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Estimation of Lifetime Attributable Cancer Risks from Head and Abdomen Computed Tomography (CT) Examinations

Running Title: Cancer Risk from CT Imaging

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ABSTRACT

Computed tomography (CT) examinations contribute substantially to patient radiation exposure and may increase the risk of radiation-induced cancer. Estimating these risks is essential for optimizing radiation protection and supporting appropriate clinical use of CT imaging. This cross-sectional study included 76 patients undergoing head and abdomen CT examinations at Square Hospital, Dhaka, Bangladesh. Radiation doses were measured using thermoluminescent dosimeters (TLDs) and a 64-slice CT scanner. Effective doses were calculated from the dose-length product (DLP) using age-dependent conversion coefficients recommended in the European Guidelines on Quality Criteria for Computed Tomography (European Commission, EUR 16262 EN). Organ doses were converted into lifetime attributable risks (LARs) of cancer incidence and mortality using the Biological Effects of Ionizing Radiation VII (BEIR VII) risk model. LAR varied according to CT examination type, patient age, sex, and absorbed dose. For abdomen CT, the mean LAR of cancer incidence was 22.4 and 13.3 per 100,000 persons in males and females, respectively, with corresponding mortality risks of 5.2 and 4.1. For head CT, the mean LAR of cancer incidence was 136 and 113 per 100,000 persons, with mortality risks of 80.3 and 60.6, respectively. Younger patients demonstrated higher estimated risks, and effective dose increased with both DLP and tube current time product (mAs). Although the estimated LAR associated with head and abdomen CT examinations was relatively low, cancer risk varied according to patient age, sex, examination type, and radiation dose. The findings support patient-specific CT protocols and optimization of scanning parameters in accordance with the ALARA principle to minimize radiation exposure while maintaining diagnostic image quality, particularly for younger patients and higher-dose CT examinations.

INTRODUCTION

Computed Tomography (CT) has become one of the most widely utilized diagnostic imaging modalities in modern medicine, owing to its ability to produce rapid, detailed cross-sectional images of internal structures. Among the most frequently performed examinations are CT scans of the abdomen and head, which play a critical role in the evaluation of trauma, stroke, malignancies, and various abdominal disorders. As the immediate medical benefits for patients are considerable, the use of CT as a diagnostic tool has increased worldwide since its invention in the early seventies [1], [2], [3], [4] . Despite its undeniable clinical value, CT delivers relatively high doses of ionizing radiation compared with conventional radiographic techniques, raising growing concern about the potential long-term risks associated with repeated exposure. CT scans play an essential role in tumour staging and treatment planning in radiation therapy, as well as in the follow-up of cancer patients [5]. Approximately half of all cancer patients (50%) are treated with radiation therapy during the course of their disease [6]. In addition, it is estimated that radiation therapy contributes 40% of the curative treatment for cancer [7]. Numerous techniques can be used to quantify radiation exposure and dose; exposure can be assessed as entrance surface dose, dose-area product, and dose-length product. However, anthropomorphic phantoms with internalized dosimeters or Monte Carlo computer simulations can be used to assess organ absorbed dosage [8], [9]. In diagnostic radiology, the effective dose is typically thought of as the best available dose descriptor for calculating hazards from non-uniform whole body exposure to ionizing radiation [8], [10]. Additionally, it offers an approximate comparison of relative deterioration between various radiation studies. Previous studies have evaluated radiation doses and lifetime attributable cancer risks associated with CT examinations, particularly chest CT imaging in Bangladesh and various CT procedures in other countries [3], [4], [11]. However, to the best of our knowledge, no published study has specifically assessed the lifetime attributable risk (LAR) of cancer associated with head and abdomen CT examinations in the Bangladeshi population using patient-specific radiation dose measurements. This lack of evidence limits the availability of local data required for radiation risk assessment and optimization of CT imaging practices. Therefore, the present study aims to estimate and compare the LAR of cancer incidence and mortality associated with head and abdomen CT examinations in Bangladeshi patients, thereby providing baseline evidence to support radiation protection, optimization of CT protocols, and informed clinical decision-making.

