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Measurement of organ dose in chest CT examination using Monte Carlo simulation

E.M.T. Harki[1] and A.T. AL-Kinani[2]*

[1] Salahaddin University, College of Science, Kurdistan of Iraq, Erbeel, Iraq
[2] AL-Mustenserya University, College of Medicine, Baghdad, Iraq and Supreme Council for environment and Natural Reserves, Doha, Qatar

Background: Exposure conditions in CT examinations are quite different from conventional X-ray. In CT examination higher dose is given to patient in comparison with the dose in other diagnostic examinations. In order to calculate organ effective dose in chest CT, Monte Carlo simulation has been used in this study. ***Materials and Methods:*** The Impact survey data were used to determine the parameters related to patient dose. This was done by correlating the measurements from the NRPB scanners with the effective dose calculated, using the CTDOSE software. Patient dose index in air ($CTDI_{air}$) was measured as function of tube exposure ranged from 90 to 225mAs at constant kVp and slice thickness, using a stack of TLD chips which was long enough to fully encompass the dose profile that could have been used. ***Results:*** Dose profile of each exposure was measured with approximately Gaussian distribution shape. The full width at half maximum (FWHM) of these profiles was nearly equal, and on average it was equal to 8 cm. Also the maximum $CTDI_{air}$ for these profiles, as expected increased with mAs ranging from 29.2 to 50.606 mGy. $CTDI_{air}$ was measured by two methods using conversion coefficient established by using software, based on Monte Carlo simulations (CTDOSE) and the other was measured in the area under the dose profile distribution. ***Conclusion:*** The slice thickness measured from FWHM and those thicknesses set by the operator were nearly equal proving that the measurements using TLD were accurate. The effective dose for chest increased with increasing mAs. By these measurements, it was also noted that the maximum equivalent dose and sharpest slope variation were for lungs, heart and breast respectively, whereas the minimum equivalent dose with lowest slope variation was related to thyroid, liver, spleen, stomach wall and kidneys respectively. **Iran. J. Radiat. Res., 2007; 4 (4): 205-209**

Keywords: *TCT X-ray, organ dose, Monte Carlo simulation.*

INTRODUCTION

The NRPB in 1989 undertook a wide-scale national survey on 75 CT scanners to investigate the doses received from CT examinations in the UK [1]. The results of the survey showed that although CT comprised only 2% of all medical examinations, it contributed over 20% of the collective effective dose from these examinations [2]. Since 1989 the number of CT scanners in the UK has increased steadily, reaching a plateau of about 360 scanners in 1995. It is estimated that today, CT scans constitute 4% of all medical examinations, contributing 40% of the collective effective dose [3]. It is therefore very important to provide information on patient dose from CT examinations.

The CT dose profile is a representation of the magnitude of the dose as a function of position along a line perpendicular to the tomography plane (i.e. in the z-direction). It is confined by beam collimation close to the X-ray source (primary collimation). Shape of the aperture of the collimator, distance from focal spot size, and shape of the focal spot are parameters which affect the dose profile [4]. Due to narrow width of collimation in combination with the finite size of the focal spot, penumbral effects occur. CT dose profile can be measured free in air or in a phantom. The sensitivity profile is a result from the secondary collimation close to the detector. The nominal slice thickness is set by the operator. And it can be calculated from the sensitivity profile as the full width at half maximum (FWHM) [5].

Today the predominant method for assessment of effective dose and organ

Corresponding author:
Dr. Athab AL-Kinani, Supreme Council for environment and Natural Reserves, P.O.Box: 7634, Doha, Qatar.
Fax: *+97 44415246*
E-mail: *drathabalkinani@yahoo.com*

absorbed doses is the application of conversion coefficients established by use of Monte Carlo simulations [6].

A number of measurement methods have been reported that use a variety of ways to describe or characterize the radiation delivery by CT, and these are quite different from methods and procedures normally employed in conventional X-ray diagnostics. The earliest versions of software for calculations of organ absorbed doses and effective doses based on the NRPB conversion factors was developed which are used in our calculations [7].

The aims of this work were to measure dose profile, determination of the dose received by chest and other organ doses due to chest examination using Monte Carlo simulation.

