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Assessment of Radiation Exposure and Attributed Risk During Chest, Abdominal and Pelvic Computed Tomography Procedures

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Abstract

Adult patients' exposure and ascribed cancer risk were calculated using CT-Expo dosimetry software. A total of eight CT scanners and 395 examination patients were used in the study. The predicted effective dose values for chest CT, abdominal CT, and pelvic CT were 8.0 mSv, 10.9 mSv, and 5.6 mSv, respectively. The estimated dose–length product to effective dose (ICRP 103) conversion coefficients for chest CT, abdominal CT, and pelvic CT were 0.020 mSv·mGy^{-1}, 0.016 mSv·mGy^{-1}, and 0.013 mSv·mGy^{-1}, respectively. In chest CT, organ doses were 16.6 mSv (lung), 14.9 mSv (esophagus), and 10.8 mSv (breast); in abdominal CT: 15.5 mSv (stomach) and 13.7 mSv (liver); and in pelvic CT: 17.9 mSv (bladder) and 11.3 mSv (colon). The estimated cancer incident cases per million were 168 for lung cancer (chest CT) and 103 for stomach cancer (abdominal CT). The study allows comparing the risk of CT examinations to those of other radiological procedures.(**International Journal of Biomedicine. 2022;12(1):115-119.**)

Key Words: computed tomography • organ-equivalent doses • effective doses • cancer risk • radiation protection

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Introduction

Because computed tomography (CT) is the major contribution to patient radiation exposure in diagnostic radiology, it merits special consideration. The frequency of CT examinations is expanding worldwide, owing to technical developments that have contributed to the clear benefit supplied to the tested persons. The number of different types of CT tests is likewise growing. Increasing concerns regarding the growing population's exposure to radiation are correlated to its increasing use.[1-3] The amount of radiation used in CT scans is a significant source of worry for the medical imaging community. As a result, physicians must have realistic instruments to allow for the console-displayed dose (i.e., dose length product $P_{KL,CT}$), which can be converted into a radiation protection, risk-related dose quantity that is understandable to the medical imaging community. Practitioners who are aware of radiation dangers are more likely to take the necessary precautions to keep all patient exposures as low as reasonably possible, especially in CT and other high-dose imaging modalities.[4] Radiation risk in CT and other ionizing radiation-based diagnostic methods can be calculated using two radiation protection quantities: organ dose and effective dose. The effective dose accounts for the radiosensitivity of different body organs and tissues, whereas the body organ dose considers the relative biological effectiveness (RBE) of different radiation types.[5] A significant amount of work has been done in CT dosimetry in the last few years.[2,6] To optimize and create national diagnostic reference levels, doses were expressed in terms of the CT air kerma index and the CT dose–length product. Estimates of radiation protection risk-related variables (organ and effective doses) and ascribed cancer risk have recently received attention.[7] The current investigation was undertaken as part of these attempts to quantify organ doses, effective doses, and associated cancer risk following adult CT scans. For the first time, body organ doses are reported, adding to the national databank on radiation exposure. Because effective dose values and radiation risk incidents in CT are assessed using tissue-weighting factors from the International Commission on Radiological Protection (ICRP) Report 103, the findings of this study are critical for updating effective dose values and radiation risk incidents in CT.[2,5]

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Materials and Methods

Survey of the ionizing radiation dose

In this investigation, organ and effective doses were computed for 395 patient examinations in eight hospitals using CT-Expo CT dosimetry software version 2.5.[8] To evaluate radiation protection risk-related variables, such as the organ-equivalent dose and effective dose (E), patient doses were calculated using the volume CT air kerma index (C_{vol} (mGy) and CT air kerma length product ($P_{KL,CT}$).[9-11]

CT dose descriptors

For a multislice scanner with N_i and slice thickness T_i, C_K, the CT air kerma index in-phantom for an integration length of 100 mm, $C_{K,PMMA,100}$, is defined as follows: [10,11]

$$C_{k,PMMA,100} = \int_{-50}^{+50} \frac{K_{a,PMMA}(Z)dZ}{N_i T_i}$$

In clinical applications, an ionization chamber (pencil-type) with an active length of 10 cm, placed along the CT machine's axis of rotation, with its center at the center of the scanning plane, can be utilized to generate a reasonable assessment of $C_{K,PMMA,100}$. $C_{K,PMMA,100}$ is derived from the expression:

$$C_{K,PMMA,100} = \frac{DL}{T} \quad \text{[mGy]},$$

in which D is the radiation dose measured by the ionisation chamber and L is the sensitive length of the chamber (in this case, 100 cm).

