ Sequential	140	500	500
D	Toshiba	ACTIVION	16	Spiral/ Sequential	135	300	500
E	Siemens	SOMATOM EMOTION	16	Spiral/ Sequential	130	345	700
F	Siemens	SOMATOM EMOTION	16	Spiral/ Sequential	130	345	700

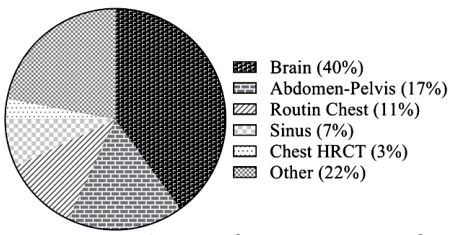

Figure 1. Distribution of CT examinations for five institutions in Yazd province in 2018.

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Table 2. The conversion factors used for the calculation of effective dose from DLP, retrieved from AAPM TG 23.

Procedure	Conversion Factor (mSv mGy^{-1} cm^{-1})
Abdomen-Pelvis	0.015
Routine Chest	0.014
Chest HRCT	0.014
Brain	0.0021
Sinus	0.0021

Risk estimation

The specific and overall REID was estimated for each patient using PCXMC software (v. 2, STUK, Helsinki, Finland) based on the calculated organ doses [32]. This program estimates the REID values based on the models retrieved from BEIR VII [27] and the published statistics reported by the ICRP-103 [11]. BEIR VII provides specific models to estimate the cancer risks for leukemia and seven solid cancers including breast, colon, liver, lung, ovary, stomach, and bladder. In order to put the results in a more tangible form, the overall REID values were compared to the risk of mortality due to the top 8 causes of premature death among the Iranian population, such as motor vehicle accidents [33].

Estimation of fetal dose and childhood cancer risk

To evaluate the risk of induced cancer mortality of CT scan on pregnant patients and fetuses, by assuming all the included women were pregnant at the time of examination, the absorbed dose by the uterus was considered as an estimate of the fetal dose, and the risk analysis was performed by the BEIR VII model. Regarding the ICRP 84 [34] recommendation, an excess absolute risk of 0.006% per mSv, was considered as excess childhood fatal cancer incidence. Furthermore, a comparison was made with the natural incidence of childhood fatal cancer (0.3%, based on ICRP 84) as a benchmark of projected risk to the fetus.

Data analysis

Descriptive statistics processes were carried out in Excel (v. 2016, Microsoft, Redmond, Wash), and SPSS software (version 16, SPSS Inc., Chicago, IL) was utilized to analyze the data. The differences across genders were then assessed by an independent-samples *t-test*. Furthermore, a one-sample t-test was used for comparison of the results with other published data.

RESULTS

Patients characteristics

A total of 932 patients undergoing CT examinations of the brain, sinus, routine chest, chest HRCT, and abdomen-pelvis were included in this study. Nearly half of the examinations were performed on patients younger than 50 years. The demographic information of the patients and the performed scan parameters are summarized in table 3.

Table 3. Number of the patients, age (years), effective diameter (cm), and scan length for five procedures for both genders averaged in six institutions. The values are expressed in mean ± standard deviation.

	Gender	Abdomen-Pelvis	Routine Chest	Chest HRCT	Brain	Sinus
#Patients	Both	258	200	138	142	194
	Female	105	88	53	64	78
	Male	153	112	85	78	116
Age (years)	Both	46 ± 20	58 ± 21	60 ± 17	55 ± 27	36 ± 16
	Female	49 ± 20	58 ± 21	59 ± 20	63 ± 24	40 ± 17
	Male	44 ± 20	57 ± 21	60 ± 16	48 ± 27	33 ± 14
Effective diameter (cm)	Both	27 ± 4	26 ± 4	26 ± 3	17 ± 1	16 ± 2
	Female	26 ± 34	25 ± 32	25 ± 34	16 ± 12	16 ± 17
	Male	27 ± 3	27 ± 4	27 ± 3	17 ± 1	16 ± 2
Scan length (cm)	Both	41 ± 10	31 ± 10	28 ± 10	15 ± 3	12 ± 3
	Female	40 ± 11	29 ± 10	26 ± 5	15 ± 3	10 ± 3
	Male	42 ± 10	33 ± 10	29 ± 11	15 ± 4	13 ± 3