METHODS

This cross-sectional study included 76 patients who underwent 64-slice CT examinations at Square Hospital, Dhaka, Bangladesh. The study cohort comprised 30 male and 22 female patients undergoing abdomen CT examinations, and 16 male and 8 female patients undergoing head CT examinations. The study population consisted of 76 patients undergoing clinically indicated CT examinations, including 52 patients who underwent abdomen CT (30 males and 22 females) and 24 patients who underwent head CT (16 males and 8 females). Patient demographic information, including age, sex, CT examination type, and scanning parameters (tube voltage, tube current-time product, scan length, CTDIvol, and DLP), was collected from the CT laboratory records and used for radiation dose and lifetime attributable risk (LAR) estimation. Table 1 summarizes the demographic characteristics of the study population, including patient age, sex distribution, CT examination type, and the CT scanning parameters used for radiation dose estimation.

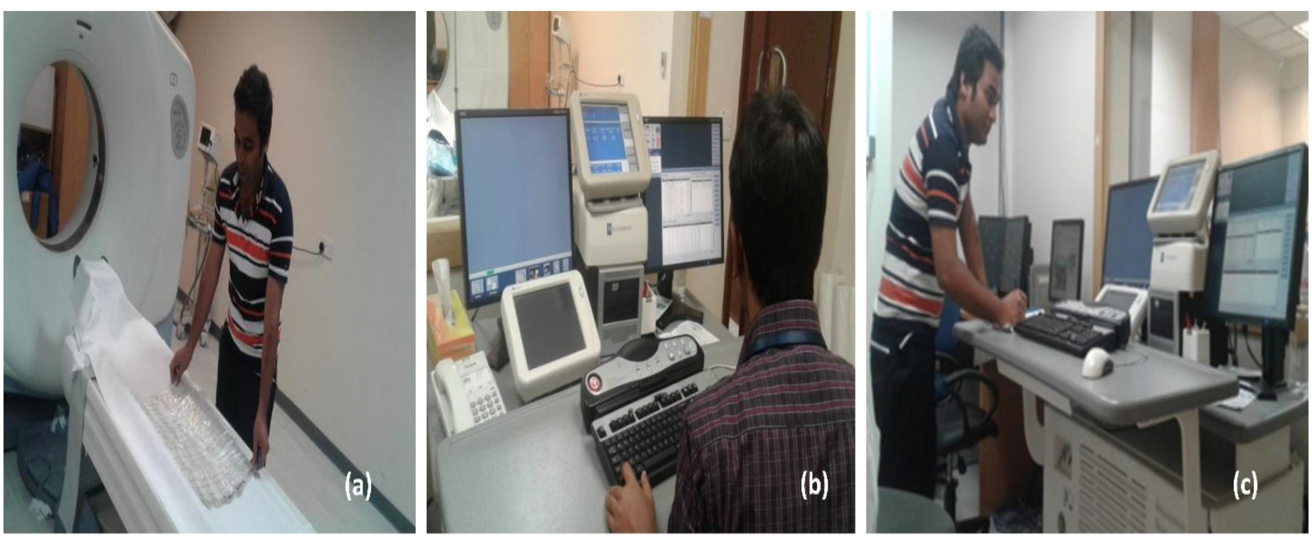

Fig.1. TLD chips used for radiation dose measurement. (a) The thermoluminescence chips in the polythene sheet are arranged schematically placed below patient body. (b) Right before reading out, the chips were being moved from a sheet to a tray (c) Reading time observation ((An operator is operating the system while author of this paper was observing the protocol applied by the operator).

Table 1. Demographic characteristics and CT examination parameters of the study population (n = 76).

