Evaluation of effective doses in CT simulation using $CTDI_w$ calculation

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Received June 2017
Accepted as revised July 2017

Abstract

Background: Computed Tomography (CT) simulator is used for primary imaging in Department of Radiation Therapy. Although it is also the leading standard of treatment planning since it directly measures electron densities needed for dosage computation, it is known to deliver more radiation dose to patients.

Objectives: The purpose of this study is to determine the effective dose for cancer patients undergoing the CT simulator.

Materials and methods: An ionization chamber was used to measure $CTDI_{air}$ in CT simulator (Siemens, Somatom Definition AS, Germany). Measurement of $CTDI_w$ was done by placing the Pencil Ionization Chamber (Radcal, USA, SN:05-0340) in PMMA head and body phantoms to measure $CTDI_{100}$ for the head and abdomen region, respectively. Twenty cases of head, thorax, and pelvic cancer patients were recorded. $CTDI_{vol}$, DLP, scan length, kV, mAs, pitch, and rotation time parameters were collected in each patient for $CTDI_w$ dose calculation to obtain the effective dose.

Results: Dose index in air ($CTDI_{air}$) was 8.84 mGy and $CTDI_w$ in PMMA head and body phantom were 16.67 and 10.33 mGy, respectively. Effective doses in head, thorax, and abdomen cases were shown to be 2.20±0.06, 5.01±1.09, 6.90±1.23 mSv, respectively.

Conclusion: Effective doses were different in each region. Although, they were less than recommended, it should still be taken into consideration. Protocol optimization in CT simulator should be considered about pitch, scan length, slice thickness and mAs while image quality would be accepted.

Journal of Associated Medical Sciences 2017; 50(3): 417-423. Doi: 10.14456/jams.2017.58

Keywords: CT simulator, effective dose, CTDI

Introduction

Radiation Therapy is one of the main treatment models that are efficient in treating cancer patients. The goal of radiotherapy is to deliver a prescribed dose to the target tissue and to keep dose to the surrounding healthy tissues as low as possible. Therefore, radiographic image is also a crucial factor for patient dose delivery. Since radiotherapy process requires high level of accuracy and precision, it should have simulation process before proceeding to deliver such high dose to a patient. Radiotherapy simulator has various models such as 2D (Conventional simulator) and 3D (computed tomography simulator and magnetic resonance imaging simulator). Main goals of the simulation process are to employ an immobilization properly with the patient's anatomy and physiology as well as to reconstruct and record radiographic image for treatment planning.

Nowadays, computed tomography (CT) simulator is the leading choice in radiotherapy simulation because it provides 3-dimensional reconstructed image that illustrates good organ delineation which is useful for bony landmark checking in patient setup procedure, Digital reconstructed radiography (DRRs) demonstration for patient positioning and electron density measurement which is principal for radiotherapy treatment planning.

The amount of radiation exposure for cancer patients undergoing CT simulation is an important point for consideration because CT simulator will deliver higher dose of radiation to patients. Although, the radiation dose from CT simulation is very low as compare to therapeutic dose, but patient should receive the lowest dose while image quality is still good. However improvement to CT protocol in the radiotherapy department is continuing, the patient's radiation dosage is still an important point of concern. Therefore the purpose of this study was to determine the effective dose for cancer patients undergoing CT simulator in Thammasat University Hospital, Pathum Thani, Thailand.

Materials and methods

The research was an observational descriptive study. Retrospective data was randomly collected between April and June 2016 in Thammasat University Hospital, Pathum Thani, Thailand. Twenty patients (36 females and 24 males) of head (aged 13-89 years), thorax (aged 42-83 years), and abdomen cancer (aged 37-76 years) were included. The process was in 3 steps.

1. A quality control check on radiation output was the first conducted on CT simulator (Siemens Somatom Definition AS with 64 slices) by referring to measurement stated in the manufacturer's guideline and verifying the radiation dose against the manual. Measurement of CT dose index (CTDI, mGy).[1] was done by hanging the pencil ionization chamber (Radcal, S/N: 05-0340) from platform in mid-air and setting the sensitive volume at isocenter (Figure 1). An axial scanning was performed along z-axis based the standard protocol stated in equation 1.[2] Parameters were set up 120 kV, 300 mAs, pitch 0.55, 10 mm scan length and 10 mm slice thickness. Measurements were repeated 3 times and mean value was collected.

$$CTDI_{100} = \frac{1}{NT}\int_{-50\ mm}^{+50\ mm} D(z)dz \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Where D(z) is dose profile originating from one axial rotation, along a line that is perpendicular to the tomographic plane, dose being expressed as absorbed dose in air. The measured integration has the units of dose and length. N is number of active acquisition channels (detector rows), and T is nominal thickness of each acquisition channel (detector row, or group of detector rows). CTDI is usually obtained using a single axial scan.

