Assessment and evaluation of patient doses in adult common CT examinations towards establishing national diagnostic reference levels

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ABSTRACT

Background: Patient radiation doses from computed tomography (CT) are increasing due to the number of CT examinations performed every day. The aim of this study was assess and evaluate patient radiation doses for adult's common CT examinations to derive local diagnostic guidance levels for common CT examinations. ***Materials and Methods:*** Volume and weighted computed tomography dose index ($CTDI_{vol,w}$) and dose length product (DLP) of four common CT examinations including head, head sinus, chest, abdomen and pelvis were measured for 8 different CT scanners using standard head and body phantoms. The image quality of acquired scan images were assessed according to European Commission (EC) image quality criteria guidelines. ***Results:*** The mean measured $CTDI_w$ for head base; head cerebrum, head sinus, chest and abdomen-pelvis were 71.8, 29.7, 35.8, 9.8 and 12.9 mGy, respectively. The DLP for head, head sinus, chest and abdomen -pelvis were 500, 371, 225 and 482 mGy.cm. The results of our study were shown more patient doses in terms of DLP for head sinus in compare with other studies while $CTDI_w$ values for head base and sinus were higher than EC measurements. ***Conclusion:*** The great variations of $CTDI_w$ and DLP observed among hospitals and relatively high values of DLP in some centers are evidence that radiation doses of patients from CT examinations is not fully optimized. It was concluded that future studies of continues optimization to minimize the dose without affecting image quality are needed.

Keywords: *$CTDI_w$, $CTDI_{vol}$, DLP, patient dose in CT, NDRLs.*

INTRODUCTION

Computed tomography (CT) is an important diagnostic tool in modern healthcare. However, CT is a high radiation exposure modality in compare to conventional X-ray devices. The number of examinations has been continuously increased and, now, CT is a major source of exposure in diagnostic X-rays for populations (1). In 1989, CT accounted for about 4% of diagnostic radiology examinations performed in the UK, contributing 40% of the collective population dose from medical radiation (2). By 1999, one North American institution quoted that 11.1% of the department workload was due to the CT examinations; a contribution of 67% to the collective dose (3). CT can now be responsible for up to 17% of the department workload accounting for 70-75% of the collective from medical radiation (4-6).

It has been shown that the effective dose delivered during some CT examinations overlaps with those doses reported to increase cancer rates (7). It is recommended that exposure levels are kept as low as reasonably achievable to reduce the potential risks, this recommendation is also known as the ALARA principle [8]. Not only should radiation exposure be kept as low as possible, the use of CT must also be justified, and other diagnostic methods should be considered when possible.

In five consecutive years from 2006-2010, the number of perscribed CT examinations were 1427157, 1376641, 1439776, 1667365 and 1784524 in the country according to national insurance organisation estimation. This means that from about 0.019 - 0.024 CT examinations per country population or 19 - 24 CT exams per 1000 population from 2006 - 2010. At present, these values are less than some countries like France but as number of CT scanners are increasing rapidly in the country and therefore number of CT exams will be increasing, the needs for individual justification for each patient and optimisation of practice in CT departments are highly recommended in near future to avoid unnecessay collective effective dose.

The study presented in this paper was planned to assess the CT patient doses in terms of $CTDI_{vol,w}$ and DLP and compare the results with other studies toward establishing National Diagnostic Reference Levels (NDRLs) for CT examinations.

MATERIALS AND METHODS

Data collection

The acquired data were collected from nine CT scanners in Tehran. Details of CT scanners and number of patients in above mentioned centers are shown in table 1. E Hospital had the lowest and A hospital had the highest number of patients in a year. The mean number of adult patients in a year in all centers was 14,000.

This study was done for routine and common CT examinations including head, head sinus, chest, and abdomen-pelvis. Details of referred patients according to CT procedures are shown in table 2.

For this study a questionnaire was prepared and filled out which was included the following items:

Hospital name, scanner model and manufacturer, year of installation, number and type of CT procedures for adults in the two years (2009 and 2010) and for each CT examination, tube voltage (kVp), current-time product (mAs) and scan technique (i.e. number of slices, slice width, scan start position, scan end position, coach increment and gantry tilt), whether or not contrast agents were used. Patient data were collected from a minimum number of ten patients for each selected CT examination and scanner.

Somatom sensation 64-slices model in E Hospital was used to only perform angiography examinations, therefore measurement of CTDI in air, head and body phantoms just were used to compare CTDIs in phantoms not CT examinations.