Effective dose and organ doses

The mean and standard deviation of effective dose and organ doses across the investigated procedures are represented in table 4. The highest mean effective dose was computed using the ImpactDose software for abdomen-pelvis CT scans (5.75 mSv). As expected, the organs located inside the scan field of view received higher doses compared to other regions. Furthermore, the highest mean doses for abdomen-pelvis, routine chest, chest HRCT, brain, and sinus examinations were 12.82 mSv for kidneys, 12.09 mSv for thymus, 13.16 mSv for thymus, 29.71 mSv for brain, and 11.70 mSv for oral mucosa, respectively. For abdomen-pelvis, routine chest, and chest HRCT scans, the effective dose was significantly higher for women than the men (*P*-Value = 0.010, 0.016, 0.021, respectively). For the rest of the procedures (i.e. brain and sinus), the difference in effective dose was not significant across the genders.

Generally, the method of dose estimation would affect the results. According to the findings, the calculated effective dose by conversion factors would underestimate the delivered dose to the patient up to 7%, 18%, 14%, 1%, and 6% regarding abdomen-pelvis, routine chest, chest HRCT, brain, and sinus examinations, respectively. These differences were significant across all the procedures except for brain scans (*P*-Value: 0.826 for brain; 0.001 for sinus; <0.0005 for the rest).

Specific and overall REID

The overall REID and the number of scans estimated to cause one radiation-related cancer death among patients are shown in table 5. The abdomen-pelvis CT examinations projected the highest risk among the investigated procedures (240 radiation-induced deaths per million), and the lowest deleterious dose of radiation was pertinent to the scan of the sinus (16 radiation-induced deaths per million). It is noteworthy that the REIDs for

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abdomen-pelvis, routine chest, and chest HRCT examinations were higher among women; however, the difference was not significant for abdomen-pelvis procedure (*P*-Value = 0.317).

Table 6 illustrates the average specific REID per one million exposed individuals for five procedures. The highest projected risk for abdomen-pelvis, routine chest, chest HRCT, brain, and sinus scans was linked to stomach cancer (61 deaths in one million), lung cancer (103 deaths in one million), lung cancer (102 deaths in one million), other cancers (24 deaths in one million), and other cancers (14 deaths in one million), respectively.

The distribution of REID in the studied procedures is depicted in figure 2. As evidenced, head CT scans (i.e., brain and sinus CT scans) are more likely to be associated with low risks (REID < 0.01%) whereas high-dose procedures such as abdomen-pelvis contribute to the higher rates of mortality.

In table 7, the REID for each procedure was compared to the top 8 causes of death among the Iranian population. On the whole, approximately 4,000, 5,500, 6,000, 37,000, and 62,500 scans of abdomen-pelvis, routine chest, chest HRCT, brain, and sinus would respectively induce a risk equivalent to the summation of death risks resulted from the top mortality causes. It is intriguing to note that around one hundred CT scans of abdomen-pelvis region might possibly induce an equivalent risk of dying from a stroke.

Table 4. Effective dose and organ doses in mSv for five procedures computed using ImpactDose software averaged in six institutions. The values are expressed in mean (standard deviation).

Procedure	Effective Dose	Bladder	Brain	Breast	Colon	Esophagus	Ovaries	Testes	Liver	Lung	Red Bone Marrow	Salivary Glands	Skeleton	Skin
Abdomen-Pelvis	5.75 (3.40)	9.47 (6.46)	0.00 (0.00)	1.24 (1.08)	9.84 (5.86)	4.18 (3.06)	4.18 (3.06)	7.14 (6.24)	11.24 (7.81)	3.17 (2.32)	1.43 (0.84)	0.01 (0.01)	7.38 (4.29)	3.56 (2.11)
Routine Chest	3.74 (2.11)	0.56 (2.43)	0.06 (0.04)	7.31 (3.23)	0.92 (2.28)	7.89 (4.70)	7.89 (4.70)	0.44 (2.13)	5.75 (3.54)	10.12 (6.51)	0.99 (0.60)	0.41 (0.41)	6.65 (3.90)	2.23 (1.39)
Chest HRCT	3.53 (2.92)	0.06 (0.50)	0.06 (0.05)	8.58 (5.93)	0.23 (0.51)	8.35 (6.36)	8.35 (6.36)	0.08 (0.58)	5.10 (5.60)	10.93 (8.18)	0.97 (0.76)	0.35 (0.30)	6.70 (5.23)	2.14 (1.81)
Brain	1.05 (0.91)	0.00 (0.00)	29.71 (44.43)	0.04 (0.05)	0.00 (0.00)	0.10 (0.14)	0.10 (0.14)	0.00 (0.00)	0.01 (0.01)	0.09 (0.11)	0.67 (0.90)	19.99 (21.18)	9.30 (12.97)	2.47 (3.18)
Sinus	0.48 (0.22)	0.00 (0.00)	9.86 (5.45)	0.01 (0.01)	0.00 (0.00)	0.03 (0.02)	0.03 (0.02)	0.00 (0.00)	0.00 (0.00)	0.04 (0.02)	0.24 (0.12)	10.57 (5.18)	3.39 (1.63)	0.83 (0.42)

