ORIGINAL ARTICLE

Dose Assessment and Evaluation of Cancer Risk Due to Prevalent CT Scan Procedures

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Abstract

Purpose: The use of Computed Tomography (CT) scans in diagnosis is increasing significantly. This research aims to evaluate the normal brain and chest (CT scans at six medical imaging departments in Tehran, the radiation dose, and the risk of cancer outbreak related to these normal CT scans.

Materials and Methods: The information and scan protocols of 1080 patients were collected. Patients were categorized into six groups. NCICT dosimetry software was used to calculate organ dose and cancer incidence evaluated by BEIR VII risk models.

Results: Among the 1080 patients, 642 (59%) were males, and the average age of the patients was 45.05 ± 22.60 years. Brain CT scans in 65% of cases and chest CT scans in 52% were reported normal. The third quartile of $CTDI_{vol}$, DLP, and ED values in the brain and chest scans were calculated and introduced as local DRL values. These values were determined as 22.13, 428.58, and 0.65 for $CTDI_{vol}$, DLP, and ED values in the brain scan and 5, 187.35, and 3.71 in the chest scan. The highest risk of cancer incidence in the brain scan was related to leukemia, with a value of 0.73 per 100000 exposures, followed by thyroid, with a value of 0.62 in women aged 20-25 years. In the chest scan, the highest risk of cancer incidence was related to breast cancer, with a value of 22.4 per 100000, followed by lung cancer, with a value of 19.02 in the same age group.

Conclusion: As age decreases, the risk of cancer increases; therefore, by optimizing the radiation dose and avoiding CT scans without indications, the risk of cancer can be significantly reduced.

Keywords: Computed Tomography; Radiation Cancer Risk; Computed Tomography Dose Index Volume; Dose Length Product.

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1. Introduction

Computed Tomography (CT) imaging is one of medicine's most important diagnostic tools. Despite the many benefits of this imaging modality in medicine, if prescribed unnecessarily, it can cause irreparable complications for patients [1, 2]. Since the radiation dose of a CT scan is significant, physicians should be extremely careful in prescribing it to patients, and technologists should use low-dose protocols, especially for children who are more sensitive to radiation. Recent epidemiological studies have shown that ionizing radiation increases the risk of leukemia, brain tumors, thyroid cancer in children, and breast cancer [3, 4]. Considering CT scan reports can find defects and is an appropriate method to improve safety in medical imaging centers. Several studies have reported the rate of normal CT scan reports in Iran to be 80 [5-7], making attention to CT scans performed without indication more prominent. According to the ALARA (As Low As Reasonably Achievable) principle, we can minimize the harmful effect of ionizing radiation by reducing patients' absorbed dose [8]. The International Commission on Radiological Protection (ICRP) introduces Diagnostic Reference Levels (DRLs) as a method for the optimization of radiation in medicine [9, 10]. DRLs are introduced in the third quartile of the dose distribution in protocols and CT scanners [11]. As the evidence of radiation hazards for less than 100 mGy [12] is available, the National Research Council's Committee on the Biological Effects of Ionizing Radiation (BEIR) in the seventh report (BEIR VII) suggests a linear no-threshold model evaluates the effects of doses less than 100 mSv [12] (Figure 1). Also, Effective Dose (ED) quantity was proposed to evaluate radiation dose values in different protocols, populations, and institutions [13, 14]. The purpose of this research is to calculate the absorbed dose of the organs that are exposed to radiation in the brain and chest scans, and the results of their scans are reported to be normal. Also, lifetime attributable cancer risk (LAR) was calculated, and finally, the effective dose in these two common procedures was estimated.

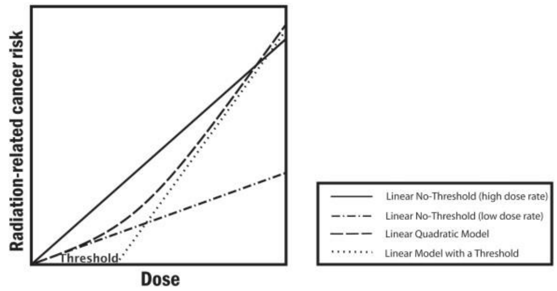

Figure 1. The linear no-threshold model in low dose cancer incidence calculation

2. Materials and Methods

2.1. CT Scanner and Data Collection

The data of 1080 patients during three months (1st of January 2023 to 30th of March 2023) were extracted from the Hospital Information System (HIS) of six medical imaging centers, and the exposure parameters of these two procedures were exported from the dose report pages in the hospital's Picture Archiving and Communication System (PACS). In this study, to check the normality of the CT scan results, the radiologist helped us in interpreting the images.