MATERIALS AND METHODS

LiF chips (Harshaw chemical Company Solon. OH) were used for dosimetry. The background of each chips were measured using TOLEDO system (Pitman Toledo mode-654 TLD reader. After calibration, the TLD stack with a size of about 32 mm warbled inside a polyethylene black bag, was fixed and extends beyond the couch end. Its length axis was toward the axis of gantry rotation and its center corresponding to the center of the slice (figure 1). The chips were irradiated by X- ray radiation for a single slice scan at mAs equal to 60 and kVp equal to 130. TLD's were replaced when exposure was repeated for other mAs values at 90, 120, 140 and 225 with a fixed kVp.

Dose Index (CTDI) is the fundamental dose quantity in computerized tomography, is defined as the integral along a line parallel to the axis of rotation (z) of single dose profile D (z) for single slice divided by the slice thickness (T) (equation 1) [4].

$$CTDI = \frac{1}{T}\int_{-\infty}^{+\infty} D(z)dz \qquad (1)$$

For each condition the $CTDI_{air}$ is derived according to the equation (2):

$$CTDI_{air} = \sum Di\ t/T \qquad (2)$$

Where Di is the air kerma to the ith TLD, t the (effective) thickness of each chip and T the nominal slice thickness, then the average $CTDI_{air}$ for each exposure condition can be calculated. Dose profile free-in-air from the individual TLD readings is obtained (figure 2).

Commercially available Monte Carlo software CTDOSE was used for calculation of organ dose, dose distribution and consequently the effective dose in a mathematically standard Hermaphrodite phantom (170cm/70Kg) from a given CT-procedure and a given CT-scanner type, as well as the dose-length-product from the CT-procedure.

The CTDOSE used to calculate normalized organ dose data sets, together with measured values of free-air axial dose for particular models of scanner, and software required the following input details of the clinical technique for each examination type. These parameters included scanned volume (in terms of baseline in the phantom and number of slices), slice width, couch increment, effective mAs, kVp and CT dose index per mAs.

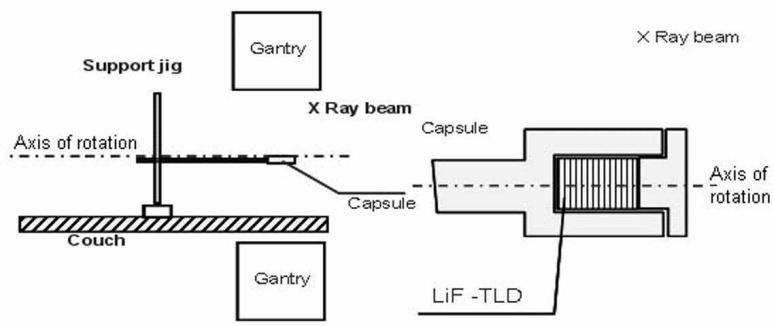

Figure 1. TLD arrangement for CTDI measurements.

RESULTS

The dose profiles are shown in figure 2 for kVp=130, Slice thickness of 8mm, mAs equal 60, 90, 120, 140, 225 respectively. The FWHM is measured which was approximately equal to the same