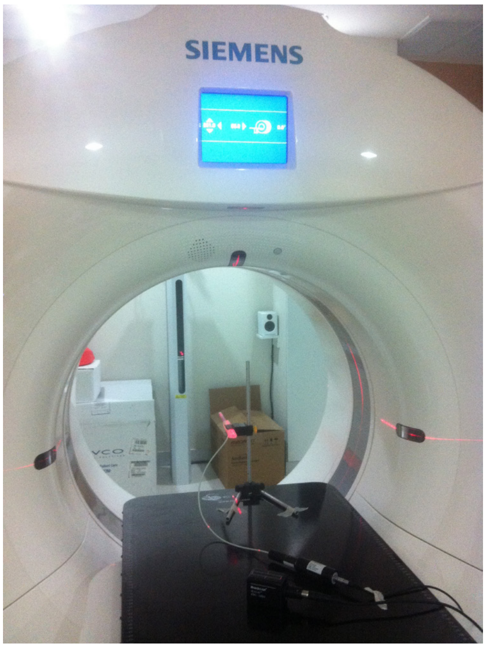

Figure 1 *Setup of pencil ionization chamber for CTDI measurement in mid-air.*

Secondly, measurements were collected from Polymethymethacrylate (PMMA) head and body phantoms to get $CTDI_{100}$ in five positions (center, north, south, east, and west) and then calculated using equation (2) to get $CTDI_w$. Phantoms were placed and aligned parallel to the couch to scan rotational axis with the slice plane going through mid-length of phantoms. Pencil ionization chamber was put into the hole while other holes were inserted with acrylic sleeves.[3] Axial scan performed by CT simulator was for a specific 120 kVp, 300 mAs and 10 mm slice thickness. It was repeated to obtain different measurements with chamber at the different positions and calculated by equation (2). Setup of PMMA head and body phantoms were demonstrated in figure 2 and 3, respectively.

$$CTDI_w = [2/3CTDI_{100}(\text{Periphery}) + 1/3CTDI_{100}(\text{Center})]\ldots.(2)$$

Where $CTDI_w$ is weighted average of $CTDI_{100}$ measurements at the center and peripheral locations in phantom. $CTDI_{100}$ (Periphery) is the average of CT dose index of four peripheral positions of phantom, and $CTDI_{100}$(Center) is CT dose index at the center of phantom. The reference $CTDI_{vol}$ and measured $CTDI_{vol}$ were compared to verify dose measurement with the reference data.

Figure 2 *PMMA head phantom with 16 cm diameter was positioned for $CTDI_{100}$ measurement in head protocol.*

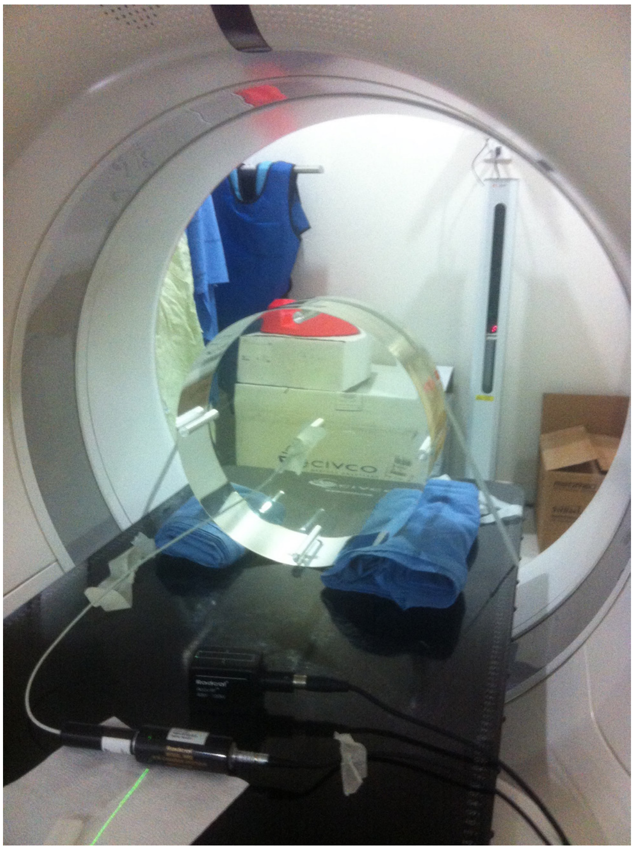

Figure 3 *PMMA body phantom with 32 cm diameter was aligned with an isocenter for $CTDI_{100}$ measurement in body protocol.*

