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Conventional and spiral CT dose indices in Yazd general hospitals, Iran

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Background: While the benefits of Computed Tomography (CT) are well known in accurate diagnosis, those benefits are not risk free. CT is a device with higher patient dose in comparison with other conventional radiological procedures. Is the reduction of exposures by requiring optimization of CT procedures [a principle concern in radiological protection]? In this study, the radiation dose of conventional and spiral CT were investigated and compared with European Commission Reference Dose Levels (EC RDLs) ***Materials and Methods:*** The dosimetric quantities proposed in the European Guidelines (EG) for CT are Weighted Computed Tomography Dose Index (CTDIW) for a single slice for axial scanning or per rotation for helical scanning and Dose-Length Product (DLP) for a complete examination. The patient-related data were collected for brain, neck, chest, abdomen and pelvis examinations in each scanner. For each type of examination, 10 typical patients were randomly included. CTDI with an active length of 10cm was measured in two CT scanners by using UNFORS (Mult-O-Meter 601) in head and body phantom (PMMA) with 16 cm and 32 cm in diameter; respectively. Mean values of CTDIW, DLP and Effective Dose(ED) were estimated for those examinations. ***Results:*** CTDIW had a range of 15.8-24.7 mGy for brain, 16.1-30.6mGy for neck, 6.8-9.2 mGy for chest, 6.8-9.8 mGy for abdomen and pelvis. DLP had a range of 246.4-397.7 mGy.cm for brain, 104.6-262.2 mGy.cm for neck, 135-248.4 mGy.cm for chest, 187-298.9 mGy.cm for abdomen and 197.2-319.4 mGy.cm for pelvis. The mean values of effective dose were 0.70 mSv for brain, 1 mSv for neck, 3.2 mSv for chest, 3.3 mSv for abdomen and 5.1 mSv for pelvis. ***Conclusion:*** The obtained results in this study have shown that CTDIW and DLP are lower than EC RDLs and other studies, in other words, the performance of all scanners has been satisfactory as far as CTDIw and DLP are concerned. The CTDIW and DLP in the conventional CT are higher than the spiral CT values. With regard to ALARA principle, for the establishment of reference dose levels, the radiation dose with spiral CT scanners should be taken into account. **Iran. J. Radiat. Res., 2006; 3 (4): 183-189**

Keywords: *CTDIw, patient dose, CT, DLP, RDLs.*

INTRODUCTION

CT provides high quality X-ray imaging with substantial benefits in health care. Clinical application of this technique has continued to increase. So that CT examination accounts for approximately 35-40% of the annual collective dose from medical X-rays whilst representing only 5% of their total number now (1). It is important to assess patient doses in different protocol of CT examination and ways to reduce patient does without considerable defection in image quality. There are different methods to describe (2, 3) and measure(4, 5) radiation does in CT. European Guidelines (EG) on quality criteria for CT were published by the European Commission(6) in which two does descriptors, weighted Computed Tomography Dose Index ($CTDI_W$) and Dose-Length product (DLP) were proposed as Reference Dose Levels (RDL_S). CTDIw is derived from the principle dosimetric quality computed tomography dose index (CTDI)(2), which is the integral along a line parallel to single slice, divided by the nominal slice thickness T. Related equation is defined by :

$$CTDI = \frac{1}{NT}\int_{-\infty}^{+\infty} D_{single}(z)dz(mGy) \qquad (1)$$

N is the number of acquired section per scan. (Also referred to as the number of data channels used during acquisition). CTDI can be measured free-in-air ($CTDI_{air}$) or in phantom ($CTDI_W$). $CTDI_{air}$ measured at isocentre of gantry and $CTDI_W$ measured in center of head and body phantom ($CTDI_C$),

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and peripheral of head and body phantom ($CTDI_P$)[7], in which;

$$CTDI_W = \frac{1}{3}CTDI_C + \frac{2}{3}CTDI_P(mGy) \quad (2)$$

The European Commission (EC) have suggested the use of a normalized dose index, $nCTDI_W$, which takes into non-uniformities of CTDI values measured at center or the periphery of these phantom[8]:

$$nCTDI_W = \frac{1}{C}(\frac{1}{3}CTDI_C + \frac{2}{3}CTDI_P)mGymAs^{-1} \quad (3)$$

C is the radiographic exposure (mAs).