Characteristic	Abdomen CT	Head CT	Total
Number of patients	52	24	76
Male	30	16	46
Female	22	8	30
Age range (years)	1.5-84	6-77	1.5-84
CT scanner	64-slice CT	64-slice CT	—
Scan parameters recorded	Tube voltage (kVp), tube current-time product (mAs), CTDIvol, DLP, scan length	Tube voltage (kVp), tube current-time product (mAs), CTDIvol, DLP, scan length	—

During the CT scan patient characteristics, scanning protocols, scan length, and exposure parameters (tube current–time product, mAs, and tube voltage, kVp) were collected from CT lab. Radiation dose was measured using thermoluminescent dosimeters (TLDs). Lithium fluoride (LiF) is the most commonly used detector material in TLDs because its effective atomic number (8.2) is close to that of human soft tissue (7.4). The radiation dosage absorbed by human tissues over a broad energy range is comparable to the absorbed dose measured with these devices because of this resemblance [12]. In an array of ten rows and five columns, fifty TLD-100 chips (Thermo Fisher Scientific) were positioned between a 34 cm and a 45 cm polyethylene sheet. The sheet was placed underneath the patient prior to the CT scan, with the columns arranged parallel to the scan length. After completion of the CT examination, each TLD chip was read using a Harshaw 3500 TLD reader at the Health Physics Laboratory, Atomic Energy Centre, Dhaka, Bangladesh.

In this work, we computed the LARs for a number of cancer types, including abdomen and head. We estimated cancer incidence and death from radiation exposure using the approach described in the BEIR VII Report (National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation, BEIR VII Report [13]. The demographics of the US population have been taken into account when adjusting these data [14]. The BEIR VII Report provided the cancer incidence and death rates per 100,000 individuals exposed to 0.1 Gy (100 mSv).

The effective dose (E) was estimated from the dose-length product (DLP) using age- and anatomical region-specific conversion coefficients (k-factors) recommended in the European Guidelines on Quality Criteria for Computed Tomography (European Commission, EUR 16262 EN). These coefficients provide a standardized method for estimating whole-body effective dose from DLP values for different CT examination types and patient age groups.

Ethical Approval

This study was approved by the Institutional Review Board (IRB) of Square Hospital, Dhaka, Bangladesh (Approval No. IRB-2020-1005). Written informed consent was obtained from all participants before inclusion in the study. All procedures involving human participants were conducted in accordance with the ethical principles of the Declaration of Helsinki and its subsequent amendments.

Statistical Analysis

Descriptive statistical analyses were performed to summarize the radiation dose parameters and lifetime attributable risk (LAR) estimates obtained from head and abdomen CT examinations. Continuous variables are presented as the mean, standard deviation (SD), minimum, and maximum values, where appropriate. LAR estimates were compared descriptively according to CT examination type (head and abdomen), patient sex, and age group. Graphical analyses were used to illustrate the relationship between patient age and estimated LAR values. All statistical summaries were generated using Microsoft Excel (Microsoft Corporation, Redmond, WA, USA).

RESULTS

Table S1 and table S2 show the age, measured dose, effective dose, organ dose, and LAR for thirty male and twenty-two female of abdomen patients. On the other hand, Table S3 and S4 show the same parameters for sixteen male and eight female of head patients. In the present study, the highest organ dose was 226 mGy in male patients undergoing head CT examinations, whereas the corresponding maximum value for female patients was 190 mGy. Bagherzadeh determined the organ doses 24.36 mGy and 41.49 mGy for male and female patients, respectively in this area [15]. For patients undergoing abdomen CT examinations, the mean effective doses were 13.26 mSv for males and 14.74 mSv for females. Additionally, the maximum effective dose values for male and female patients were 45.93 mSv and 45.45 mSv, respectively. For head CT examinations, the mean effective doses for both male and female patients were higher than those reported [16]. Government regulatory bodies have set an effective dose limit of 100 mSv every five years or 20 mSv per year, with a maximum of 50 mSv in any given year [17], [18]. On the other hand, In Table 2, DLP and $CTDI_{vol}$ for all types of CT were higher than the recommended values of Australian MDCT. In CT head scanning DLP was comparatively higher than the recommended value. LAR of cancer is higher for pediatric patients than the adult patients because the LAR of cancer is increased with the increasing of effective dose and the decreasing of age of the patients.