Table 4 continued. Effective dose and organ doses in mSv for five procedures computed using ImpactDose software averaged in six institutions. The values are expressed in mean (standard deviation).

Procedure	Stomach	Thyroid	Adrenals	Extratho-racic Region	Gall Bladder	Heart	Kidneys	Lym-phatic Nodes	Muscle	Oral Mucosa	Pancreas	Prostate	Small Intestine	Spleen	Thymus	Uterus
Abdomen-Pelvis	11.83 (7.97)	0.04 (0.03)	11.23 (8.48)	0.02 (0.01)	12.3 (8.13)	4.43 (3.36)	12.82 (8.48)	4.87 (2.78)	4.87 (2.78)	0.01 (0.01)	10.67 (7.56)	7.84 (5.65)	11.17 (7.16)	10.79 (7.50)	0.55 (0.38)	10.44 (6.43)
Routine Chest	4.92 (3.49)	2.92 (3.51)	7.05 (4.17)	0.94 (1.12)	3.54 (3.57)	10.31 (6.71)	3.97 (3.87)	2.67 (1.69)	2.67 (1.69)	0.30 (0.27)	5.63 (3.43)	0.36 (2.04)	1.09 (2.57)	5.34 (3.40)	12.09 (8.66)	0.76 (2.64)
Chest HRCT	3.94 (4.85)	2.17 (2.27)	6.86 (7.09)	0.69 (0.61)	2.16 (3.22)	11.12 (8.49)	2.49 (4.12)	2.53 (2.04)	2.53 (2.04)	0.27 (0.23)	5.03 (5.76)	0.07 (0.63)	0.28 (0.57)	4.64 (5.58)	13.16 (9.69)	0.07 (0.07)
Brain	0.00 (0.00)	2.29 (5.50)	0.01 (0.01)	14.26 (16.35)	0.00 (0.00)	0.02 (0.02)	0.00 (0.00)	1.04 (1.18)	1.04 (1.18)	19.91 (22.19)	0.00 (0.01)	0.00 (0.00)	0.00 (0.00)	0.01 (0.01)	0.07 (0.09)	0.00 (0.00)
Sinus	0.00 (0.00)	0.35 (0.19)	0.00 (0.00)	6.61 (3.01)	0.00 (0.00)	0.01 (0.00)	0.00 (0.00)	0.44 (0.21)	0.44 (0.21)	11.7 (5.46)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.02 (0.02)	0.00 (0.00)

Table 5. Mean ± standard deviation of risk of exposure-induced death (REID) per one million and the number of scans that resulted one cancer death for five procedures in terms of both genders averaged in six institutions.

Gender	Abdomen-Pelvis	Routine Chest	Chest HRCT	Brain	Sinus
REID ± per million					
Sex-Averaged	240 ± 174	181 ± 135	166 ± 170	27 ± 31	16 ± 8
Female	246 ± 186	216 ± 134	226 ± 201	23 ± 31	16 ± 9
Male	236 ± 165	154 ± 130	129 ± 136	30 ± 31	16 ± 7

Table 6. Mean ± standard deviation of site-specific risk of exposure-induced death (REID) per one million across investigated procedures averaged in six institutions.