The weighted CT dose index ($CTDI_W$), which is the first of the two reference dose quantities proposed by the EC for a single slice in serial scanning or per rotation in helical scanning is then simply:

$$CTDIW = nCTDIW . C\ (mGy) \quad (4)$$

In practice, measurements are carried out using a pencil shaped ionization chamber with 100mm active length ($CTDI_{100}$) or using thermo luminescent dosimeter (TLD_S) or using Unfors Mult-O-Meter 601 with 100mm active length. The second quality is the Dose-Length Product (DLP) that characterized the total radiation from a complete examination, and is estimated by the following formula:

For axial scanning:

$$DLP = \sum_i nCTDI_W.T.N.C(mGy, cm) \quad (5)$$

For helical scanning

$$DLP = \sum_i nCTDI_W.T.A.t(mGy, cm) \quad (6)$$

Where I, represent each serial or helical scan sequence forming part of an examination; T is the slice thickness (cm); N, the number of slices; C, the radiographic exposure; A, the tube current (mA) and t, is total acquisition time. $CTDI_W$ and DLP values for a specific examination using different protocols or scanners will provide information on relative performance [9]. In order to estimate the radiation risk associated with CT examination, it is necessary to estimate effective dose (ED) which is the sum of the products of organ doses and corresponding weighting factors[10].

Shrimpton et al. calculated E from CTDI measurements using Monte Carlo conversion coefficients [11, 12]. Another way for measuring ED is using an anthropomorphic physical phantom, that dose are measured in the location of organ or tissue of interest usually by using thermo luminescent dosimeter (TLD_S) and then ED can be calculated. As a practical alternative, EC[13] give region-specific normalized coefficients (E_{DLP}) to estimate the risk of CT examination protocol. Effective dose is derived from values of DLP with following equation:

$$E = E_{DLP} . DLP\ (mSv) \quad (7)$$

Where EDLP is in $mSv.mGy^{-1}cm^{-1}$ and DLP is in mGy.cm unit. General Levels for different regions of patient (Brain, Neck, Chest, Abdomen and Pelvis) are given in table 1. However, these dose values are based on the result of older survey data from late 1980s [14]. The technical improvement in CT, in particular use of the spiral technique, has offered new possibilities in both diagnosis and dose reduction [14]. The tube current time product for spiral CT usually cannot be set as high as for conventional CT due to the limited tube heat capacity; therefore, the radiation dose should be effectively lower for spiral than for conventional CTs [14]. The results of older survey that were based on investigation of dose for conventional CT may not be representative of the present situation. To our knowledge, there are no measured dosimetry data with PMMA phantom in Iran. The purpose of this study was to evaluate routine examination protocols utilized in

Table 1. Proposed European Commission reference Levels and region specific normalized effective doses for some routine CT examination [14].

Type of examination	$CTDI_W$ (mGy_{air})	DLP (mGy.cm)	EDLP ($mSv.mGy^{-1}cm^{-1}$)
Brain	60	1024	0.0023
Necka	60	1024	0.0054
Chest	30	650	0.0170
Abdomen	35	780	0.0150
Pelvis	35	570	0.0190

$CTDI_W$: weighted CT Dose index; DLP: dose-length product; E_{DLP}: region specific normalized effective dose.
a: No specific reference value for neck is yet available, but for comparison brain values are used.

Yazd city, and to compare results with European Commission Reference Dose Levels (EC RDL_S).