CT dose measurements

The absorbed dose is the amount of energy absorbed per unit mass of an organ or tissue.

Table 1. Details of CT scanners and number of patients.

CT scan center	scanner manufacturer	scanner model	year of installation	slice class	Number of patients per year
A1	HITACHI	PRATICO	2001	1	26870
A2	SIEMENS	Somatom Emotion 16	2010	16	17800
B	GE	Hispeed	2000	1	18230
C	Neusoft	Neuviz Dual	2008	2	12815
D	SIEMENS	Somatom Emotion 16	2009	16	9945
E1	SIEMENS	Somatom Sensation 64	2006	64	-
E2	GE	Hispeed	2002	1	3750
F	SIEMENS	Somatom Sensation 16	2008	16	14000
G	GE	Bright Speed 16	2008	16	9840

The ebsorbed dose cannot be practically measured in patients. So in CT, computed tomography dose index (CTDI) can be measured instead of it by the integral along a line parallel to the axis of rotation (z) of the dose profile, D(z), for a single slice, divided by the nominal slice thickness (T) [9]:

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

Measurements of CTDI in air ($CTDI_{100,air}$) and in the cylindrical polymethyl methylacrylate (PMMA) phantoms ($CTDI_{100,phantom}$) of diameters 16 cm (head) and 32 cm (body) were made as recommended by EC guidelines based on the typical patient and exposure related parameters obtained from each hospital [9]. Such measurements may be accomplished using a CT pencil ionistion chamber (RTI AB Electronic, Sweden). $CTDI_{100,\,air}$ is measured in the center of rotation using a 100 mm ionization chamber. Combination of $CTDI_{100}$ at 1 cm below the surface ($CTDI_{100,p}$) and at the center ($CTDI_{100,c}$) of standard head and body CT dosimetry PMMA phantoms yields a weighted CTDI ($CTDI_w$) that provides an indication of the average dose over a single slice for each setting of nominal slice thickness. On the assumption that dose in a particular phantom decreases linearly with radial position from the surface to the center, then the normalized average dose to the slice is approximated by the weighted $CTDI_w$, normalized to unit mAs:

$${}_{n}CTDI_{W}=1/C\ (1/3CTDI_{100,c}+2/3CTDI_{100,p})$$

Where C is the mAs and $CTDI_{100,p}$ represents an average of measurements at different locations around the periphery of the phantom [1].

If variations of in pitch are added to the equation, then the term volume CTDI ($CTDI_{vol}$) is introduced.

$$CTDI_{vol}=CTDI_w/Pitch$$

Where; pitch is the ratio between table increment per rotation and beam width [9]. CTDI values are expressed in mGy. The second reference dose quantity proposed by the EC is the dose length product for a complete examination, DLP:

$$DLP = \sum_i nCTDIw.T.N.C\ \ (mGy.cm)$$

where i represents each scan sequence forming part of an examination and N is the number of slices, each of thickness T (cm) and radiographic exposure C (mAs), in a particular sequence [1,9].

The quality control (QC) for all scanners has been done and all scanners passed QC tests including mechanical, electrical, tube and generator and image quality tests. The last tests were done using AAPM model 610 phantom.

RESULTS

The mean values and related statistics of scanning parameters conducted in each hospital for CT examinations (head, sinus, chest, and abdomen-pelvis) were analysed and the results of the analysis in the year 2010 are presented in table 3. From the table 3, it is evident that large variation of mAs values for a given examination exists among scanners. The results of measured CTDI in center ($CTDI_{center}$) and peripheral ($CTDI_{prepheral}$) of head and body phantom, normalised CTDI in air (${}_nCTDI_{air}$), head phantom (${}_nCTDI_{w,h}$) and body phantom (${}_nCTDI_{w,b}$) are presented in table 4 for different scanners. According to this table, Somatom Emotion 16-Slices and Brightspeed 16-Slices had the highest CTDI values while Somatom sensation 64-Slices and Neuviz Dual had the lowest CTDI

Table 2. Details of patients' number referring to CT departments.

CT Examination	CT Scan Center						
	A1	A2	B	C	D	E2	G
Head	13870	-	12350	5126	6387	1500	4920
Head sinus	13000	-	1880	2563	730	850	984
Chest	-	8900	2000	2563	1368	570	1968
Abdomen-Pelvis	-	8900	2000	2563	1460	830	1968

values.