Image quality in CT [4] was determined by scanning CT water phantom to obtain CT number accuracy, CT number uniformity, and image artifacts. A phantom was scanned in tomographic plane with selected protocol of 120 kVp, 361 mAs, 224 mm FOV, and 5 mm slice thickness. Then, phantom was scanned in axial mode and CT number was centrally measured in circular ROI. CT number uniformity was measured by placing different ROIs (north, east, west, and south) and compared with the center ROI. Finally, CT image was inspected for image artifacts.

2. Patients' data were obtained from monitor/ PACS (Picture Archiving and Communication System) by collecting scan types, kV, mAs, pitch, scan length, rotation time, collimation, $CTDI_{vol}$(mGy), and DLP (mGy.cm). Radiation dose calculation was then employed using $CTDI_w$ calculation procedure for the effective dose computation by equation 3, 4, and 5, respectively.

$$CTDI_{vol} = CTDI_w/\text{Pitch}\ldots\ldots\ldots\ldots\ldots (3)$$

Where $CTDI_{vol}$ is absorbed radiation dose over x, y, z-direction within scan volume for standardized phantom and divided by pitch which is the ratio of table travel normalized to total beam collimation.

DLP (mGy.cm) = $CTDI_{vol}$ (mGy)*Scan length (cm)……..… (4)

where DLP is dose length product (absorbed dose integrated along the scan length and expressed in mGy.cm.)

Effective dose (mSv) = k (mSv/mGy*cm)*DLP (mGy*cm)………(5)

where k is the conversion factor from European Commission (EC, 2004) and National Radiological Protection Board (NRPB, 2005). Value for head, thorax, and abdomen are 0.0021, 0.014, and 0.015 mSv/mGy*cm, respectively.[5]

3. The effective dose was compared between results from Chulalongkorn Memorial Hospital (Pyone Y. et al) and Thammasat University Hospital and subsequently compared against the diagnostic reference levels (DRLs).

Results

Average CT dose index in air ($CTDI_{air}$) per 100 mAs measured by pencil ionization chamber was 8.84 mGy. In addition, weighted CT dose index ($CTDI_w$) per 100 mAs calculated by equation 2 and $CTDI_{vol}$ for head and body phantom were shown in table 1 and table 2, respectively.

Table 1 Dose measurement in PMMA head phantom with pencil ionization chamber for $CTDI_{100}$per 100 mAs(mGy) (in all positions), $CTDI_w$(mGy), and $CTDI_{vol}$(mGy).

Position	Reading (mGy)
Center	5.44±0.03
North	6.19±0.20
South	4.99±0.14
East	5.71±0.15
West	5.56±0.20
$CTDI_w$ (mGy)	5.56
$CTDI_{vol}$ (mGy)	4.63

Table 2 Dose measurement in PMMA body phantom with pencil ionization chamber for $CTDI_{100}$ per 100 mAs(mGy) (in all positions), $CTDI_w$(mGy), and $CTDI_{vol}$(mGy).

Position	Reading (mGy)
Center	2.14±0.01
North	4.41±0.06
South	3.48±0.07
East	4.27±0.09
West	4.21±0.08
$CTDI_w$ (mGy)	3.44
$CTDI_{vol}$ (mGy)	2.87

Result of CT number accuracy was passed due to CT number of water was -1.56±3.51 that agree with criteria which is within 0±5 HU.[4] CT number and noise in the different locations are shown in table 3. Result of CT number uniformity was accepted with the criteria that peripheral ROI should be differed from the central ROI within ±5 HU. Moreover, a uniform image of water phantom was without artifacts. Thus, the image quality in CT was within agreement.

Table 3. CT number accuracy and CT number uniformity

Location in phantom	CT number±noise
Center	-1.56±3.51
North	-2.11±3.07
East	-1.33±3.34
West	-1.77±3.22
South	-2.03±3.42

Patients' data were recorded from monitor/PACS. Average effective doses in head, thorax, and abdomen regions were 2.20±0.06, 5.01±1.09, and 6.90±1.23 mSv, respectively.

