Dose assessment of the patient and the helper in emergency head computed tomography

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Abstract

Computed Tomography (CT) becomes more and more important and is frequently used in modern diagnostic techniques. CT offers an effective diagnosis on lesion and pathology; however, it also deliveres a radiation dose to patients. Besides, in some special emergency cases, the patient may require someone to help him in the examination room to perform the head CT, due to the patient lost intellectual and operational capacity. This study evaluated the delivered radiation dose and the risk of radiation-induced cancer for the patient and for the helper after carrying out the emergent head CT examination. A Rando phantom with thermoluminescent dosimeter (TLD) chips inside relevant organs was used to simulate the patient during head CT examination. An effective dose of 2.06±0.16 mSv and 1.46±0.07 mSv without and with wearing the lead apron were found respectively, considering ICRP 60 recommendation. ICRP 103 recommendations the readings would have been 1.29±0.15 mSv and 0.71±0.04 mSv. The effective dose determined from the dose length product (DLP) method (2.19 mSv) was similar to the value (2.06±0.16 mSv) estimated by TLD method considering the ICRP 60 recommendation (without lead apron). Assuming a 5% total risk for fatal cancer per Sv in the general population, risk of radiation-induced cancer for patients were 1.03×10^{-2} % (without lead apron) and 7.80×10^{-3} % (with lead apron) for ICRP 60, and were 6.45×10^{-3} % (without lead apron) and 3.55×10^{-3} % (with lead apron) for ICRP 103. The dose received by the helper was assessed by wearing a personal badge. The helper during emergent head CT examination may receive a personal dose equivalent ($H_p(10)$) of 19.36±5.89 μSv and 138.81±101.28 μSv with and without lead apron, respectively, at distance of 0.3 to 1 m from the center of CT scanner. Based on the observed dose reduction of a factor of 7.17 we recommend that helpers wear lead apron in the CT examination room.

Keywords: effective dose; CT; TLD; radiation-induced cancer risk

1. Introduction

Computed tomography (CT) provides an excellent diagnosis for small lesions. The rapid development of CT and its outstanding multi-slice recombination techniques, enable its use more widely. Today, CT has become more and more important and is frequently used in modern medical diagnosis (Chang et al., 2010). When CT is carried out on a patient, normal tissue inevitably receives a certain amount of radiation. Radiation is known to be a major cause of cancer in normal tissue. (Sharma et al., 2008; Verellen et al., 1999) The risk of radiation-induced cancer is more problematic among younger patients or patients surviving for a long time following CT examination. CT scan offers the effective diagnosis on lesion and pathology; anyhow, it also delivers higher radiation dose to patients than traditional X-ray examinations. Because of the effective density of the head is higher than that of other tissues and organs, then, higher energy would be applied in the cases of head CT examinations. It will cause patients to receive a relatively high radiation dose when the head CT scan is done. Besides, in some special emergency cases, the patient needed someone to help him in the CT room to carry out the scan, due to the patient was in the situation of losing intellectual and operational capacity. The helper usually is a family member of the patient or a medical assistant. The purpose of this study is to evaluate the delivered radiation dose and the risk of radiation-induced cancer for the patient after performance of the emergent head CT examination, and also to estimate the dose delivered to the helper.

2. Methods and materials

This study investigated the doses delivered to a patient and the helper during emergent head CT examination. The Rando phantom, see Figure 1 (left), was used to simulate the patient performing the emergent head CT scan. The Rando phantom (Alderson Research Labs) was composed of 35 sections with several holes distributed in each 2.5 cm thick. Compositions of the phantom were made of rubber isocyanate (equivalent to soft tissues), epoxy resin (equivalent to lung) and human skeleton. Taking the head CT examinations to the phantom with and without shielding covered below the neck. Thermoluminescent dosimeters (TLD-100 chips) were used to measure the tissue and organ doses in the phantom. TLD-100 LiF chips, with the size of $3\times3\times1$ mm^3, were put inside the region of radiation sensitive organs recommended by the International Commission on Radiological Protection (ICRP) (ICRP, 1991; ICRP, 2007) in the phantom. A total of 41 points distributed throughout the organs recommended by ICRP report were measured in each emergent head CT scan. Distribution of these measurement points are shown in Figure 1 (middle and right). Between two and four measurement points were uniformly distributed in the center of each area of tissue or organ in the phantom, depending on its size. Three TLD chips were placed in each measurement point.