The measured $CTDI_w$ and DLP for selected CT examinations and those proposed by EC guidelines are presented in table 5 [9,10]. The mean values of $CTDI_w$ per hospital for base and cerebum were in the ranges of 15.4 to 116.2 and 15.4 to 42 mGy, respectively, while those for sinus, chest and abdomen-pelvis were 13 to 69.2, 7.2 to 12.5 and 6.99 to 21.5 mGy, respectively. On the other hand, the ranges of the mean values of DLP per hospital for CT examinations of head and sinus were 169.2 to 792 and 105 to 935.1 mGy.cm, respectively, while the ranges for chest and abdomen-pelvis were 155.1 to 313 and 244.5 to 774 mGy.cm, respectively. Almost in all hospitals, it was generally seen that head and abdomen-pelvis examinations exhibited higher DLP than other examinations.

The measured CTDI in air and in standard PMMA phantoms were compared with ImPACT values and some others studies in table 6 [11-13]. The results of the total mean values of $CTDI_w$ and DLP for different examinations and other studies are shown in figure 1 and 2 [14-16]. The highest $CTDI_w$ values were generally from head cerebrum and head sinus examinations, which it is need for related investigation on their justification and optimization.

Table 3. Details of CT scanning protocols for a given examination employed by each of the participating hospitals.

Hospital	CT Examination	Axial or Helical	Number of phases	Applied potential (kVp)	Exposure setting (mAs)	Pitch	Slice width (mm)	Number of slices
E Hospital (GE)	Head	axial	2	120	300,200	-	3,10	8,9
	Sinus	axial	3	120	80	-	5,2,5	12,6,5
	Chest	helical	1	120	160	1.5	7	32
	Abdomen-pelvis	helical	1	120	160	1.5	7	54
A Hospital (Hitachi)	Head	axial	2	120	250,200	-	5,10	6,9
	Sinus	helical	1	120	75	1	5	24
B Hospital	Head	axial	2	120	120	-	10	11
	Sinus	helical	1	120	120	1	5	15
	Chest	helical	1	120	160	1.8	10	26
	Abdomen-pelvis	helical	1	120	160	1.8	10	41
C Hospital	Head	axial	2	120	320,290	-	5,7	6,14
	Sinus	axial	1	120	187.5	-	2.5	26
	Chest	helical	1	120	170	1	10	27
	Abdomen-pelvis	helical	1	120	170	1	7	55
G CT Scan Center	Head	axial	2	120	160,140	-	3.75,7.5	8,13
	Sinus	helical	1	120	95	0.562	3.75	30
	Chest	helical	1	120	91	1.375	7.5	40
	Abdomen-pelvis	helical	1	120	105	1.375	9	55
A Hospital (Siemens)	Chest	helical	1	130	58	0.8	5	47
	Abdomen-pelvis	helical	1	130	82	0.8	5	60
D Hospital	Head	axial	2	130	260,220	-	5,10	8,9
	Sinus	axial	1	130	100	-	5	19
	Chest	helical	1	130	63	0.8	8	35
	Abdomen-pelvis	helical	1	130	76	0.8	10	43
F CT	Head	axial	2	120	220,200	-	4.5,9	8,10
	Sinus	helical	1	80	55	1	3	27
	Chest	helical	1	100	95	1.15	6	45
	Abdomen-pelvis	helical	1	100	115	0.75	5	70

Table 4. Summary of normalized CTDI measured in air and in standard dosimetry phantoms.

CT scanner model	Applied potential (kVp)	$_nCTDI_{10,air}$ (mGy/100mAs)	Head (mGy/100mAs)			Body (mGy/100mAs)		
			$CTDI_{center}$	$CTDI_{peripheral}$	$_nCTDI_{w,h}$	$CTDI_{center}$	$CTDI_{peripheral}$	$_nCTDI_{w,b}$
PRATICO	120	27.69	14.51	16.85	16.07	4.46	9.90	8.08
Neuviz Dual	120	14.88	8.74	9.47	9.22	3.03	6.66	5.45
Hispeed (E1 Hospital)	120	18.87	11.42	11.73	11.62	3.49	6.47	5.47
Hispeed (B Hospital)	120	22.48	12.50	13.00	12.82	4.16	8.00	6.71
Bright speed 16	120	31.19	16.23	19.53	18.44	5.33	11.22	9.25
Somatom Sensation 16	120	20.94	10.03	11.00	10.67	3.33	6.64	5.53
Somatom Emotion 16	130	30.78	18.63	19.99	19.54	4.93	11.34	9.2
Somatom sensation 64	120	13.93	9.55	10.03	9.86	3.10	5.71	4.83

Table 5. Comparison of mean $CTDI_w$ and DLP among hospitals and with the proposed reference dose levels by EC guidelines.