2.2. Dose Measurements

Organ dose and Effective Dose (ED) were calculated by the National Cancer Institute dosimetry system for Computed Tomography (NCICT version 3) [1]. The exposure parameters such as kVp, mAs, CT volume dose index ($CTDI_{vol}$), Dose Length Product (DLP), scan length, and pitch factor that were extracted from the dose report page and the demographic information of the patient such as age, gender and Body Mass Index (BMI) were plugged into the software and finally, the absorbed dose of each organ and the effective dose were calculated. Also, the third quartile of $CTDI_{vol}$, DLP, and ED were calculated to be set as regional DRL.

2.3. Statistical Analysis

SPSS software version 23 was used to analyze data and Chi-square and t-test examinations were done to compare results. The significance level was considered 0.05.

2.4. Cancer Risk Estimation

Patients were classified into six groups: 20-25, 25-30, 30-35, 35-40, 40-45, and 45-50. The risk of cancer incidence in each group was calculated separately. National Research Council's Committee on the Biological Effects of Ionizing Radiation (BEIR) in phase two of the seventh report (BEIR VII) recommends a linear no-threshold model to evaluate the effects of doses less than 100 mSv. In this article, Table 12D-1 [2] was used to calculate LAR. This table provides age and sex-specific risk estimates for several organs. Using the data in the above table, which was calculated for the absorption dose per 0.1 Gy, we calculated the amount of LAR for each patient using linear interpolation.

3. Results

In this retrospective study, we examined 1080 prevalent CT scan procedures (brain and chest respectively) in six Tehran imaging centers, performed in three months. Table 1 shows the specifications of CT scan devices in six imaging centers separately. Multi-slice CT machines were used in all of the centers except the C center.

The third quartile of $CTDI_{vol}$, DLP, and ED values in the brain and chest scans were calculated and introduced as local DRL values. These values were determined as 22.13, 428.58, and 0.65 for CTDIvol, DLP, and ED values in the brain scan and 5, 187.35, and 3.71 in the chest scan.

Table 2 shows the exposure parameters including (kVp, mAs, $CTDI_{vol}$, DLP, scan length, and pitch factor) in CT scan of the brain and chest in six centers separately. As it is clear in Table 2, the exposure parameters in different centers are significantly different (p-value<0.05).

Also, in this study, we used NCICT version 3.0 software to investigate the absorbed dose of organs directly placed in the radiation field. In the brain scan, the highest absorbed dose was for the eye lens, eyeballs and brain with values of 15.16, 14.44, and 12.95 mGy and in the chest scan, thyroid, thymus and trachea, respectively, with the value of 8.97, 6.93, and 6.80 mGy had the higher values (Table 3). As breast and lung tissues were exposed directly, they received a significant dose of radiation (Table 3). The highest effective dose in the brain scan corresponds to A center with an average value of 0.75 mSv and in a chest scan corresponds to a center F with an average value of 9.06 mSv.

Also, we investigated the risk of cancer incidence using BEIR VII reports. The highest risk of cancer incidence in the brain scan was related to leukemia with a value of 0.73 per 100000 exposures, followed by thyroid with a value of 0.62 in women aged 20-25 years. In the chest scan, the highest risk of cancer incidence was related to breast cancer with a value of 22.4 per 100000 followed by lung cancer with a value of 19.02 in the same age group (Table 4).

4. Discussion

Usually, a significant number of scans performed in the imaging centers are reported as normal, by reviewing the reports of CT scans performed in six imaging centers, we concluded that about 65% of brain CT scans and 52% of lung CT scans were normal. Considering that the radiation dose in this imaging modality is high, following the indications and avoiding unnecessary CT scans is a significant issue that should be addressed in imaging centers. Indications for a brain CT scan include brain trauma, Intracerebral Hemorrhage (ICH), decreased level of consciousness, continuous and sudden headache with dangerous symptoms, paralysis, paresthesia, and scan for post-operative controls. Also, indications for chest CT scan include Covid-19, shortness of breath,

Table 1. Characteristics of the CT scanners in each imaging center

Center	Company	Model	Number of slices	AEC presence
A	Siemens	Somatom sensation	MSCT (64 slices)	YES
B	Siemens	Somatom emotion	MSCT (16 slices)	YES
C	GE	High speed	SSCT	NO
D	Toshiba	Aquilian	MSCT (16 slices)	YES
E	Philips	Brilliance	MSCT (16 slices)	YES
F	Siemens	Somatom scope	MSCT (16 slices)	YES