Procedure	Leukemia	Breast cancer	Colon cancer	Liver cancer	Lung cancer	Ovary cancer	Stomach cancer	Bladder cancer	Other cancers
Abdomen-Pelvis	4 ± 3	2 ± 3	35 ± 25	46 ± 43	37 ± 35	3 ± 5	61 ± 48	16 ± 12	36 ± 27
Routine Chest	2 ± 2	9 ± 20	3 ± 7	18 ± 18	103 ± 80	0 ± 1	21 ± 19	1 ± 4	24 ± 21
Chest HRCT	2 ± 2	9 ± 23	1 ± 2	15 ± 22	102 ± 96	0 ± 0	16 ± 23	0 ± 1	21 ± 22
Brain	2 ± 2	0 ± 0	0 ± 0	0 ± 0	1 ± 1	0 ± 0	0 ± 0	0 ± 0	24 ± 28
Sinus	1 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	14 ± 7

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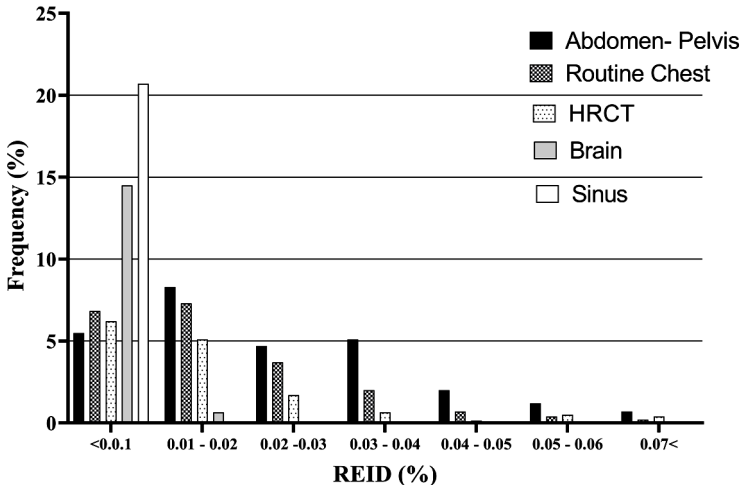

Figure 2. Distribution of the risk of exposure-induced death (REID) among all patients for five procedures.

Table 7. Number of equivalent CT scans to induce an identical risk of death as other causes for the assessed five CT procedures averaged in six institutions.

Procedure	Cardiovascular diseases	Motor vehicle accidents	Cancers	Unintentional injuries	Intentional injuries	Stroke	Lower respiratory infection	Diabetes
Abdomen-Pelvis	1100	738	475	267	254	117	92	71
Routine Chest	1459	978	630	354	337	155	122	94
Chest HRCT	1590	1066	687	386	367	169	133	102
Brain	9778	6556	4222	2370	2259	1037	815	630
Sinus	16500	11063	7125	4000	3813	1750	1375	1063

Risks of concept us irradiation

On average, the dose delivered to the fetus (uterus) was about 10 mSv for abdomen-pelvis procedure and virtually zero for the rest. At the highest level, the fetal dose did not exceed 35 mSv. The estimated cancer risks (per one million scan) projected to the fetus, subsequent to the CT scans averaged for each procedure, were in the following order: 627 (21% above normal baseline), 47 (1% above normal baseline), 4, 0, and 0 excess childhood fatal cancer for abdomen-pelvis, routine chest, chest HRCT, brain, and sinus CT scans, respectively. To the utmost extent, the scans would induce an excess risk of 2122, 878, 20, 0, and 0 per one million scan to the conceptus for abdomen-pelvis, routine chest, chest HRCT, brain, and sinus CT scans, respectively.

DISCUSSION

In this study, the REID for patients and specifically embryos during various CT examinations were estimated in Yazd province. The organ doses were evaluated by ImpactDose software and conversion factors; however, we have use only ImpactDose for estimating the risks of radiation induced cancer mortalities. Overall, the calculated organ doses based on conversion factors underestimated the patient dose. This may be attributed to the use of former tissue weighting factors (published by ICRP 60) in AAPM conversion method [35]. The outdated conversion factors published by AAPM [36] in 2008 might have led to such discrepancy. Furthermore, the conversion coefficients do not account for several factors, including pitch factor and patients' size [37]. Therefore, the conversion factors should not be implemented unless for standard-sized patients as it was already pointed out by Shrimpton *et al.* [38].

