Original Article

Dosimetric Evaluation of Multislice CT Using Anthropomorphic Head Phantom

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A B S T R A C T

Purpose- The most general form to report dose in Multislice CT is the CTDI and DLP which are computed for several slices. The goal of the current study was to estimate actual doses and dose distribution during CT examinations in a head and neck anthropomorphic phantom.

Methods- After construction of the head and neck phantom using natural bone and paraffin wax with NaCl as impurity, several places were considered in different sites to fill with badges of Gafchromic film. These places include brain, Parotid, Thyroid and Lens of eye. Phantom was scanned at CT Angio and Spiral protocols with 10 and 256 slice scanners.

Results- Our findings showed that in 10 slice scanner, selected organ doses were in the range of 0.09-23.1 mSv while in the 256 slice scanner, it was in the range of 0.14-18.01 mSv. The CT Angio protocol has a higher organ dose at all.

Conclusion- In CT Angio protocol, organ dose (except for the lens of eye) is lower in 10 slice compared to 256 slice CT; the brain dose in both protocols has no difference statistically. In the spiral protocol, the dose in 256 slice scanner is lower than the 10 slice scanner which might be due to higher number of detector arrays in 256 slice scanner.Thyroid dose is mainly due to scattered radiation and because of strict beam collimation; it has a small value in all protocols.

1. Introduction

X-rays in medical imaging modalitieshas the greatest man-made source of radiation to the population which has significantly increased the cumulative exposure to ionizing radiation; from 15% of the total annual exposure of the population in the United States from all sourcesin 1987 to about 50% in 2006 [1-3]. Recently, the number of CT examinations has been raised significantly due to the wide-spread use of multi-slice CT scanners [4, 5]. Performing a detailed dose measurement is important to keep radiation doses during CT examinations as low as reasonably achievable is of great importance.

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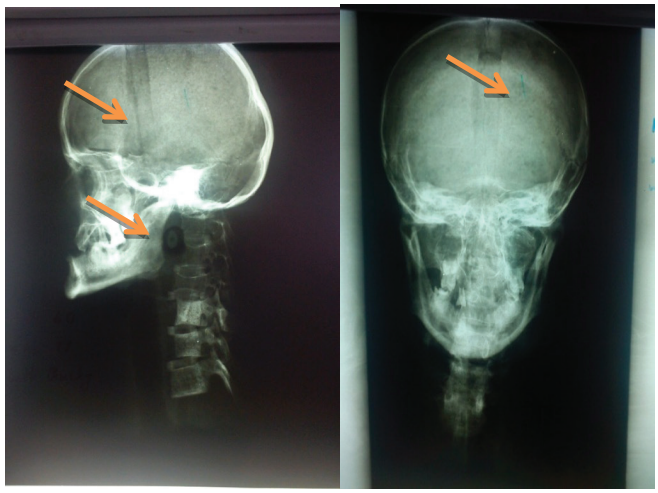
There are several ways to express dose in CT such as CTDI, $CTDI_{vol}$ and DLP which measurements are based on ionization chambers [6-9]. A better way of estimating doses to patients undergoing CT examinations is to directly measure organ dosesor to perform computer simulations in anthropomorphic phantoms [10]. There exist several candidates to measure dose such as TLDs, gels and films [11-13]. Film has been used for dosimetric measurements for decades with the advantage of its high spatial resolution. Gafchromic film has a spatial resolution on the order of 25 μm [13-16], a high sensitivity and reasonable uniformity.

The purpose of this study was to assess patient's radiation exposure in several standard protocols in MSCT. To do so, a 2D film dosimetry was applied for dose measurements using XR-QA radiochromic film MSCT examinations carried out on anthropomorphic head phantom. Performing a detailed dose measurement is important to keep radiation doses during CT examinations as low as reasonably achievable.

2. Materials and Methods

2.1. Phantom

Natural human skull and paraffin wax with different amounts of *NaCl* as impurity was used for bone, soft tissue and fat, respectively. Two hollow plastic tubes were placed to consider trachea and esophagus and a hollow plastic box was placed to consider the mouth cavity. Two cylinders were considered vertically and horizontally from the upper limit of skull downwards and from left parotid to right parotid on the base of skull to place films in order to estimate total brain dose (arrows in Figure 1). The left and right extremes of the later were used to estimate parotid dose. Besides, two cylinders were considered at side lobes of thyroid in order to place films vertically and measure thyroid dose. Radiation dose to eye was measured at the surface in place of each eye.



(a) **(b)**

Figure 1. (a) lateral and (b) AP radiographs of the head & Neck phantom.

2.2. Calibration of Dosimeters

To obtain calibration curve, films were cut into multiple pieces; divided into 7 groups each consisting 3 pieces, deliver a known dose which was measured using a solid state real-time dose monitor device (Pehamed, Germany) in the range of 0-21 mGy to each batch.