Table 2. A Comparison of estimated values with Australian national diagnostic reference levels for MDCT

	Australian MDCT DRLs				From our study			
	Child (5-14 years)		Adult (15+ years)		Child (5-14 years)		Adult (15+ years)	
CT Type	DLP (mGy.cm)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	$CTDI_{vol}$ (mGy)
Abdomen	390	10	700	15	-	-	953	19.8
Head	600	35	1000	60	969	57.0	1473	86.1

In contrast to the LAR values of cancer mortality, which were 5.2 and 4.1 cancers per 100,000 males and females, respectively. The mean LAR values of cancer incidence for male and female abdomen patients were 22.4 and 13.3 per 100,000 persons, respectively, whereas the corresponding values for head CT patients were 136.28 and 113.69 per 100,000 persons. Figs. 2 and 3 depict the LAR of cancer-related incidence for male and female in abdomen patients, respectively, showing that in both situations, the LAR of cancer incidence falls as exposure age increases.

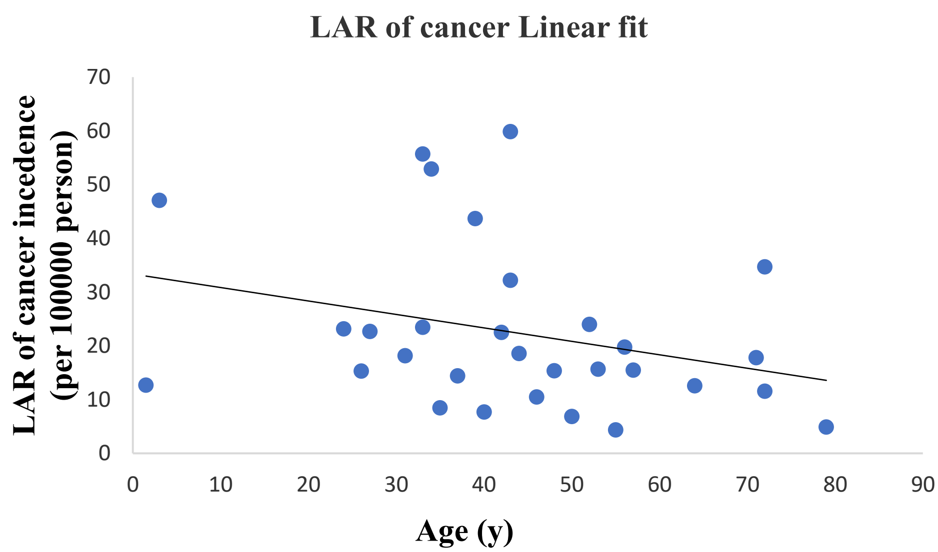

Fig. 2. Age-dependent variation in the LAR of cancer incidence among male patients undergoing abdominal CT examinations

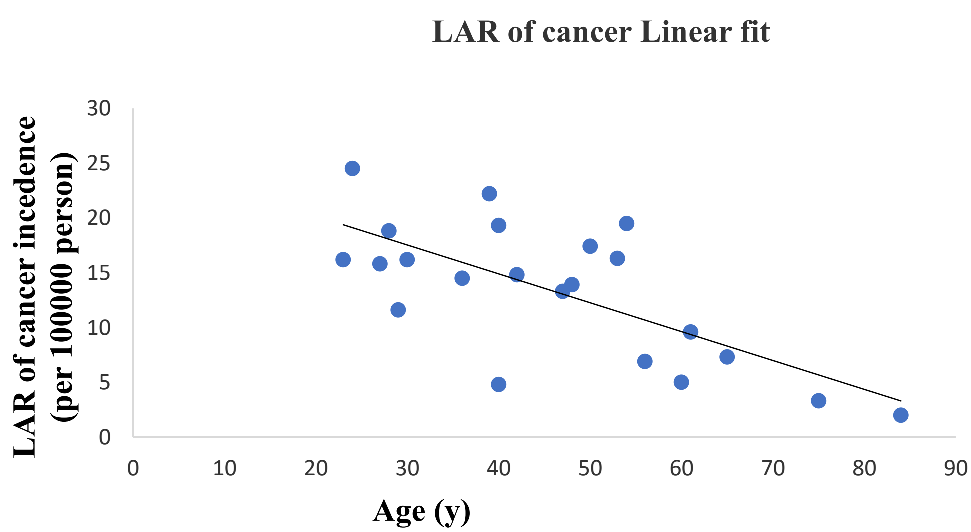

Fig. 3. Age-dependent variation in the LAR of cancer incidence among female patients undergoing abdominal CT examinations