Dose quantities	CT Examination	Average $CTDI_w$(mGy) and DLP(mGy.cm) values per hospital								
		E Hospital (GE)	A Hospital (Hitachi)	B Hospital	C Hospital	G CT Center	A Hospital (Siemens)	F CT Center	D Hospital	EC Guidelines [9,10]
$CTDI_w$	Base	116.2	80.4	15.4	59.1	78.7	-	52	101	60
	Cerebrum	23.2	32.1	15.4	38.2	34.4	-	23	42	60
	Sinus	27.9	24.1	30.8	69.2	46.7	-	13	39	35
	Chest	12.5	-	10.7	9.3	11.2	10.67	7.3	7.2	30
	Abdomen-pelvis	12.5	-	10.7	13.2	21.5	15.09	10.6	6.99	35
DLP	Head	488	530	169.2	552	572	-	400	792	1050
	Sinus	213	289.3	230.8	449.8	935.1	-	105	371	360
	Chest	186.8	-	155.1	250.3	244.9	313	171	253	650
	Abdomen-pelvis	315.3	-	244.5	509.9	774.5	660	494	375	1350

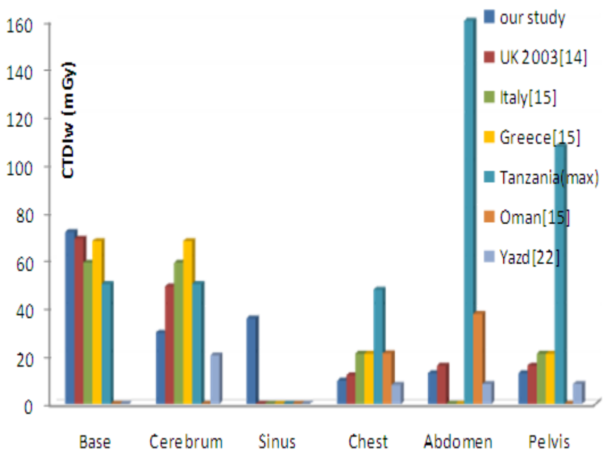

Figure1. Measured mean values of $CTDI_w$ in this study compared to other studies.

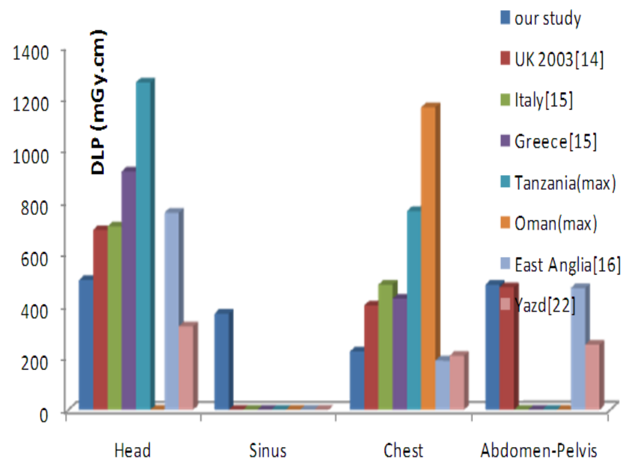

Figure 2. Measured mean values of DLP in this study compared with other studies.

Table 6. Comparison of measured CTDI with ImPACT values and other studies.

CT model	$CTDI_{10,air}$ (mGy / 100mAs)		$CTDI_{w,h}$ (mGy / 100mAs)			$CTDI_{w,b}$ (mGy / 100mAs)		
	Our study	ImPACT[11]	Our study	ImPACT[11]	Other studies [13]	Our study	ImPACT [11]	Other studies [12,13]
PRATICO	27.69	-	16.07	-	_	8.08	-	6.21
Hispeed (E Hospital)	18.87	19.3	11.62	11.77	_	5.47	6.17	-
Hispeed (B Hospital)	22.48	20.4	12.82	11.77	_	6.71	6.17	-
Somatom sensation 16	20.94	21.8	10.67	16.58	18.5	5.53	6.83	7.6
Somatom sensation 64	13.93	16.1	9.86	11.96	13.4	4.83	5.82	6.63, 6.5

DISCUSSION

The mAs values which are directly related to CTDI were varied by a factor of 2.6, 2.4, 3.4, 2.9 and 2.2 for head base, head cerebrum, head sinus, chest and abdomen-pelvis, respectively. Automatic exposure control techniques represent the most important and efficient method for reducing radiation dose while maintaining desired image quality [17, 18]. From a single topogram, Siemens made scanners use, the CARE Dose4D technique to measure attenuation profile in the z-axis in the direction of projection and also in the perpendicular direction with a sophisticated algorithm [19]. Tube current values are calculated and adapted to the patient size and attenuation changes based on these attenuation profiles.