Before irradiation, the TLD-100 chips were annealed at 400^oC for 1 hour, following by 100^oC for 2 hours. The irradiated TLD chips were preheated with 100^oC for 10 minutes before reading, and were then read with a Harshaw 3500 TLD reader. The time temperature parameters (TTP) were set to heat from room temperature to 300 ^oC with the heating rate of 20 $^oC\ s^{-1}$. Calibration of TLD-100 chips was performed before carrying out the examination of emergent head CT. For calibration, TLD chips were distinguished into 7 groups, each group had 6 chips. Each TLD group was irradiated with different dose by the photon beam of a standard Cs-137 source to determine the reading-to-dose factor of TLD-100 chips. The reading-to-dose factor was determined using the calculations of averaged net readings and doses.

A reading-to-dose factor of 0.12 mGy/nC was used to transfer the measured TLD reading into absorbed dose. Due to the TLD calibration was performed with Cs-137 gamma rays (662 keV) and the TLD-100 chips were used to estimate the absorbed doses measured at 120 kV, a Monte Carlo simulation using MCNP code was performed to obtain the responses of TLD-100 at different photon energies in this work. Assuming that the mean energy of the investigated 120 kV x-ray beams is 70 keV, the ratio of the response of TLD-100 at the 70keV photon beam to the response at the Cs-137 energy is 1.09. Hence a correction factor of 0.92 was used to obtain the absorbed dose.

The equivalent dose for each organ and the effective dose of the patient taking head CT scan can be calculated by Equation 1 and Equation 2.

$$H_T = D_T \times W_R \qquad \text{(Eq.1)}$$

$$E = \sum_T W_T H_T \qquad \text{(Eq.2)}$$

Where H_T is the equivalent dose of organ T in Sv, D_T is the dose absorbed in Gy, W_R is the radiation weighting factor (W_R is 1 for photons), E is the effective dose in Sv, W_T is the tissue weighting factor recommended by ICRP report. The values of W_T are indicated in Table 1.

The effective dose may also be derived from dose-length product (DLP) for an examination using appropriately normalized coefficients (Bongartz et al., 1999):

$$E(mSv)=E_{DLP}\times DLP \qquad \text{(Eq.3)}$$

Where E_{DLP} is the region-specific normalized effective dose ($mSv\ mGy^{-1}\ cm^{-1}$). For head CT, the value of E_{DLP} is 0.0023 ($mSv\ mGy^{-1}\ cm^{-1}$). DLP value was determined by following equation:

$$DLP= CTDI_{vol} \times \text{Scan length} \qquad \text{(Eq.4)}$$

Where $CTDI_{vol}$ is the CT dose index in mGy and in this study was obtained by automatical calculation of the CT system. Scan length is in cm.

According to the estimated effective doses and the 5% total risk for fatal cancer per Sv, suggested by the ICRP 60 report, the health risk of radiation-induced cancer for a patient carrying out a head CT examination was assessed.

For the dose investigation of the helper, personal dosimeter badges (PDBs) were used in several clinical cases (15 helpers in emergent head examinations were investigated) in this research. The helpers usually wear the lead apron and stay in the examination room in a distance range of 0.3 to 1 m apart from the center of CT scanner as performing the patient's head CT scan. The PDBs were worn inside (1 PDB) and outside (1 PDB) at the chest area of the lead apron, and were not overlapped for each helper dose investigation. Personal dosimeter badges were read by a Harshaw 6600 TLD reader to estimate the personal dose equivalent, $H_p(10)$ and $H_p(0.07)$.

3. Results and discussion

The experiment for estimating organ equivalent doses of the patient by using the phantom and TLD chips was repeated 3 times in each case (with or without lead apron), to get the average doses. The operation conditions for the emergent head CT scan were: 120 kV, 380 effective mAs, scan time of 14.47 sec, and scan length of 160 mm. The results of averaged organ equivalent doses for patient with and without lead apron are presented in Table 1. For both cases, with and without lead apron, Ht of brain and lens were in the dose range between 50 to 60 mSv. Lens is an organ sensitive to radiation for deterministic effects but not for stochastic effects, therefore, it was not considered in the estimation of effective dose. Organ doses decreased dramatically below the lens. In the cases of wearing lead apron, Ht values were down to background level for organs at position in the location of the lung and below. The reproducibility of TLD readings was within ±7%. The uncertainty in the calibration of photon dose was less than 2 % and in the positioning of TLD was approximately ±2 %. Statistical error of the TLD readings was ±5 %. Uncertainty of doses received by organs is presented in Table 1.