The LAR of cancer incidence per 100,000 male and female patients for head is displayed in Figs. 4 and 5. The cancer incidence per 100,000 values reported by Bagherzadeh were 35.3 and 34.5 for male and female patients, respectively, but in present study, it is found to be 136 and 114 for male and female patients in head patients. For both male and female patients for head CT patients, the mean LAR of cancer mortality was 80.3 and 60.6 respectively. In contrast, Bagherzadeh recorded 15.4 and 16.7 deaths per 100,000 male and female patients, respectively [20]. Figs. 4, and 5 showing that in both states, the LAR of cancer incidence reductions as exposure age increases.

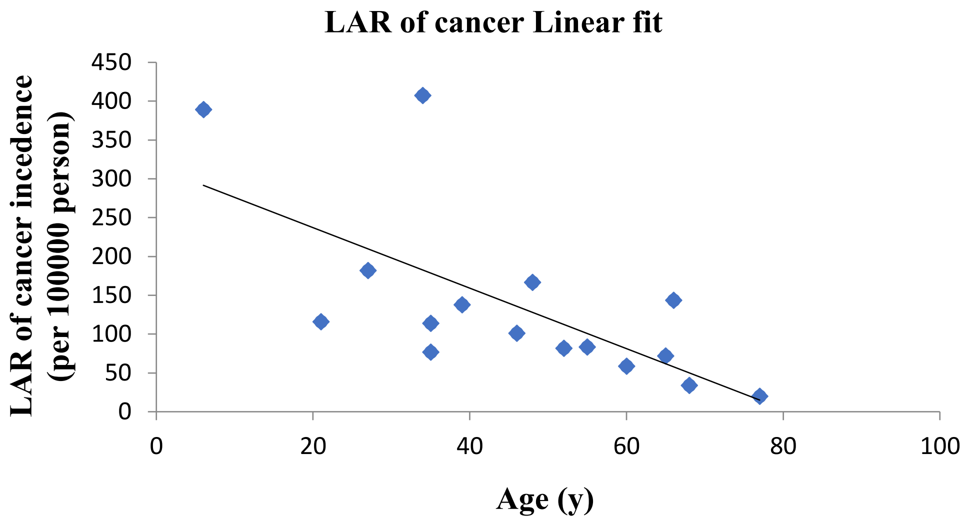

Fig. 4. Age-dependent variation in the LAR of cancer incidence among male patients undergoing head CT examinations

For both male and female patients, the LAR of cancer incidence and death is inconsistent with the age of exposure, as Figs. 2–5 demonstrate. In the present cohort, male patients exhibited higher average cancer incidence and mortality risks than female patients, consistent with the estimated organ doses and effective doses observed during CT examinations.

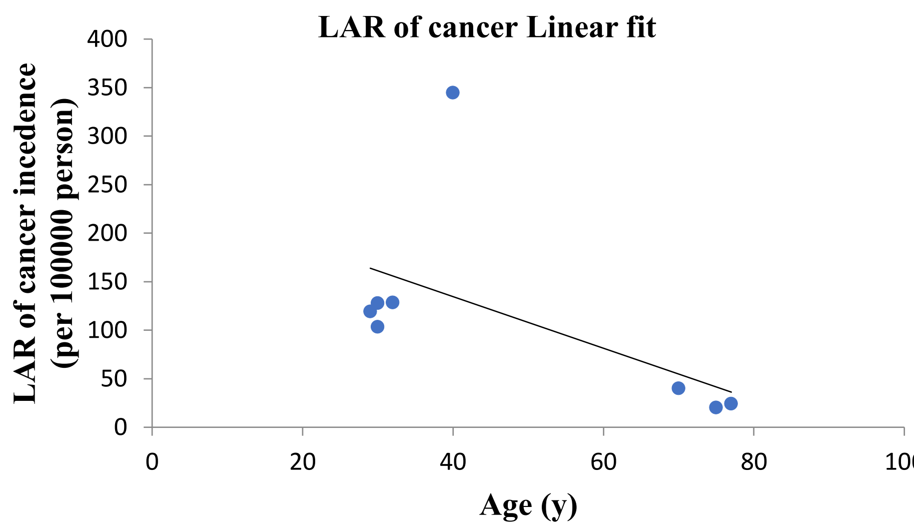

Fig. 5. Age-dependent variation in the LAR of cancer incidence among female patients undergoing head CT examinations