The following equation was used to obtain the net optical density (net*OD*):

$$\text{net}OD = OD_{exp} - OD_{unexp} = \log_{10}[(PV_{unexp} - PV_{bg})/(PV_{exp} - PV_{bg})]$$

Where PV_{unexp} refers to the pixel value of blank film, PV_{exp} refers to pixel value of exposed film, and

PV_{bg} refers to pixel value of opaque black cardboard. Reading the film with scanner was performed after a certain time. Some correction is needed for scanner artifacts such as scanner fluctuation and light scattering effect. After obtaining optical density and dose values, a calibration curve with certain parameters and equation was obtained.

2.3. Imaging Protocols

Two common imaging protocols as spiral CT and CT Angio were conducted on the phantom with two existing CT machines (Siemens Somatom definition flash 256 slice and Somatom sensation 10 slice, Germany, healthcare). It is notable that imaging condition was identical to an adult patient with a similar head size (kV_p=120).

(a)

(b)

Figure 2. The head phantom placed at the (a) 256 slice and (b) 10 slice CT.

2.4. Dosimetric Measurements

Organ doses were measured using calibrated radiochromic films embedded in the phantom. The exposed radiochromic film was read-out using a flatbed scanner in reflection mode which red channel was extracted in Matlab (version 7.8, Mathworks, USA) to convert to dose using calibration equation described earlier. In order to increase reproducibility and reduce temporal noise, each measurement was repeated 3 times.

3. Results

Figure 3 shows the calibration curve for Gafchromic films used in this study with its calibration equation and correlation coefficient.

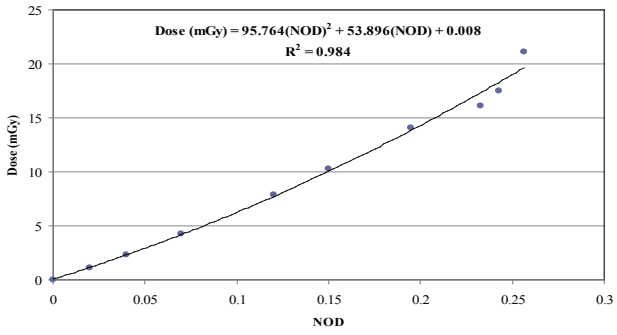


Figure 3. The calibration curve for films used with the calibration equation.

In this graph, the horizontal axis shows the net optical density (NOD) as described before and the vertical axis shows dose values in mGy. Because we used 120 kV_p for imaging the head phantom, the calibration was performed at this condition, too. Table 1 shows the absorbed dose to brain, left and right parotid (as mean depth dose), lens of eye (as mean surface dose) and thyroid (as mean depth dose). It is notable that to measure brain dose, two perpendicular directions was selected and by inserting appropriate applicators to insert films, the average brain dose was estimated. Besides, using similar applicators, parotid and thyroid depth dose at both sides was measured. The obtained results for both protocols in each system with the $CTDI_{vol}$ are presented in Table 1.

Table 1. Mean organ dose (SD) in mGy and $CTDI_{VOL}$ at CT Angio and spiral protocols in 10 and 256 slice CT systems.

	Protocol	Parotid	Thyroid	Brain	Lens of eye	$CTDI_{vol}$
10 slice	CT Angio	2.15 (0.04)	0.09 (0.01)	8.41 (0.03)	7.53 (0.17)	23.32
	Spiral	7.06 (0.02)	0.77 (0.14)	23.11 (0.47)	23.04 (0.06)	54.43
256 slice	CT Angio	7.16 (0.001)	0.14 (0.05)	8.99 (0.1)	5.32 (0.5)	28.84
	Spiral	6.01 (0.12)	0.68 (0.08)	18.01 (0.15)	17.15 (0.01)	50.92

4. Discussion

There are many variables within each CT examination procedure that influence patient dose, in particular, slice thickness and the tube current time product (mAs). Slice thickness and mAs are linked through image noise [4]. One method to report dose in computed tomography is to compute CTDI and DLP for a single slice or several slices in a reference phantom. These parameters have the merits of simple calculation, considering scan parameters such as pitch factor, detector rotation time and beam filtration; but they do not consider patient size and tissue types and mass which disturbs dose distribution in patient's body. Anthropomorphic phantoms with appropriate tissue substitutes allow simulating clinical situations more accurately. Films are capable to provide continuous dose distribution at each site they embedded in the phantom. In order to measure doses in clinical situations, standard protocols for a patient with same size as the phantom without any modification was used.