MATERIALS AND METHODS

This survey was performed on two CT scanners which are operating in 2 radiology departments of two general hospitals in Yazd. In one center, Shimadzu 7800 TX (Shimadzu, Tokyo, Japan) (A), and in the other was helical and conventional scanners Shimadzu 3000 TX (Shimadzu, Tokyo, Japan) (B) in were applied. It is necessary to mention that scanner A operated both conventional and helical. The examinations were categorized as follows: 1) brain, 2) neck, 3) chest, 4) abdomen and 5) pelvis. For each examination, data concerning examination parameters, such as kVp, mAs, number of slices, slice thickness and slice increment for 10 typical patients were recorded in CT clinic which performed the related examination. For conventional CT slice increment, and for spiral CT, pitch factor P is recorded. In total, 150 patients (100 patients for conventional and 50 patients for helical) were included in this study. It was found that for each examination, each CT center used constant kVp, mAs and slice thickness and only the slices frequency varied slightly from patient to patient. We determined actual slices frequency or average scan length from the data related to 10 patients for each examination, and for each clinic. All the measurements were carried out with a pencil probe solid state dosimeter (Unfors Mult-O-Meter 601, Sweden), with active Length of 100mm, and a diameter of 9mm. For measurement of $CTDI_{air}$ (free-in-air) probe of dosimeter was placed on the axis of rotation of each scanner, and then with selection of appropriate parameter for different examination, the measurement was performed. For measurement of CTDI in phantom, a head and body phantom were used. Phantoms were cylindrical solid Perspex (PMMA) used according to United States Food and Drug Administration [15]. A phantom with diameter of 16cm and length of 14cm for head and a diameter of 32cm and length of 14cm for body were made by seven PMMA circular slabs (with 2-centimeter thickness). The circular slabs were adherent together. Head and body phantom had five 13mm diameter holes (the size of holes is with consider to diameter of dosimeter probe) were drilled parallel to its long axis, one at the axial central and four around the perimeter, 1cm apart from the edge. Holes were positioned at 12, 3, 6, 9 O'clock [16]. Measurement in the conventional CT was performed in whole holes of phantoms, and measurement in helical (Spiral) CT was performed in the center and the hole that positioned at the 12 O'clock according to current practice in ACR (American College of Radiology). All the used holes must have been filled with a cylindrical solid Perspex rod. The head phantom for head and Neck and the body phantom for chest, abdomen and pelvis examinations were used. The head phantom was placed on the head holder and the body phantom was placed on the patient table of the CT scanner. $CTDI_W$, DLP and effective dose were then calculated according to European Commission [13] to check compliance with dose criteria and compared with other studies. The dosimeter was calibrated by the seller company. The overall accuracy of Mult-O-Meter for measurement of dose was estimated to be ±5%. The mean of $CTDI_W$ was calculated for each of examinations from three measurements in the head and body phantoms

RESULTS

The examination protocol details are shown in tables 2 and 3. Table 2 presents the different examination protocols used in two scanners presented in this study for the head, neck, chest, abdomen and pelvis in typical patient with fixed kV, mAs, T, slice increment, I and mean scan length, L at each scanner, in the conventional CT. Table 3 presents the different examination protocols used in CT scanner A, for brain, neck, chest, abdomen and pelvis in typical patient with fixed kV, mAs, T, pitch, factor, P and mean scan length L, in the spiral CT. The accuracy of kVp and mAs set up of CT scanner were checked up by Mult-O-Meter in mode of kVp and mAs measurement. The accuracy was in ±2%.

All examinations were performed with a constant tube voltage (120 kV). The slice thickness for all examination protocol, in

Table 2. Details of examination protocols, including kVp, mAs, slice thickness, T, slice increment I, and mean scan length L in the conventional CT.

scanner	examination	kVp	mAs	T(mm)	I(mm)	L(cm)
A	Brain	120	195	10	10	16.1
A	Neck	120	240	5	5	8.8
A	Chest	120	140	10	10	27
A	Abdomen	120	150	10	10	30.5
A	Pelvis	120	150	10	10	32.6
B	Brain	120	180	10	10	15.6
B	Neck	120	180	5	5	6.5
B	Chest	120	180	10	10	25
B	Abdomen	120	180	10	10	27.5
B	Pelvis	120	180	10	10	29

A: SCT-7800TX, Shimadzu CT scanner.
B: 3000 TX, Shimadzu CT scanner.