Tables S1-S4 evaluated the different dosage parameters observed during abdomen and head CT imaging techniques and their possible effects on health. The male patients had a higher mean effective dose (3.28 mSv) in head CT than female patients (2.72 mSv), suggesting that males were more exposed to radiation. According to a recent study of Ernest K. Osei1 et al. in 2012 the mean effective dose for adult head CT examinations is 1.8 mSv [19] but in this study which was 3.28 mSv. The effective dose observed in the present study was higher than that reported by Osei and Darko. Due to variations in body composition and organ sensitivity, male patients got a higher organ dosage (86.1 mGy) than female patients (72.4 mGy) for head CT imaging. In both CT examination types, male patients exhibited higher estimated cancer incidence and mortality risks than female patients.

The current study reviewed radiation dose parameters and the LARs of cancer incidence and mortality in patients receiving abdominal and head CT evaluations. Results showed that a measurable amount of radiation dose from CT examinations may contribute to differences in estimated risk for cancer as a function of examination type, age group, sex, and dose absorbed. Here, the doses obtained in effectiveness were generally higher than some values reported in the existing investigations. LAR estimates were greater in younger patients than in older patients after radiation exposure. This is in agreement with the BEIR VII risk model and other work showing that younger people are more at risk for radiation-induced cancer, as they have a longer post-exposure life expectancy and higher tissue radiosensitivity. Estimated LAR values varied between abdomen and head CT examinations and were generally higher in male patients than in female patients. The differences could possibly be attributed to differences in organ dose distribution patterns, patient anatomy, and exposure characteristics. More studies with larger patient populations are required to corroborate these results. Collectively, these results reflect the value of radiation protection, dose optimization, and radiation suppression in CT imaging. For further effective optimization of patients' image quality, it is essential to follow patient-specific scanning protocols following the ALARA concept, as these processes prevent unnecessary radiation exposure.

The findings of this study have important clinical implications for radiation protection in CT imaging. Patient-specific CT protocols should be implemented to ensure that radiation exposure is optimized according to patient age, body size, and clinical indication. In particular, reducing the tube current-time product (mAs) for younger patients, while maintaining adequate diagnostic image quality, may help minimize unnecessary radiation exposure. Furthermore, the use of automatic exposure control (AEC) and iterative reconstruction techniques, where available, can substantially reduce patient dose without compromising image quality. These optimization strategies are consistent with the ALARA (As Low As Reasonably Achievable) principle and should be incorporated into routine clinical CT practice to enhance patient safety.

CONCLUSION

The present study evaluated radiation dose parameters and the lifetime attributable risks (LARs) of cancer incidence and mortality associated with head and abdomen CT examinations in a Bangladeshi patient population. The findings indicate that LAR is influenced by patient age, sex, examination type, and radiation dose, with younger patients demonstrating higher estimated risks. Head CT examinations were associated with greater LAR values than abdomen CT examinations, highlighting the importance of careful dose management in higher-dose imaging procedures. Although the estimated cancer risks were relatively low, the results emphasize the need for optimization of patient-specific CT protocols in accordance with the ALARA (As Low As Reasonably Achievable) principle to minimize unnecessary radiation exposure while maintaining diagnostic image quality. This study has several limitations that should be acknowledged. First, the study was conducted at a single medical center with a relatively small sample size, particularly for female patients undergoing head CT examinations, which may limit the generalizability of the findings. Second, radiation dose measurements were performed using TLD chips positioned beneath the patients rather than within anthropomorphic phantoms; therefore, the measured doses may not fully represent actual organ absorbed doses. In addition, organ doses and lifetime attributable risk (LAR) estimates were derived using established dose conversion coefficients and the BEIR VII risk model, which may introduce some uncertainty in individual risk estimation. Future multicenter studies involving larger and more diverse patient populations, together with advanced patient-specific dosimetry approaches, are recommended to further validate these findings and improve the accuracy of radiation risk assessment.