Discussion

Reported CT values commissioned by medical physicist were 3.98 mGy (small FOV) and 1.74 mGy (Large FOV) and therefore the obtained results for $CTDI_{vol}$ values from this study were more than reported CT values. For this dedicated CT scanner, $CTDI_{vol}$ values are still within range of values from conventional CT.

Another finding discovered was that the effective doses of CT simulator in Thammasat University Hospital was differ from the effective dose of Chulalongkorn Memorial Hospital's machine in different regions. Firstly, in head, thorax and pelvic regions, effective dose in Thammasat University Hospital is discovered to be lower than report of Pyone Y.[6] for CT simulator, as shown in table 4. Factor of higher effective dose were due to the use of lower slice thickness, higher mAs, lower pitch, higher scan length, and thicker collimation setting[7,8] for every regions followed by table 5. A parameter which is the major effect on dose is pitch and scan length especially in breast because of the scan length in chest protocol.[6] Moreover, assistance provided by automatic tube current modulation (ATCM)[9] for effective dose in cancer patients in Thammasat University Hospital was also affected the effective dose. When slice thickness is reduced, dose will be increased to maintain the same level of noise as with the thicker slices.[10]

Table 4 Comparison of effective dose (mSv) from CT simulator in head, thorax, and abdomen regions between Thammasat University Hospital and Chulalongkorn Memorial Hospital.

Study	Effective dose (mSv)		
	Head	Thorax	Abdomen
Pyone Y. et al	3.30	13.00	7.20
Thammasat University Hospital	2.20	5.01	6.90

Table 5 The comparison of scanning parameters in CT simulator between Thammasat University Hospital (TU) and Chulalongkorn Memorial Hospital (CU).

Parameter	Head		Thorax		Pelvis	
	CU	TU	CU	TU	CU	TU
kV	120	120	120	120	120	120
mA	325	410	325	180	325	250
Scan length	357	213	355	398	280	368
Pitch	0.938	0.55	0.938	1.20	0.938	1
Rotation time	0.75	1	1	1	1	1
Collimation	16* 1.5	64* 0.6	16* 1.5	64* 0.6	16* 1.5	64* 0.6

DLP values from this study were lower than diagnostic reference levels (DRLs) collected by the European Commission (EC) in 1999,[11] as shown in table 6. Therefore, data was agreed with DRLs and patients safely got radiation dose from CT simulator in Thammasat University Hospital while image quality is acceptable.

Table 6 Comparison of dose length product (DLP) between dose reference levels from European Commission (EC, 1999) and Thammasat University Hospital.

Study	DLP (mGy-cm)		
	Head	Thorax	Abdomen
DRLs	1050.00	650.00	800.00
Thammasat University Hospital	1048.51	357.80	460.16

The radiation doses in CT Simulator can be reduced by decreasing the CT examination repetition especially in pediatric simulation in order to diminish the radiation dose to sensitive organs. The communication between radiological technologist and patient are also important as well. Moreover, a scan protocol should be optimized and adjusted properly to patients such as higher pitch (should be more than 1 because the X-ray beam profiles do not overlap, there are gaps in the acquisition and the absorbed dose decreases),[12] the lowest scan length is used, the lowest dose patients receive. Moreover, the slice thickness should be considered because if thicker slices are used, it can give more photons and less noise but higher doses.[13] Due to good quality image, we can adjust and take into account about the scanning parameter so that the radiation dose level follows the principle of “As Low As Reasonably Achievable” or ALARA.

Conclusions

In conclusion, the effective doses in head, thorax, and abdomen cases were shown to be 2.20±0.06, 5.01±1.09, and 6.90±1.23 mSv, respectively. Although doses from CT simulator were much lesser than doses from therapeutic treatment machine, there was also additional concern on increased chances of contracting secondary cancers due to the presence of imaging dose. However, these stochastic risks have already been recognized and estimated by the American Association of Physicists in Medicine (AAPM) Task Group 75.[14]

Acknowledgements

I would like to thank Department of Radiation Therapy and Oncology, King Chulalongkorn Memorial Hospital and Thammasat Radiation Oncology Center, Thammasat University Hospital for their equipment’s support. Many thanks are for medical physicists in King Chulalongkorn Memorial Hospital for their suggestions in this research work. Finally, I am thankful to Mr.Lau See Yang for his support.

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