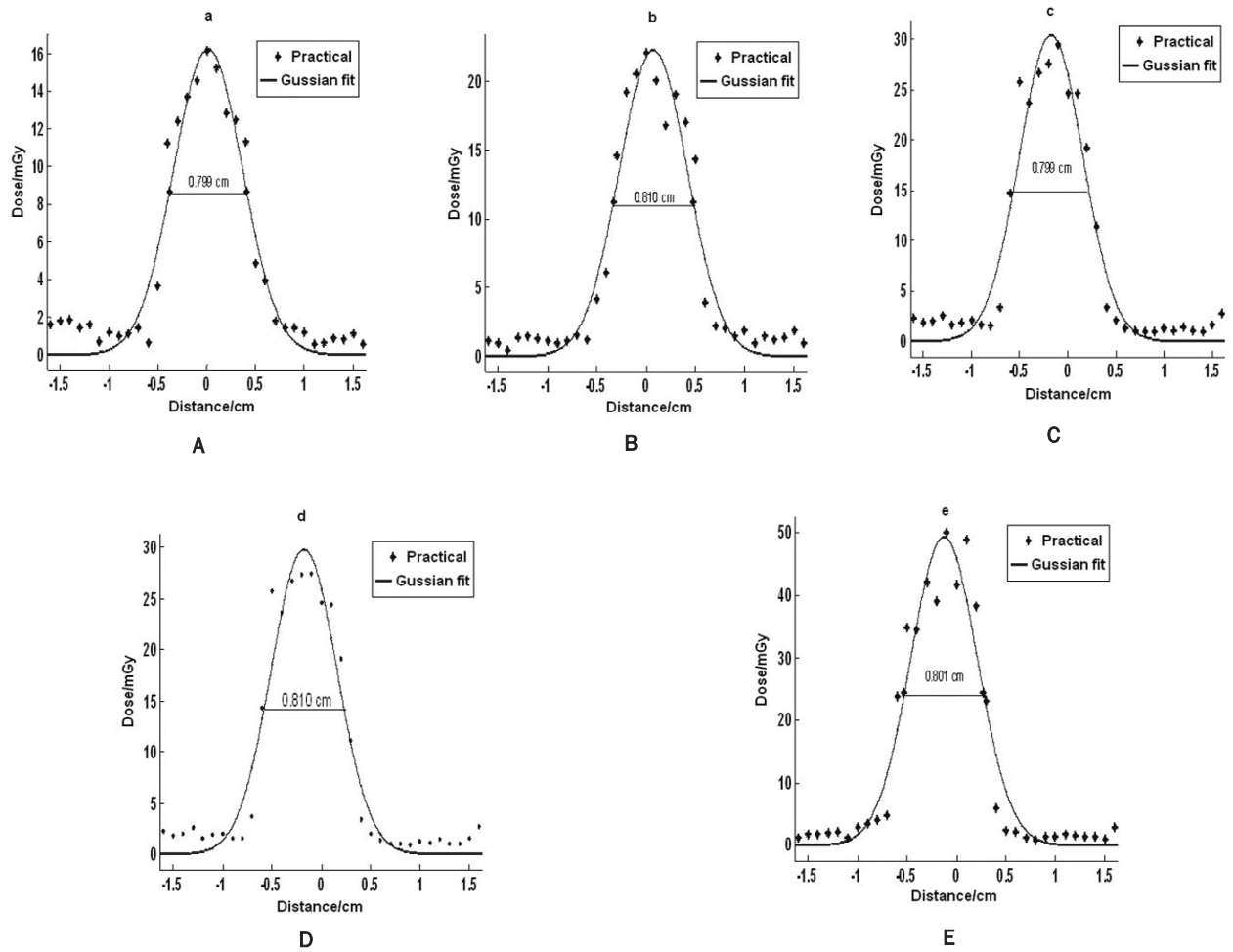

Figure 2. Dose profile in-air for slice thickness=8mm, kVp=130, s=60, 90, 120, 140, 225, respectively.

value set by the operator (8 mm). The average $CTDI_{air}$ of chest was calculated using equation 2 and also measured from the area under the profile curve as shown in table 1.

Table 1. mAs as a function of $CTDI_{air}$ /mGy.

mAs	Slice thickness 8mm		
	$CTDI_1$	$CTDI_2$	Average
60	27.789	30.611	29.200
90	33.226	35.615	34.420
120	39.941	43.227	41.084
140	40.188	43.227	41.707
225	48.066	53.147	50.606

$CTDI_1$ is the Computed Tomography Dose Index by using eq. (2).
$CTDI_2$ is the Computed Tomography Dose Index by using area under curve for Gussian fitting.

The two $CTDI_{air}$ measurements are plotted in figure 3.

The equivalent dose in different organ, effective dose in a chest exam as a function of

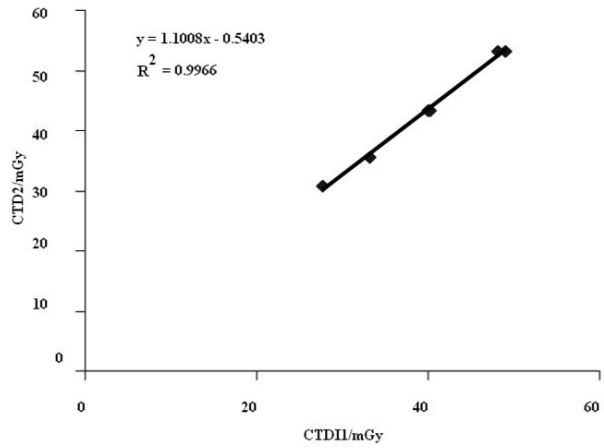

Figure 3. Correlation CTDI1 with CTDI for slice thickness=8mm.

mAs scanner were calculated using CTDOSE Monte Carlo package as shown in figures 4 and 5.

As shown in figure 4, the maximum equivalent dose and sharpest slope variation were observed for lungs, heart and breast respectively, whereas the minimum equivalent dose with lowest slope variation was related to thyroid, liver, spleen, stomach wall and kidneys respectively.