By means of the recommendations of tissue weighting factors from ICRP, effective doses for wearing and not wearing the lead apron were estimated and are listed in Table 2. For consideration of ICRP-60 recommendation, effective doses were 2.06±0.16 mSv and 1.46±0.07 mSv without and with the lead apron, respectively. For ICRP-103 recommendation, effective doses were 1.29±0.15 mSv and 0.71±0.04 mSv without and with the lead apron, respectively. Using the DLP method (Eq.2 and Eq.3), where $CTDI_{vol}$ was 59.49 mGy in all cases of this study and DLP was 951.84 (mGy cm), an effective dose of 2.19 mSv was determined. The effective dose obtained by the DLP method (2.19 mSv) was similar to the value (2.06±0.16 mSv) estimated by TLD method considering the ICRP 60 recommendation (without lead apron).

Risk of radiation-inducing cancer due to an emergent head CT examination were then assessed after the determination of effective dose and assuming a 5% total risk of fatal cancer per Sv in the general population suggested by the ICRP 60 report (see Table 2). For ICRP-60 recommendation, risk of radiation-induced cancer for patients without and with lead apron were 1.03×10^{-2} % and 7.80×10^{-3} %, respectively. For ICRP-103 recommendation, risk of radiation-induced cancer for patients without and with lead apron were 6.45×10^{-3} % and 3.55×10^{-3} %, respectively. Uncertainty of the estimated risk is presented in Table 2.

The dose were estimated for 15 helpers in emergent head CT examination, the maximum doses received by the helpers were $H_p(10)$, 409.6 μSv and $H_p(0.07)$, 415.5 μSv (badge placed outside of the lead apron) at 0.3 m from the center of CT scanner. The average doses received by the helpers were $H_p(10)$, 19.36±5.89 μSv and $H_p(0.07)$, 12.60±4.18 μSv (badge placed inside the lead apron) at distance of 0.3 to 1 m from the center of CT scanner; and were $H_p(10)$, 138.81±101.28 μSv and $H_p(0.07)$, 128.70±96.25 μSv (badge placed outside the lead apron). A factor of 7.17 was calculated for the $H_p(10)$ ratio of the measurement with the badge placed outside and inside the lead apron; and a factor of 10.21 was calculated for the $H_p(0.07)$ ratio of the measurement with the badge placed outside and inside the lead apron.

4. Conclusion

In summary, this study investigated the doses delivered to patient by means of the Rando phantom and TLD method in carrying out an emergent head CT examination. Effective dose of 2.06±0.16 mSv and 1.46±0.07 mSv without and with the lead apron were estimated respectively, considering ICRP 60 recommendation; and were 1.29±0.15 mSv and 0.71±0.04 mSv considering ICRP 103 recommendation. The effective dose determined by the DLP method (2.19 mSv) was similar to the value (2.06±0.16 mSv) estimated by TLD method considering the ICRP 60 recommendation (without lead apron). Assuming a 5% total risk of fatal cancer per Sv in the general population, risk of radiation-induced cancer for patients without and with lead apron were 1.03×10^{-2} % and 7.80×10^{-3} % for ICRP 60, and were 6.45×10^{-3} % and 3.55×10^{-3} % for ICRP 103, respectively. The helper during an emergent head CT examination may received an $H_p(10)$ of 19.36±5.89 μSv and 138.81±101.28 μSv for wearing lead apron and without wearing, respectively, at distance of 0.3 to 1 m from the center of CT scanner. A factor of 7.17 was calculated for the $H_p(10)$ ratio of values obtained without and with wearing lead apron, the helper was strongly recommended to wear the lead apron in the CT examination room.