The organ doses estimated in our study were in the similar ranges to those reported by Bahreyni *et al.* [39], although different approaches for dose estimation were employed. The organ doses published by Akpochafor *et al.* [40] were consistent with our results for head scans; however, those for abdomen-pelvis and chest procedures were approximately three times higher compared to our findings. The reasons can be attributed the use of different scan parameters and machines. ICRP has defined the threshold dose for tissue reactions as the dose level that results in a 1% incidence of death among exposed individuals in publication 118 [41]. ICRP assigned the lowest threshold for an acute dose of 500 mSv to radiation-induced cardiovascular and cerebrovascular diseases. The organ dose thresholds for brain in head scans and for heart in chest examinations were approximately 30 and 11 mSv, respectively. Regarding our findings for the organ doses, these threshold doses reveal that CT scans cannot be considered safe, especially in the multiphase CT examinations. There are several studies reporting brain and heart doses of patients undergoing CT examinations, in which the estimated organ doses were close to threshold dose values or it can be higher if multiphase or contrast enhanced

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examination is used for imaging [42].

Further concerns may arise when CT is performed on pregnant patients, particularly for abdomen-pelvis scans where the fetus is exposed to primary radiation. The highest delivered dose to embryo in abdomen-pelvic CT scans did not exceed 35 mSv, which is below 100 mSv as a threshold dose [34]. Although in these low doses producing malformations in the fetus is very rare, the stochastic effects are probable [43]. Generally, abdomen-pelvis CT scans may induce an excess risk of 0.06% to fetus which seems negligible; however, the rate of childhood cancer risk in CT scan is about 21% higher than background doses.

Neighboring non-irradiated organs which just receive scatter radiations should also be considered in organ dose assessment due the fact that absorbed dose in these organs on average could be as high as 18% of the mean dose delivered to fully irradiated organs. For example, the average dose to breast tissue in abdomen-pelvis procedures was estimated at approximately 9% of the mean dose of fully-irradiated organs [18, 25, 34]. Contrary to expectations, the mean dose of some partially-irradiated organs could exceed the mean dose of some fully-irradiated organs in our study. This might be related to the high amount of scatter radiations in some tissues near the fully irradiated organs and exposure modulation techniques which altered the radiation in different anatomical regions. Furthermore, in low energy photon irradiation conditions, like CT scan, organs located closer to skin will receive much higher doses compared to organs at deeper sites [18].

Generally, the REID due to cancer incidence in CT scans is supposed to be 1 excess death in 2000 scans [42] which was estimated to be lower in our study (0.7). Since we used the same model (BEIR VII) for predicting the REID values, this discrepancy may have resulted from different exposure parameters. The REIDs estimated for abdomen-pelvis and chest (routine chest and chest HRCT) procedures were comparable with those published by Andrade *et al.* [44]; however, our findings slightly differed with regard to head (brain and sinus) scans. Based on our results, the excess risk of death from a head CT scan would be approximately 27 cases per one million individuals, whereas Andrade *et al.* estimated an additional risk of 4.7 to 20 excess deaths in one million [44].

Although the induced risk from CT scans seems to be low for individuals, it bears the potential health complications on large scales. Furthermore, by comparing these low but real risks with other causes of human death, it can be concluded that the mortality of an order of one hundred of these exams is equivalent to the average probability of the top 8 mortality causes nationwide [33], and the frequency of CT and other radiological exams using ionizing radiations in different geographical regions must be measured in order to have an appropriate estimation of medical radiation induced cancer mortalities in a country.

Interestingly, the patient doses and consequent induced risks varied considerably from patient to patient, even for the same procedures. Although this variation may partly be a consequence of patients' size differences and different imaging protocols, these reasons are an unsatisfactory explanation of this fact. Accordingly, it appears that in some institutions, patients will likely receive unnecessary doses of ionization radiation to some anatomical regions outside the disease/problem regions.

The REIDs projected by head scans are mainly distributed at low grades of risk (lower than 100 cases per one million), whereas the induced fatal cancer risk from abdomen-pelvic examinations reaches far out the tail of the distribution. This phenomenon may be triggered by two main reasons. First and foremost, the mean radiation dose delivered to the organs in abdomen-pelvis scans is over two times higher than that of the head scans (6.15 vs. 2.59 mSv, respectively). Second, in abdomen -pelvis CT procedures, numerous radiation-sensitive tissues are directly irradiated by the primary radiation so that each organ could develop cancer with a high mortality rate; in contrast, in head procedures, these effects prove to be far smaller.

CONCLUSION

In general, death risks related to induced cancer from CT exposures were estimated to be very low; however, this risk can be relatively significant for children exposed during fetal period. Since the results are presented in a tangible form for the ease of interpretation, they can clinically be considered as important by radiologists, technologists, patients, and particularly physicians, so as to hinder unnecessary scans and diminish the patient exposure to the extents which are reasonably achievable.

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