Table 2. The average value of scan parameters (kVp, mAs, pitch factor, CTDIvol, DLP) of the brain and chest CTs in six medical imaging centers

	A	B	C	D	E	F	P value
			Brain				
kVp	120	110	120	120	120	110	<0.001
mAs	100	100	80	120	80	80	<0.001
Pitch factor	1	1	1.6	0.75	1	0.9	<0.001
CTDIvol	22	21.7	11.28	25.3	12.32	12.92	<0.001
DLP	440	434	248.16	422.3	221.76	268.76	<0.001
Scan length	20	20	22	16.69	18	20.8	<0.001
			Chest				
kVp	120	110	120	120	120	120	<0.001
mAs	52	77	70	50	75	70	<0.001
Pitch factor	1.4	1.5	1.6	0.75	0.813	1.5	<0.001
CTDIvol	3.99	1.02	2.7	5.5	3.15	10.46	<0.001
DLP	130.9	36	98.5	203.3	110.4	391.96	<0.001
Scan length	32.68	35.29	36.48	36.96	35.5	36	<0.001

continuous cough, chest pain and chest trauma, examination of hemothorax, and pleural effusion [16]. Any prescription without a CT scan indication is considered unnecessary.

Although a CT scan is a very powerful tool in diagnosing many diseases, its inappropriate and unnecessary use imposes additional radiation doses for patients and may leave irreparable effects [17]. Optimizing the radiation dose patients receive and determining a DRL at the national level is considered essential. By reducing the effective dose, as long as it does not have a detrimental effect on the quality of the image, it is possible to prevent additional doses to patients [9, 10]. The wide range of CT scanners, the level of technology used in them, and the talent and skills of the radiation technologist are effective and influential factors in the dose received by the patient [18]. As it is clear in Tables 2 and 3, there is a significant difference between exposure parameters, organ doses, and effective doses in different centers (p-value<0.05). One of the reasons for suggesting a national DRL level is to standardize and optimize the radiation parameters and eliminate these differences within a country.

Since younger people are more sensitive to radiation, and this sensitivity decreases with age, protection against radiation is more important and significant in younger age groups [19-22]. As in Table 4, it is known that the risk of cancer incidence decreases with increasing age, and this risk is reported to be higher in women than in men in most cases (Table 4). Organs like thyroid, breast, and bone marrow reports are more sensitive than others [4]; the dosimetry data in this study showed that the received thyroid dose in the chest scan is significantly higher than the received dose in the brain scan (Table 3).

The average effective dose in head and chest scans in our study is 0.54 and 3.85 mSv, while in the study of AJ VAN DER MOLEN et al., 0.4±1.9 and 3.8±0.4 mSv and in Tahmasabzadeh et al.'s study that on children 0 to 15 years had been done 1.60 and 4.16 mSv was reported [23, 24]. According to the mentioned values, the effective dose in this study is lower than in similar studies, but this does not justify unnecessary scans.

One of the ways to reduce the absorbed dose in brain scanning is to perform it in a conventional mood, except in case of the need for three-dimensional reconstruction, in which case the scan should be performed in a spiral mood [23]. In this study, brain scanning in centers A, B, and E was done in the conventional and spirally in the C, D, and F centers, so in centers C, D, and E, we had a higher amount of radiation absorbed dose.

By evaluating the number of frequent CT scans in this imaging center and analyzing the percentage of them reported to be normal, it can be emphasized the unnecessariness of many scans performed and the impression of unnecessary radiation doses to patients. Since carcinogenesis is one of the late side effects of radiation, by applying unnecessary radiation doses to people in society, the risk of cancer increases, and the cost is imposed on the healthcare system [23-25].