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Table S1. Dose and risk of cancer due to 'CT Abdomen' of thirty male patient's

Age (years)	Organ Dose (mGy)	Measured $CTDI_{vol}$ (mGy)	Measure DLP (mGy.cm)	Effective Dose (mSv)	Current time product (mAs)	LAR of cancer incidence per 100,000	LAR of cancer mortality per 100,000 persons
1.5	6.1	2.5	76	2	1904	13	2.6
3	24.8	13.8	335	5	3696	47	10.4
24	23.2	14.4	481	7	2135	23	4.6
26	15.6	6.6	411	6	3976	15	3.1
27	23.4	13.7	804	12	6720	23	4.4
31	23.1	16.5	757	11	6594	18	3.9
33	70.5	36.7	1454	22	1885	56	11.9
33	29.8	17.2	799	12	2110	24	5.1
34	67	2.9	158	2	3500	53	11.4
35	10.8	8.0	324	5	2352	9	1.8
37	18.2	12.2	1078	16	3220	14	3.1
39	55.3	12.7	2107	32	6482	44	9.4
40	9.7	4.0	204	3	2340	8	1.6
42	28.5	21.4	1354	20	8526	23	4.8
43	41.3	9.1	2337	35	2910	32	7.0
43	76.8	53.3	3062	46	13810	60	13.0
44	23.8	15.5	701	11	6510	19	4.0
46	13.6	6.9	402	6	2660	11	2.3
48	20.0	13.8	617	9	5376	15	3.4
50	9.1	4.6	250	4	2450	7	1.5
52	31.6	36.2	992	15	5100	24	5.4
53	21.5	15.6	661	10	6090	16	3.6
55	6.3	23.8	1004	15	11150	4	1.1
56	29.1	20.7	115	17	7224	20	4.9
57	22.8	16.1	479	7	4284	16	3.9
64	20.4	16.2	724	11	6300	13	3.5
71	37.8	24.6	788	12	2954	18	5.7
72	77.1	43.8	1460	22	1410	35	11.6

Age (years)	Organ Dose (mGy)	Measured $CTDI_{vol}$ (mGy)	Measure DLP (mGy.cm)	Effective Dose (mSv)	Current time product (mAs)	LAR of cancer incidence per 100,000	LAR of cancer mortality per 100,000 persons
72	25.7	16.6	967	15	2385	12	3.8
79	20.7	11.7	545	8	2954	5	2.1
Mean	**29.4**	**17.0**	**848**	**13**	**4633**	**22**	**5.2**
Std.	**20.20**	**11.93**	**686**	**10.11**	**2906**	**15.32**	**3.42**
Min.	**6.1**	**2.5**	**76**	**2**	**1410**	**4**	**1.1**
Max.	**77.1**	**53.3**	**3062**	**46**	**13810**	**60**	**13**

Table S2. Dose and risk of cancer due to 'CT Abdomen' of twenty-two female patient's

Age (years)	Organ dose (mGy)	Measured $CTDI_{vol}$ (mGy)	Measured DLP (mGy.cm)	Effective Dose (mSv)	Current time product (mAs)	LAR of cancer incidence per 100,000 persons	LAR of cancer mortality per 100,000 persons
23	15.5	34.4	1751	26.3	6945	16.2	4.8
24	23.4	16.0	684	10.3	6174	24.5	6.7
27	17.6	10.7	626	9.4	2660	15.8	4.4
28	20.7	14.1	435	6.5	4200	18.8	5.2
29	14.1	65.4	3030	45.5	2590	11.6	4.7
30	20.5	13.8	583	8.7	6090	16.2	4.7
36	18.8	13.5	548	8.2	4872	14.5	4.3
39	28.4	14.9	849	12.7	3626	22.2	6.5
40	24.8	21.7	1093	16.4	6636	19.3	5.7
40	6.2	2.9	137	2.1	3024	4.8	1.4
42	19.0	13.1	508	7.6	4662	14.8	4.4
47	17.5	6.9	380	5.7	6090	13.3	4.0
48	18.6	8.0	435	6.5	3395	13.9	4.1
50	23.8	14.4	608	9.1	6090	17.4	5.2
53	22.6	11.4	570	8.6	2250	16.3	4.9
54	27.9	15.5	720	10.8	2954	19.5	6.1
56	10.2	5.3	873	13.1	2849	6.9	2.3
60	7.9	3.8	245	3.7	4165	5.0	1.7
61	15.0	84.2	2752	41.3	2590	9.6	3.3
65	13.3	75.3	2920	43.8	17545	7.3	2.6
75	7.4	4.7	252	3.8	3402	3.3	1.2
84	8.6	48.1	1627	24.4	11640	2.0	1.1
Mean	**17.3**	**22.6**	**983**	**14.7**	**5202**	**13.3**	**4.1**
Std.	**6.54**	**23.73**	**874**	**13.12**	**3504**	**6.27**	**1.69**
Min.	**6.2**	**2.9**	**137**	**2.1**	**2250**	**2**	**1.1**
Max.	**28.4**	**84.2**	**3030**	**45.5**	**17545**	**24.5**	**6.7**