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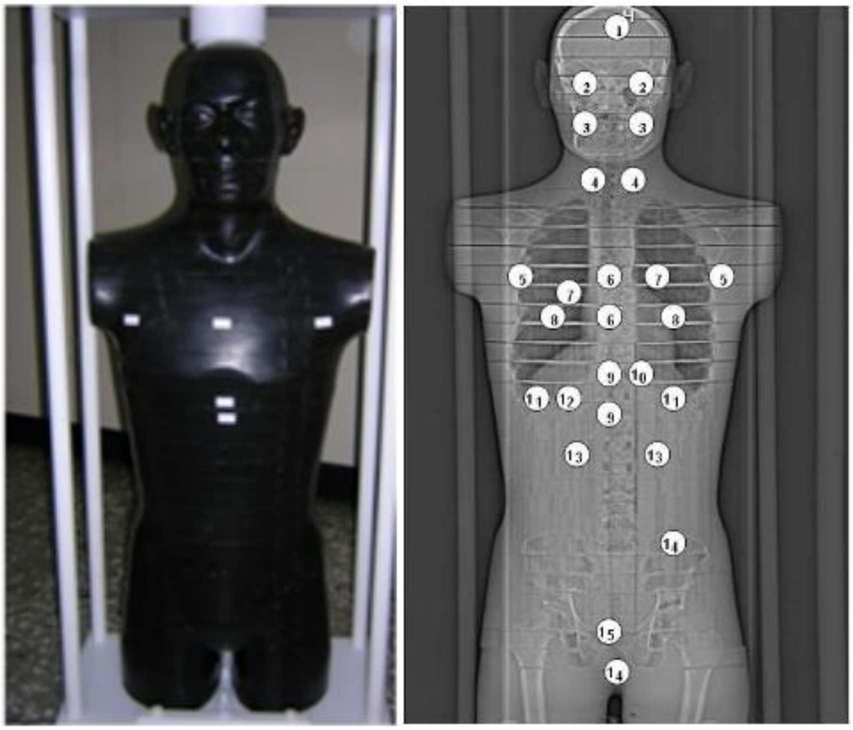
Table 1. Averaged equivalent dose (H_T) of the Patients and the tissue weighted factor (W_T) from ICRP 60 and ICRP 103 reports.

Organ or Tissue	H_T (mSv) without lead apron	H_T (mSv) with lead apron	W_T (ICRP-60)	W_T (ICRP-103)
Brain	57.14±2.90	55.25±2.76	---[2]	0.01
Lens	56.46±3.06	54.90±3.23	---[2]	---[2]
Salivary gland	12.46±1.13	10.97±1.43	---[2]	0.01
Thyroid	3.38±0.97	2.89±0.25	0.05	0.04
Bone surface	0.73±0.47	0.43±0.17	0.01	0.01
Esophagus	0.84± 0.46	0.67±0.23	0.05	0.04
Lung	0.55±0.39	---[1]	0.12	0.12
Breast	0.59±0.29	---[1]	0.05	0.12
Red bone marrow	1.14±0.98	---[1]	0.12	0.12
Stomach	0.37±0.16	---[1]	0.12	0.12
Skin	0.68±0.32	---[1]	0.01	0.01
Liver	0.38±0.19	---[1]	0.05	0.04
Colon	0.34±0.14	---[1]	0.12	0.12
Gonad	0.30±0.21	---[1]	0.20	0.08
Bladder	0.28±0.08	---[1]	0.05	0.04
Remainder			0.05	0.12

[1]The dose is in background level.
[2] Not available.

Table 2. Effective doses calculated with the tissue weighting factor recommended by ICRP 60 and ICRP 103 reports and risk of radiation-induced cancer.

	ICRP-60	ICRP-103
E(mSv)		
Without lead apron	2.06±0.16	1.29±0.15
With lead apron	1.56±0.07	0.71±0.04
Risk of radiation-induced cancer (%)		
Without lead apron	$1.03\times10^{-2}\pm8.50\times10^{-4}$	$6.45\times10^{-3}\pm7.50\times10^{-4}$
With lead apron	$7.80\times10^{-3}\pm3.50\times10^{-4}$	$3.55\times10^{-3}\pm2.00\times10^{-4}$



Number	Organ	TLD Position (slice number)	Number of TLD Point
1	Brain	2	4
2	Len (Remainder)	5	2
3	Salivary gland	7	2
4	Thyroid	9	4
5	Bone surface	14	2
6	Esophagus	14,16	2
7	Lung	14,15	4
8	Breast	16	4
9	Bone marrow	19,21	4
10	Stomach	19	2
11	Skin	20	3
12	Liver	20	2
13	Colon	23	2
14	Gonad	28,33	2
15	Bladder	32	2

Figure 1. The photo of Rando phantom (left) and its CT image (middle). In the right is the distribution list of TLD measurement points inside the Rando phantom.