The variations were as large as a factor of 2.23 and 2.11 for mean values of $_{n}CTDI_{air}$ and $_{n}CTDI_{w,h}$ respectively and 1.91 for $_{n}CTDI_{w,b}$. The wide variations of mean, as also observed elsewhere are largely attributed to beam geometry, shaping filters, radiation quality for different scanners [20]. Siemens scanner model Somatom Emotion 16 did not have the choice of selection of 120 kVp; hence, the reported value for this scanner is slightly higher than the others.

The $CTDI_w$ values for head, sinus, chest and abdomen-pelvis recommended By EC, are 60, 35, 30 and 35 mGy, respectively [9,10]. From the table 5, it is evident that wide variations of $CTDI_w$ per given examination exist among hospitals. These variations were mainly due to applied different exposure parameters (i.e. kVp, mA, exposure time) [21]. It was observed that $CTDI_w$ of head base at E l, D and A (Hitachi) Hospitals and G CT Scan Center were higher than proposed value by EC, while for head cerebrum all values were lower than EC value. B Hospital due to the use of lowest mAs for base and cerebrum relative to other hospitals had the lowest value of $CTDI_w$. B Hospital, G CT Scan Center and D Hospital had the highest $CTDI_w$ values relative to other hospitals for Sinus and those values were higher than EC values. For CT examination of chest E Hospital and G CT Scan Center and for abdomen-pelvis G CT Scan Center had the highest $CTDI_w$ values relative to other hospitals. The high value of $CTDI_w$ for A2 (Siemens) and D Hospital might be due to the use of 130 kVp while the rest of them were using 120 kVp.

Wide variations of mean values of DLP were largely due to different scanning protocols (i.e. slice thickness, number of slices, Pitch and table increments). D Hospital had the highest mean DLP value for head, while G CT Scan Center had the highest mean value of DLP for sinus. G CT Scan Center was applied low value of pitch (0.562) for sinus, threfore had larger DLP. Mean value of $CTDI_w$ for sinus at G CT Scan Center, C Hospital and D Hospital were higher than proposed value by EC. On the other hand, A Hospital (Siemens) and G CT Scan Center had the highest mean values of DLP for Chest and abdomen-pelvis, respectively. The reason for the highest values at the A Hospital (Siemens) and G CT Scan Center is probably due to the use of large scan length for chest and abdomen-pelvis examinations. B Hospitalhad the lowest value of

Table 7. Comparison of $CTDI_w$ and DLP in the year 2009 and 2010.

Dose quantities	Year	Head	Sinus	Chest	Abdomen-pelvis
$CTDI_w$ (mGy)	2009	72.4, 31.2	32.8	10.03	13.17
	2010	66.9,27.7	35.2	10.2	13.7
DLP (mGy.cm)	2009	500	313	205	451
	2010	451	370	201	467

DLP for head, chest and abdomen-pelvis due to the use of minimum number of slices and pitch factor (Pitch=1.8). Increasing the pitch factor means a reduction in the total radiation exposure of the patient.

In this study, almost in 15% of chest and abdomen-pelvis examinations, contrast media were administered, so, mean value of DLP were become twice. However, when medically appropriate, the large scan length can be reduced by eliminating pre-contrast scans.

According to table 7 there is no meaningful difference between data of 2009 and 2010 years and as you can see in table 2, the number of referred patients in some centers is too high and implementing of optimization techniques will reduce collective effective doses easily, which is our aim in next step.

CONCLUSIONS

The estimated mean values for $CTDI_w$ were lower than reference values for all CT examinations except for the head base and sinus. The mean values of DLP for sinus was higher than the proposed value by EC guideline.

In order to achieve the required level of dose, it was concluded that further investigation of optimization of scanning protocols is needed. This can be achieved through provision of adequate education to CT personnel on factors that affect patient dose and image quality, optimal selection of scanning parameters, careful selection of the anatomical region to be scanned and the extent of the scan with and without contrast.

In next steps of this study, the $CTDI_{vol,W}$ and DLP for the children in different ages will be report and the reference levels of Tehran and country will be derived and established. Then specific actions for CT protocols optimization in terms of reducing patient doses while maintaining adequate image quality will implement in some CT departments.

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