Table S3. Dose and risk of cancer due to 'CT Head' of sixteen male patients.

Age (years)	Organ dose (mGy)	Measured $CTDI_{vol}$ (mGy)	Measured DLP (mGy.cm)	Effective Dose (mSv)	Current time Product (mAs)	LAR of cancer incidence per 100,000	LAR of cancer mortality per 100,000
6	58.9	57.0	969	3.1	6290	389	324
21	55.2	68.6	1167	2.5	6290	115	71.7
27	58.6	64.1	1154	2.4	6660	182	58.6
34	226	216	3861	8.1	10776	407	204
35	63.1	66.1	1190	2.5	6660	113	58.0
35	42.7	42.9	772	1.6	3150	76.8	39.3
39	79.1	76.4	1375	2.9	6660	137	71.1
46	70.2	49.3	1448	3.0	7400	101	57.6
48	115	125	1505	3.2	7200	166	92.4
52	60.5	58.1	1117	2.3	6660	81.7	45.4
55	69.4	68.3	1291	2.7	6660	83.2	50.6
60	59.8	73.4	1208	2.5	5920	58.6	34.7
65	75.2	69.2	1392	2.9	6660	71.4	36.1
66	220	251	3576	7.5	9600	143	106
68	56.1	73.2	1171	2.5	5920	33.6	22.4
77	66.0	66.4	1285	2.7	6660	19.8	13.2
Mean	**86.1**	**89.2**	**1530**	**3.3**	**6823**	**136**	**80.3**
Std.	**55.71**	**59.38**	**874**	**1.81**	**1627**	**111.39**	**78.66**
Min.	**42.7**	**42.9**	**772**	**1.6**	**3150**	**19.8**	**13.2**
Max.	**226**	**251**	**3861**	**8.1**	**10776**	**407**	**324**

Table S4. Dose and risk of cancer due to 'CT Head' of eight female patients.

Age (years)	Organ dose (mGy)	Measured $CTDI_{vol}$ (mGy)	Measured DLP (mGy.cm)	Effective Dose (mSv)	Current time Product (mAs)	LAR of cancer incidence per 100,000 persons	LAR of cancer mortality per 100,000 persons
29	58.3	60.7	1031	2.2	6290	120	61.2
30	61.9	60.0	963	2.0	5920	128	63.7
30	50.0	59.1	886	1.9	5920	104	51.5
32	64.2	65.2	1174	2.5	6290	128	64.2
40	191	194	3404	7.1	17760	345	185
70	59.2	64.7	1026	2.2	5550	40.3	27.8
75	33.8	37.0	593	1.2	2800	20.3	13.5
77	61.1	69.3	1297	2.7	6660	24.4	18.3
Mean	**72.4**	**76.3**	**1297**	**2.7**	**7149**	**114**	**60.7**
Std.	**48.9**	**48.56**	**876**	**1.82**	**4452**	**104**	**54.33**
Min.	**33.8**	**37**	**593**	**1.2**	**2800**	**20.3**	**13.5**
Max.	**191**	**194**	**3404**	**7.1**	**17760**	**345**	**185**