The measurement can be performed either free-in-air (Cair) or in the center (C100,c) and periphery (C100,p) of a typical head or body CT dosimetry phantom.[9] The average dose (in the air) can be described by the weighted C:D ratio, assuming that the dose decays exponentially with radial position from the top to the middle of the phantom:

$$C_w = C_{K,PMMA,w} = \frac{1}{3}.C_{K,PMMA,100,c} + \frac{2}{3}.C_{K,PMMA,100,p}$$

Organ and effective doses and risk estimates

In addition to the main CT radiation dose units (C_{vol} and $P_{KL,CT}$), the software is capable of quantifying the organ-equivalent and effective radiation doses (mSv) in accordance with the recent ICRP recommendations. Effective doses were calculated using: (1) tissue-weighting factors given in ICRP-60; and (2) tissue-weighting factors given in ICRP-103. The ratios of the effective doses (E103/E60) and conversion coefficients (E103/$P_{KL,CT}$) are also provided. Detailed descriptions of the dose survey, including presentation of the common patient dose descriptors, are presented in our previous publication.[2] Organ-equivalent doses are used to calculate attributed cancer risk incidence using the cancer incidence risk coefficient given in ICRP-103[5]:

$$Risk\ Index = \Sigma_T\, r_T\, H_T$$

Results

This study contained a total of eight CT machines: two 16-slice CT machines, five dual-slice CT machines, and one single-slice CT machine. The diversity of manufacturers and types, as well as the year of installation and the measured CT air kerma index, are summarized in Table 1. Dose estimates were produced for 395 patients who had a routine chest, abdomen, or pelvic CT scan. Doses were computed using CT-Expo software and patient scan information obtained during a countrywide exposure survey conducted throughout the country.

Table 2 presents the mean scan parameter, CT dose descriptors (C_{vol} and $P_{KL,CT}$). The effective doses for chest, abdomen, and pelvic CT have been determined. The tissue-weighting factor described in ICRP publication 60 (E60) and ICRP publication 103 was used to derive the effective doses shown here (E103). An increase in the breast tissue-weighting factor from 0.05 to 0.12 and a reduction in the gonad tissue-weighting factor from 0.2 to 0.08 are significant modifications from the preceding tissue-weighting factors described in ICRP Guideline 60 (ICRP, 1991). (ICRP, 2007). Changes in risk estimates from E60 to E103 were normalized to E60 to demonstrate changes in risk estimates due to changes in the tissue-weighting factor, which represents the effective dose.

Conversely, the conversion coefficients (E103/$P_{KL,CT}$) were also determined; these were used to convert the values of the console-displayed $P_{KL,CT}$ into a corresponding effective dose.

Table 2 shows that abdominal CT had the highest effective dosage (10.9 mSv), followed by chest CT (8.0 mSv), and pelvic CT (5.7 mSv). CT scans of certain bodily regions have a longer scan length, which allows them to cover the majority of radiosensitive organs. Physicians may ask that chest–abdomen or abdomen–pelvis tests be performed as a single operation, resulting in greater extended scan coverage, high total mAs, and consequently increased radiation dosage to the patient, depending on the physicians' explanations.

Table 3 presents a comparison of the E103/$P_{KL,CT}$(μSv/mGy.cm) coefficients and the E103/E60 ratios obtained in this study with those from the literature. The E103/E60 ratios are below unity for the abdomen (0.85) and pelvis (0.76), but above unity for the chest, which is expected due to the increased tissue weighting of certain organs in ICRP 103.[5]

In Figure 1, the mean organ-equivalent doses are presented in chest, abdominal, and pelvic CT. In chest CT, the lung (16.6 mSv) presented with the highest dose, followed by the esophagus (14.9 mSv) and the breast (10.8 mSv). In abdominal CT, organ-equivalent doses as high as 20.7mSv (urinary bladder) and 15.5 mSv (stomach) are presented. With respect to pelvic CT, the colon (5.6 mSv) presents the highest organ dose, followed by the gonads (7.2 mSv). Radiation doses to the gonads serve as indicators for possible cancer risk in the offspring of exposed individuals.

Table 4 shows the cancer risk estimates for adult patients that were computed using the sex-averaged, organ-specific cancer risk coefficients given in E103. Projected risk incidence rates as high as 168 per million people are presented for lung cancer (chest CT), whereas the incidence rate is as high as 102 per million people among those with stomach cancer (abdominal CT).