Table 3. Average organ-doses (mGy) in six age groups by type of CT scan

BRAIN														
ORGAN	A		B		C		D		E		F		AVERAGE	P value
	MALE	FEMALE	MALE	FEMALE	MALE	FEMALE	MALE	FEMALE	MALE	FEMALE	MALE	FEMALE		
Brain	15.76	16.86	15.54	16.63	8.13	8.69	17.54	18.99	8.72	9.37	9.25	9.9	12.95	<0.05
Pituitary gland	15.2	13.25	14.99	13.07	7.9	6.88	16.37	14.34	8.31	7.27	8.92	7.78	11.19	<0.05
Lens	19.05	19.09	18.79	18.83	9.81	9.82	21.45	21.42	10.59	10.61	11.19	11.21	15.16	<0.05
Eyeballs	18.15	18.23	17.9	17.98	9.35	9.38	20.3	20.46	10.06	10.14	10.66	10.71	14.44	<0.05
Salivary glands	14.77	18.33	14.57	18.08	9.08	10.22	7.53	11.77	6.21	7.56	8.67	10.77	11.46	<0.05
Oral cavity	12.4	16.15	12.24	15.93	6.95	8.9	3.72	5.15	5.29	6.01	7.28	9.49	9.13	<0.05
Thyroid	0.65	1.61	0.64	1.58	0.56	1.53	0.3	0.65	0.23	0.51	0.38	0.94	0.80	<0.05
Active marrow	1.07	1.11	1.05	1.09	0.61	0.66	0.95	0.88	0.52	0.51	0.63	0.65	0.81	<0.05
Effective dose	0.66	0.83	0.65	0.82	0.39	0.51	0.48	0.58	0.31	0.36	0.39	0.49	0.54	<0.05
CHEST														
ORGAN	A		B		C		D		E		F		AVERAGE	P value
	MALE	FEMALE	MALE	FEMALE	MALE	FEMALE	MALE	FEMALE	MALE	FEMALE	MALE	FEMALE		
Spinal cord	2.63	3.31	0.8	0.87	2.17	2.31	4.43	4.7	2.33	2.82	8.42	8.94	3.64	<0.05
Thyroid	7.38	7.85	2.09	2.01	5.61	5.32	11.44	10.83	6.32	6.43	21.75	20.59	8.97	<0.05
Esophagus	4.28	5.39	1.27	1.39	3.38	3.67	6.9	7.47	3.78	4.45	13.11	14.21	5.78	<0.05
Trachea	5.7	5.94	1.59	1.52	4.25	4.02	8.67	8.19	4.81	4.9	16.48	15.58	6.80	<0.05
Thymus	5.92	6.27	1.56	1.61	4.14	4.25	8.44	8.66	4.77	5.01	16.05	16.47	6.93	<0.05
Lungs	5.15	6.34	1.33	1.63	3.52	4.31	7.17	8.78	4.1	5.03	13.63	16.7	6.47	<0.05
Breast		5.85		1.5		3.97		8.09		4.63		15.38	6.57	<0.05
Heart wall	5.43	6.71	1.4	1.73	3.68	4.57	7.5	9.31	4.3	5.32	14.27	17.71	6.83	<0.05
Stomach wall	4.95	5.15	1.27	1.57	3.23	4.16	6.58	8.47	3.91	4.39	12.51	16.11	6.03	<0.05
Liver	4.84	6.02	1.24	1.65	3.17	4.37	6.45	8.91	3.82	4.91	12.27	16.94	6.22	<0.05
Active marrow	1.53	2.05	0.41	0.56	1.06	1.49	2.16	3.03	1.24	1.69	4.11	5.77	2.09	<0.05
Effective dose	3.16	3.49	0.83	0.96	2.14	2.53	4.36	5.16	2.54	2.86	8.3	9.82	3.85	<0.05

Table 4. Estimated sex-averaged LAR per 100,000 exposed subjects by CT scan type in four age groups

	20-25		25-30		30-35		35-40		40-45		45-50	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
Brain												
Thyroid	0.15	0.62	0.09	0.47	0.05	0.26	0.04	0.16	0.02	0.07	0.01	0.03
Leukemia	0.73	0.54	0.7	0.53	0.34	0.51	0.34	0.5	0.34	0.5	0.34	0.5
Chest												
Stomach	2.05	2.65	1.87	2.41	1.66	2.14	1.64	2.13	1.57	2.02	1.54	1.97
Liver	1.62	0.74	1.5	0.68	1.34	0.62	1.32	0.62	1.28	0.62	1.24	0.59
Lung	8.25	19.02	7.52	17.33	6.8	15.59	6.71	15.56	6.62	15.2	6.5	15.04
Thyroid	0.31	6.91	7.5	5.29	0.13	2.46	0.09	1.86	0.04	0.81	0.03	0.58
Leukemia	1.88	1.4	1.75	1.36	1.75	1.31	1.75	1.3	1.75	1.29	1.75	1.29
Breast		22.4		19.51		12.94		11.18		6.93		5.77

5. Conclusion

Considering that CT scan plays an important role in diagnosis in medical science, but due to its higher radiation dose, it should be prescribed with caution, especially for younger people. Since the exposure parameters in different centers are significantly different from each other, it is necessary to optimize the dose and create a DRL at the national level to realize this subject.

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