Table 3. Details of examination protocols including kVp, mAs, slice thickness T, and pitch factor, P, and mean scan length L in the spiral CT.L in the conventional CT.

scanner	Examination*	kVp	mAs	T (mm)	p	L (cm)
A	Neck	120	240	5	1.5	8.8
A	Chest	120	130	10	1.5	27
A	Abdomen	120	140	10	1.5	30.5
A	Pelvis	120	140	10	1.5	32.6

A: SCT-7800TX, Shimadzu CT scanner.
*: In the scanner A center, spiral technique of brain was not used.

spiral and conventional CT was 10 mm, except the neck examination which was 5 mm. The variable parameter between scanners and the examinations was mAs, were the lowest value (130 mAs) was used in the brain examination of the spiral CT, and the highest value (240 mAs) in the neck examination of the conventional CT. It was found that the scanner B had used constant tube current-time product (180 mAs) for the all examinations. The pitch factor value was equal to 1.5 in the spiral CT, and the values of slice increment (I) was equal to the slice thickness (packing factor =1) to have a series of contiguous slices in all examinations. In other words, according to clinic requirement, it was not necessary to have overlapping slices because of patient dose decrease. The CTDI measurements in air are shown in table 4. In order to compares the scanners the results are normalized by the tube current-exposure time product (mAs).

The $CTDI_W$ and DLP were calculated for each examination. The mean results are shown in table 5 for the conventional and the spiral CT. CTDLw was calculated for each of examinations by average of three measurements in head and body phantom. EG of $CTDI_W$ and DLP are also shown in table 5. $CTDL_W$ and DLP for each of the examinations protocol investigated in this study were lower than the EG.

Table 4. Normalized computed tomography dose index free-in-air ($CTDI_{air}$).

Scanner	Slice thickness (mm)	$CTDI_{air}$ (mGy.mAs-1)
A	10	0.197
A	5	0.199
B	10	0.141
B	5	0.148

A: SCT-7800TX, Shimadzu CT scanner;
B: 3000 TX, Shimadzu CT scanner.

DISCUSSION

The protocols utilized in CT centers of Yazd general hospitals have $CTDI_W$ and DLP

Table 5. The mean weighted computed tomography dose index (CTDIW, mGy) and the dose-length (DLP, mGy.cm) results were compared with European Guidelines (EG).L in the conventional CT.

Examination	Parameter	Scanner A	Scanner B	Scanner A[1]	EG
Brain	$CTDI_W$	24.7	15.8	-	60
	DLP	397.8	246.6	-	1024
Neck	$CTDI_W$	30.6	16.1	26.8	60
	DLP	269.6	104.8	157.2	1024
Chest	$CTDI_W$	9.2	6.8	7.8	30
	DLP	248.4	170	135	650
Abdomen	$CTDI_W$	9.8	6.8	8.9	35
	DLP	300.7	187	180	780
Pelvis	$CTDI_W$	9.8	6.8	8	35
	DLP	321.4	197.2	290.1	570

A: SCT-7800TX, Shimadzu CT scanner; B: 3000 TX, Shimadzu CT scanner.
A[1] is scanner A that is operated in helical.

values which are lower than EG dose criteria. This is encouraging, since the most important aspect of radiation protection is to have the amount of dose absorbed by the patients as low as reasonably achievable, provided that, this dose does not affect image quality and accurate diagnosis. One possible method of dose reduction is mAs reduction in examination protocols, especially for patients who are thinner than the standard sized patients.

As the table 6 shows the values of weighted CT dose index in this study are compared with those of Hidajat *et al.*(14), Scheck *et al.*(17), Smith *et al.*(18), Shrimpton *et al.*(19) and Tsapaki *et al.*(7). The values obtained in this study in the most circumstances, were lower than the other studies, because of the lower mAs used and lesser frequency scanner included in our study. Only the value of neck examination (spiral) was similar to the other studies using mAs. Table 7 shows the values of DLP and they are lower than the other studies as a resource of using shorter scan length the present. The effective dose is calculated for the examination protocols included in this study, with regard to the conversion factor (13). Table 8 presents the mean effective dose values of the examinations included in this study and others. It is found that then obtained values are lower than the studies.