Table 1.
Summary of characteristic performance parameters for the CT systems used for dose calculation

Scanner Code	Made	Type	Number of detectors	U_{ref}(kV)	Brain mode		Trunk mode	
					$_nC_{w.}$ (mGy/mAs)	P_H	$_nC_{w.}$(mGy/mAs)	P_B
GE I	GE	CT/e	1	120	0.160	0.70	0.072	0.32
GE II		CTe dual	2	120	0.154	0.71	0.154	0.71
GE III		High Speed Nx/i	2	120	0.151	0.63	0.072	0.30
S I	Siemens	Emotion Duo	2	130	0.215	0.71	0.215	0.71
S II		Sensation 16	16	120	0.184	0.76	0.131	0.77
S II		Sensation 16	16	120	0.184	0.76	0.131	0.77
T I	Toshiba	Steion dual	2	120	0.293	0.65	0.149	0.32
T II		Steion TSX	2	120	0.067	0.30	0.135	0.61

P_H: Scanner-specific (C_w/C_{air}) ratio for the head (16 cm) CT dosimetry phantom.
P_B: Scanner-specific (C_w/C_{air}) ratio for the body (32 cm) CT dosimetry phantom.

Table 2.
CT scan parameters, dose indices, and conversion coefficients

Scanner	N	Scan parameters			CT Doses	Effective Dose (mSv)			E103/$P_{KL,CT}$ (mSv/mGy.cm)
		mAs	L (cm)	C_{vol}(mGy)	$P_{KL,CT}$ (mGy.cm)	ICRP 60	ICRP 103	E103/ E60	
Chest CT									
GII	5	63	15	2.9	61.2	1.1	1.2	1.08	0.020
GIII	11	131	25	9	237.9	4.3	5.0	1.12	0.021
SI	9	83	46	5.1	94.1	1.7	1.9	1.10	0.020
SII	9	105	40	9	410.2	6.5	8.0	1.23	0.020
SIII	16	41	28	3.1	98.1	1.6	1.9	1.12	0.019
TI	5	210	24	31.7	1123	24.0	22.0	1.17	0.022
TII	18	150	33	18.5	799.7	14.1	16	1.13	0.020
Average	10.4	111.9	30.1	11.3	403.5	7.61	8.00	1.14	0.020
Abdominal CT									
GI	22	102	29	4.9	164.4	2.9	2.4	0.79	0.015
GIII	19	119	20	15.9	286.7	5.3	3.8	0.72	0.013
SI	32	63	36	5.0	195.2	3.3	2.9	0.88	0.015
SII	22	73	43	6.1	270.5	4.9	4.3	0.87	0.016
SIII	21	60	38	9.3	516.7	9.4	8.9	0.94	0.017
TI	10	253	38	51.6	2309	42	36	0.84	0.016
TII	20	150	42	20.1	1012.6	20	18	0.90	0.018
Average	20.9	117.1	35.1	16.1	679.3	12.54	10.90	0.85	0.016
Pelvic CT									
GIII	10	104	12	10.4	229.3	4.0	3.0	0.77	0.013
SI	10	28	22	2.7	72.3	1.2	0.9	0.75	0.012
TII	12	200	24	25.8	902.4	17.2	12.8	0.75	0.014
Average	10.7	110.7	19.3	13.0	401.3	7.47	5.57	0.76	0.013

E103 refers to the effective dose calculated according to the recommendation of the ICRP 103.
E60 refers to the effective dose calculated according to the recommendation of the ICRP 60.

Table 3.

Comparison of E103/E60 (µSv/mGy cm) coefficients and (E103/E60) ratios (mSv/mSv) obtained in this study and the presented data

Study		Chest (32 cm)	Abdomen (32 cm)	Pelvis (32 cm)
This study (2016)	E103/ $P_{KL,CT}$	20.4	16.0	13
	E103/E60	1.14	0.85	0.76
	Scan length (cm)	30.1	35.1	19.3
Deak et al. (2010)	E103/ $P_{KL,CT}$	14.5	15.3	12.9
	E103/E60	1.07	0.99	0.77
	Scan length (cm)	22.6	20.2	21.1
Huda et al. (2011)	E103/ $P_{KL,CT}$	20.4	16.3	14.3
	E103/E60	1.20	1.02	0.75
	Scan length (cm)	35	24	20

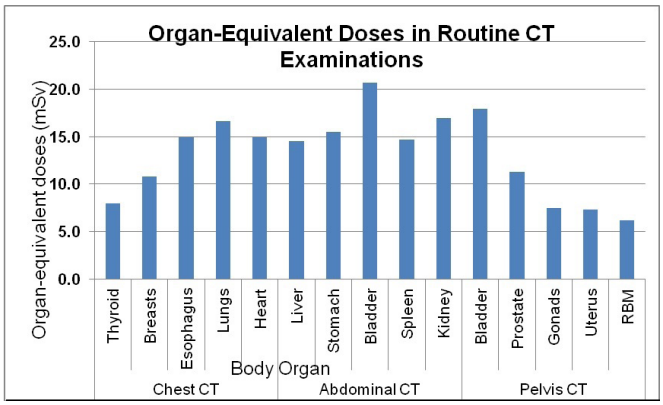

Fig. 1. *Mean organ-equivalent doses in chest, abdominal, and pelvic CT.*

Table 4.