As it is observed from Table 1, in CT Angio protocol organ dose (except for the lens of eye) is lower in 10 slice CT compared to 256 slice CT; the brain dose in both protocols has no difference statistically. This agrees with the results of NRPB survey which compared 4 slice scanners with scanners capable to obtain 8 or more slices simultaneously [17]. Yates *et al* compared SSCT with MSCT scanners and found that on average the mean effective dose levels for MSCT were about 35% higher than SSCT [18]. This significant difference might be due to different protocols used in two scanners. In the case of eye, the difference could be due to surface measurements and its position relative to slices and also beam collimation. In the spiral protocol, it is observed that the dose in 256 slice scanner is lower than the 10 slice scanner. This is due to higher number of detector arrays in 256 slice scanner which leads to lower organ doses and it is possible to perform a scan with the same quality and lower dose levels. In the case of thyroid, received dose is mainly due to scattered radiation and because of strict collimation of radiation, has a small value in all protocols. In some studies, the effective dose was estimated from DLP and EDLP values without any direct measurement of organ dose using TLD or any other clinical dosimeters [17, 19]. Among the studies on organ dose in CT examination on phantoms, our study agrees with study of Cohnen *et al* [20] which used TLD and anthropomorphic phantom but has some differences with findings of Feng *et al* [21] study which is due to considering pediatric phantom and some differences in scanners. It is notable that the risk of inducing a fatal cancer is estimated to be about 0.05/Sv which equates to a fatal cancer risk of 1 in 20,000 for every 1 mSv [22] for low doses, such as in diagnostic CT. So, estimation of dose levels in CT helps to estimate public dose and increase in the probability of cancer induction.

In conclusion, according to different studies and the radiation carcinogenesis, it is necessary to estimate organ effective dose in different protocols in newer systems to assure that dose levels and indeed public dose are being kept low and no increase in the risk of cancer induction. It is suggested to perform such study for other imaging protocols and systems.

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References

1- Amis ES, Jr., Butler PF. ACR white paper on radiation dose in medicine: three years later. *Journal of the American College of Radiology*. vol. 7, pp. 865-870, 2010.

2- NCRP. Ionizing radiation exposure of the population of the United States. Report 93, 1987.

3- NCRP. Ionizing radiation exposure of the population of the United States. Report 103, 2009.

4- McCann C, Alasti H. Comparative evaluation of image quality from three CT simulation scanners. *Journal of applied clinical medical physics*. vol. 5, pp. 55-70, 2004.

5- Nakae Y, Oda M, Minamoto T. [Patient dose simulation in X-ray CT using a radiation treatment-planning system]. Nihon Hoshasen Gijutsu Gakkai Zasshi. vol. 5, pp. 935-943, 2003.

6- EUR 16262 EN: European guidelines on quality criteria for computed tomography. European Commission Report, 1999.

7- FDA. Performance standards for ionizing radiation emitting products. Sec 1020.33, Computed Tomography (CT) equipment. Food and Drug Administration. Bureau of Radiological Health, 1980.

8- Garvey CJ, Hanlon R. Computed tomography in clinical practice. *British medical journal*. vol. 324, pp. 1077-1080, 2002.

9- Siemens AG MS. Siemens Sensation 64. Available from: www.siemens.com/medical.

10- Brenner DJ. Is it time to retire the CTDI for CT quality assurance and dose optimization? *Medical Physics*. vol. 32, pp. 3225-3226, 2005.

11- Attix FH. Introduction to radiological physics and radiation dosimetry. New York: Wiley; 1986.

12- McKinlay AF. Thermoluminescence dosimetry. Bristol: Adam Hilger in collaboration with the Hospital Physicists' Association; 1981.

13- Cohnen M, Poll L, Puttmann C, Ewen K, Modder U. Radiation exposure in multi-slice CT of the heart. *ROFO FORTSCHR GEB RONTGENSTR NUKLEARMED*. vol. 173, pp. 295-299, 2001.

14- Ebert MA, Asad AH, Siddiqui SA. Suitability of radiochromic films for dosimetry of very-low energy X-rays. *Journal of applied clinical medical physics*. vol. 10, pp. 2957, 2009.

15- Chiu-Tsao ST, Ho Y, Shankar R, Wang L, Harrison LB. Energy dependence of response of new high sensitivity radiochromic films for megavoltage and kilovoltage radiation energies. *Medical Physics*. vol. 32, pp. 3350-3354, 2005.

16- Rampado O, Garelli E, Deagostini S, Ropolo R. Dose and energy dependence of response of Gafchromic XR-QA film for kilovoltage x-ray beams. *Physics in Medicine and Biology*. vol. 51, pp. 2871-2881, 2006.

17- Shrimpton PC, Hillier MC, Lewis MA, Dunn M. NRPB - W67 Doses from Computed Tomography (CT) Examinations in the UK - 2003 Review. NRPB. 2005.

18- Yates SJ, Pike LC, Goldstone KE. Effect of multislice scanners on patient dose from routine CT examinations in East Anglia. *British Journal of Radiology*. vol. 77, pp. 472-478, 2004.

19- Bongartz G, Golding S, Jurik A, Leonardi M. European guidlines on quality critria for CT. EUR 16262 EN, 1999.

20- Cohnen M, Poll LJ, Puettmann C, Ewen K, Saleh A, Modder U. Effective doses in standard protocols for multi-slice CT scanning. *European Radiology*. vol. 13, pp. 1148-1153, 2003.

21- Feng ST, Law MW, Huang B, Ng S, Li ZP, Meng QF, *et al*. Radiation dose and cancer risk from pediatric CT examinations on 64-slice CT: a phantom study. *European Journal of Radiology*. vol. 76, pp. e19-23, 2010.

22- ICRP. Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. vol. 21, pp. 1-3, 1991.