One of the main points in this study was increasing of the slope of dose with increasing mAs. The slope of increasing equivalent dose for some organs is calculated and presented in table 2.

In this work we simulated the variation of equivalent and effective dose for a chest exam as a function of mAs. The effective dose for this scanner is increased from 4.7 mSv at 60 mAs to 9.1 mSv at 225 mAs at fixed kVp = 130 kV, as shown in figure 5.

DISCUSSION

The slice thickness measured from FWHM and those thicknesses set by the operator are nearly equal, because measurements of $CTDI_{air}$ are easily accomplished with either the 100 mm pencil-shaped ionization chamber or a stack of TLD chips. The tails on the dose profiles in air are less significant than in a phantom due to lower amount of scattered radiation (figure 2).

The agreement between the practical and

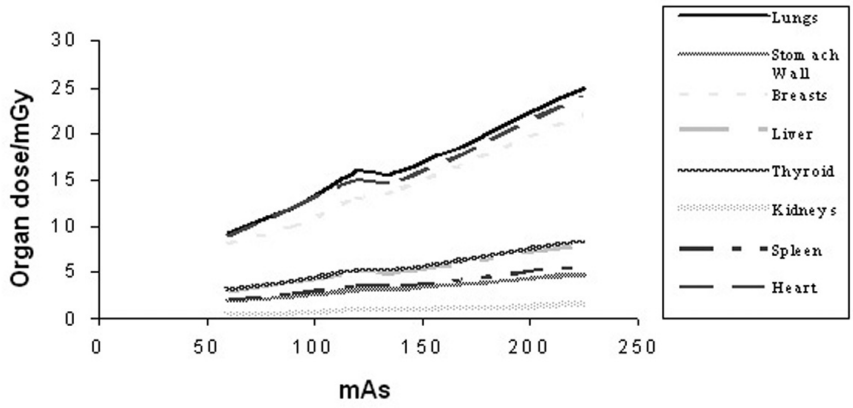

Figure 4. Organ doses as functions of mAs.

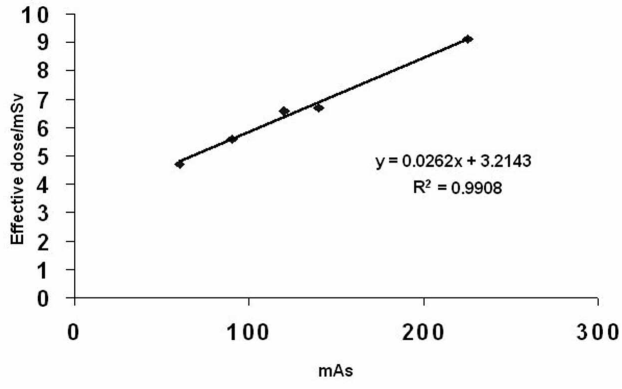

Figure 5. Effective dose as function of mAs.

Table 2. Slope of increasing equivalent dose in terms of mAs.

Organ	Slope of Increasing Equivalent Dose mGy/mAs @ 130kVp
Lungs	0.1095
Heart	0.1019
Brest	0.0869
Liver	0.0350
Thyroid	0.0354
Spleen	0.0252
Stomach Wall	0.0214
Pancreas	0.0252
Kidneys	0.0075

the Gaussian distribution depends on the exposure (mAs) values (figure 2 a and b). There is not a good agreement at higher exposure conditions (figure 2 c and d). Our results are similar to the results published by Kalender *et al.* [9].

The $CTDI_{air}$ measured from area under the dose profile and that calculated by Monte Carlo simulations are in good agreement (table 1 and figure 3). Because in this study the dose profiles measurements with TLD in free air are used rather than that of measured in phantom, because there is a considerable contribution to the out side of directly exposed slice as a result of scatter radiation in phantom which increase with slice thickness and objects diameter. These results are inconsistent with the recent report by Kalender [10].

As shown in figure 5 the effective dose for chest increased as mAs increased from 4.7 mSv at 60 mAs to 9.1mSv at 225 mAs. These results well agree with the report by Ay *et al.* [11].

CT chest examinations appear to have the highest effective dose. Reducing the extent of the scan as much as possible, without missing any vital anatomical regions, could be a first step to reduce the effective dose. Furthermore, reducing mAs of the examination protocol is also important which requires careful consideration of signal-to-noise loss.

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