Cancer risk estimates for adult patients during CT exams

Organs	Organ doses (mSv)	Nominal risk coefficients (cases per 10,000 persons per Sv)		Radiation-induced cancerprobability per 10^6	
		Non-Fatal	Fatal	Non-Fatal	Fatal
Esophagus	14.9	14.0	1.1	21	2
Stomach	15.5	65.5	3.5	102	5
Colon	11.3	31.3	34.2	35	39
Liver	13.7	28.9	1.4	40	2
Lung	16.6	101.5	12.6	168	21
Breast	10.8	33.0	79.1	36	85
Ovary	5.7	6.0	4.6	3	3
Bladder	17.9	12	31	21	55
Thyroid	8.0	2.2	30.3	2	24
Bone Marrow	6.2	28.0	13.9	17	9
Gonads (Heritable)	7.5	16	4.0	12	3

Discussion

Doses were determined for patients undergoing CT procedures of the chest, abdomen, and pelvis. Head CT was excluded due to large inaccuracies in determining the organs included in the scan; there was also a great deal of uncertainty when determining organ and effective doses.

Computing the effective dose is of paramount importance, as it provides a common measure by which to compare exposure in different radiological procedures, as well that from natural background radiation.[12] The annual dose limit for occupational exposure, the yearly dose limit for public exposure(1 mSv), and the annual effective dose from natural background radiation (2.4 mSv) can all be compared to the effective dose in body CT exams.[1,5]

The E103/E60 ratios obtained in this study for chest (1.18) and pelvic (0.76) CT are not much different from those reported by Huda and He,(13) who presented with ratios of 1.20 (chest CT) and 0.75 (pelvic CT), and these are very similar to the results reported by Deak et al.[14] Both results showed an E103/E60 ratio below unity for abdominal CT. It is crucial to report that the current results are averaged over eight scanners, as compared to the one scanner that was used in the study by Huda and He,[13] and the two scanners that were employed in the study by Deak et al.[14] The average conversion factor (E103/E60) per CT procedure could be used to attain a reasonable estimation of effective doses from previous studies, which were calculated using ICRP 60. In Tanzania, Ngaile and Msaki [15] found that the mean organ doses for the lens of the eyes (for head), the thyroid (chest CT), breast(chest CT), stomach(abdominal CT), and gonads (for pelvis) were 63.9 mGy, 12.3 mGy, 26.1 mGy, 35.6 mGy, and 24.0 mGy, respectively. When compared to the results of this study, the organ doses reported in Tanzania are much higher. This may be primarily attributed to the old scanner model used in Tanzania. All scanners were single-slice, as compared to the 4- and 16-multislice CT scanner used in this study.

Projected risk incidents as high as 168 per million people are presented for lung cancer during chest CT (Table 3). These values are much higher than the cancer incidence rate previously reported for multiple-radiograph intravenous urography.[7] In a study by Andrade et al.,[16] the effective attributed cancer risk per million during chest CT ranged from 203–330, whereas in abdominal CT, this rate ranged from 113–270 per million. The current values are lower than those previously reported by Andrade et al.[16] Those authors presented the effective average attributed cancer risk in a given bodily region (chest/abdomen), whereas in our study, attributed cancer risks were computed for each body organ of interest. Attributed cancer risk determines which organ-equivalent doses are more appropriate, as their incidence rates depend upon which organ is irradiated; that organ is thus added to the individual's organ sensitivity.[5,17-24]

Variations in organ-equivalent dose indicate that dose reduction can be achieved without jeopardizing the quality of diagnostic information. High doses were mainly due to using the same protocol for all patients regardless of their sizes (Scanner SIII), as well as using inappropriate technique factors, primarily including higher mAs than necessary(TI scanner). Dose optimization using various technique factors involved

decreasing mAs, using tube-current modulation where possible, and limiting scan coverage.[2,17,18,25,26] Shielding radioprotective organs during CT procedures may better mitigate the health consequences of ionizing radiation.

Conclusion

The effective radiation dose is a useful metric for comparing exposure during various radiological treatments, whereas organ doses are better for predicting cancer induction. The input of estimated dosages to the national patient exposure databank is critical. They allow for a comparison of the risks associated with CT scans to those associated with other radiological techniques. The conversion of the dose length product to effective dose conversion coefficients gives radiologists operating without medical physics support with an accessible and user-friendly method for determining CT-effective doses. The most recent ICRP was used to calculate current effective dosage values.

Competing interests

The author declares that there is no conflict of interest.

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