Mayo *et al.* (22) presented a study regarding the minimum tube current required for good image quality with the least radiation dose on CT chest examination.

Results of the research of Tsapaki *et al.* (7) also indicated that the lowest mAs can be used without affecting diagnosis, despite the

Table 6. The weighted CT dose index in this study and the other studies.

Examination		This study	Hidajat(14)* *et al.*	Scheck(17) *et al.*	Smith(18) *et al.*	Shrimpton(19) *et al.*	Tsapaki(7) *et al.*
Brain	conventional	20.3	18.2-82.6	51.1±9.8	60±12	50±14.6	27-52
Neck	conventional	23.3	15.8-61.6	NA	NA	NA	NA
	spiral	26.8	15.7-52.5	30.7±9.2	NA	NA	NA
Chest	conventional	8	18.8-40.3	NA	NA	NA	14-27
	spiral	7.8	7.41-39.5	12.9±5.5	NA	NA	NA
Abdomen	conventional	8.3	18.8-47.5	NA	NA	20.3±7.6	14-27
	spiral	8.9	11.9-26.4	15.1±4.6	NA	NA	NA
Pelvis	conventional	8.3	23.7-47.5	NA	NA	25.6±8.41	14-25.3
	spiral	8.9	12.6-25.3	NA	NA	NA	NA

Note. Data are the mean and their unit is mGy.
*Numbers in parentheses are references. NA=not available

Table 7. The mean Dose-Length Product in the present study compared with those of Shrimpton *et al.*[19], Tsapaki *et al.*[7], Hidajat *et al.*[14].

Examination, DLP		This study	Shrimpton *et al.*	Tsapaki *et al.*	Hidajat *et al.*
Brain	conventional	322.2	882±332	430-758	218-899
Neck	conventional	187.2	NA	NA	143-946
	Spiral	157.2	NA	NA	164-600
Chest	conventional	209.2	517±243	348-807	405-1031
	Spiral	140.4	NA	NA	134-714
Abdomen	conventional	243.9	597±281	278-582	284-1185
	Spiral	180	NA	NA	119-543
Pelvis	conventional	259.3	443±233	306-592	504-2018
	Spiral	290.1	NA	NA	168-486

Note: data are the mean and their unit is mGy.cm
NA=not available.

Table 8. The mean values of effective dose (mSv) compared with those of Tsapaki *et al.* [7], Clark *et al.*[20], Polettiet *et al.*[21], Shrimpton *et al.*[19],Hatziioann *et al.*[8].

Examination	This study	Tsapaki *et al.*	Clarck *et al.*	Poletti *et al.*	Shrimpton *et al.*	Hatziioann *et al.*
Brain	0.7	1.4	1.6	1.8	1.8	1.6
Neck	1	NA	NA	NA	NA	NA
Chest	3.2	10.9	7.6	8.9	8.3	6.8
Abdomen	3.3	7.1	7	9.7	7.2	7
Pelvis	5.1	9.3	7.6	6.9	7.3	6.4

Note: unit is mSv.
Numbers in parentheses are references.
NA: not available

fact that the images may be noisier. In this study, the tube current-time product (mAs) in the most examination of conventional CT was higher than the spiral CT. In addition of lower tube-current time product, the increase in pitch of spiral CT leads to a dose-length product that is lesser than those values for conventional CT. Reducing the extent of the scan as much as possible without missing any vital anatomical regions, could be the first step to lower DLP and ED.

The RDL_S act as the parameter to identify relatively poor or inadequate use of the technique. The exposure setting and the extent of scan should be further investigated for lower dose without affecting image quality. The weighted CT dose index values in spiral CT scanner should be measured.

The users of conventional CT scanner should change their examination parameters to get weighted CT dose indexes similar to those of spiral CT scanners. In other words, for the establishment of reference dose levels, the radiation dose with spiral CT scanners should be taken into account.

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