Radiation Dose Evaluation in Computed Tomography Scanning for Patients by Using CT-EXPO

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Abstract:

CT is a diagnostic imaging modality giving higher patient dose in comparison with other radiological procedures. The aims of this study are, first, to determine the magnitude of radiation doses received by selected organs of patients undergoing CT examinations, secondly to assess how CT scanning protocols in practice affect patient organ doses. In order to achieve these objectives, patient organ doses from four common CT examinations were obtained from sixteen hospitals in Libya with different CT models.

The Impact survey data were used to determine the parameters related to patient dose. This was done by correlating the measurements from the National Radiological Protection Board (NRPB-R250) scanners with the effective dose calculated, using the CT-EXPO software. Patient dose index in air ($CTDI_{air}$) was measured as function of tube exposure ranged from 80 to 250 mAs at constant kVp and slice thickness, using a special pencil-shaped ionisation chamber and phantoms . The mean organ doses in this study for head, chest, abdomen and for pelvis were 61.5 mGy, 28.5 mGy, 38.4 mGy, and 24.0 mGy, respectively. These values were slightly higher than the values of organ doses reported from the literature.

It was concluded that patient organ doses could be substantially minimized through careful selection of scanning parameters based on clinical indications of study, patient size, and body region being examined. Additional dose reduction to superficial organs would require the use of shielding materials.

Introduction:

Although computed tomography (CT) represents only a small percentage of radiological examinations, it is nonetheless a major source of the collective dose to the population from medical x-ray procedures (UNSCEAR 2000, ICRP 2000). This undesirable feature is bound to remain unchanged since CT scanners still deliver high dose per examination and the number of CT examinations in the population is on the increase (UNSCEAR 2000, Gray 2001). As a result, the use of this modality has been of great concern due to undesired health effects to the population such as induction of cancer (Brenner *et al* 2001). In view of these concerns, a number of studies globally have been investigating possible methods to minimise radiation dose to patients from CT examinations without compromising the image quality required for diagnostic accuracy. Since it is inappropriate to impose strict limits on the doses received by patients for medical purposes, the International Commission for Radiological Protection.

(ICRP) introduced the concept of diagnostic reference dose levels (RDLs) (ICRP 1991, 1996).

The purposes of this concept was to provide the first step in the optimization of patient doses and identify those practices in great and urgent need of intervention. The concept of RDLs was adopted by the European Commission (EC), which hence published guidelines on quality criteria for CT scanners (EC 1999). In these guidelines two dose descriptors, weighted computed tomography dose index (CTDIw), that measures dose for a single slice, and dose– length product (DLP), which estimates dose for a complete examination, were proposed as reference dose levels (RDLs) for CT examinations (Shrimpton *et al* 1998, EC1999, Rosenstein 2001, Tsai and Tung 2003).

In Libya, the use of the CT imaging modality for medical imaging services started as early as 1982, and at present about 12 000 CT examinations are annually performed from seventy CT scanners. In view of this trend, it is almost certain that there will be an increased use of this high dose procedure in the future. Unfortunately, however, the current increasing trend of acquisition of CT scanners in Libya without the knowledge on the RDLs from CT examinations would make it difficult to assess the extent to which radiation dose to patients from CT is optimised in Libya. This is a preliminary study to investigate the need and urgency to establish national reference dose levels from CT examinations in Libya. With this knowledge, it would be easy to identify practices in need of immediate intervention in order to reduce radiation harm to patients undergoing CT examinations in Libya.

Materials and methods

Data collection

The data used in this study were collected from sixteen hospitals in Libya with CT scanners in period between 2018- 2019 .

These included: Tripoli Medical Center (TMC), Tripoli Central Hospital (TCH), Musratah Central Hospital (MCH), Abosalem Trauma Hospital (ATH), Plastic Surgery Hospital (PSH), Apensena Central Hospital (AH), Al-zawya Central Hospital (ZCH), Al-Afia Central Hospital (FCH), Azleten Central Hospital (AZCH), AL-Zahef Al-akhther Clinic (ZAC) , 2nd March Central Hospital (MCH), AL-Hawary Hospital (ALHH) ,AL-Jala Medical Centre (JMC) , Garyan Central Hospital (GCH), AL-Marj Central Hospital (JCH) and Bangahazi Diagnostic and Radiotherapy Center (BDRC).

TMC ,TCH , PSH and ZAC had a GE and Philips scanner, while MCH and ATH had a Tomoscan M-EG scanner (Philips Medical Systems, The Netherlands).

JMC and BDRC had a Somatom Plus 4 and a Somatom AR.Star scanner (Siemens, Erlargen, Germany), respectively, while FCH and GCH had a CT/e and a CT max 640 scanner (General Electric Medical Systems, Milwaukee, WI, USA), respectively. With the exception of the CT max 640 scanner, that had a single slice with axial mode only, the rest of the scanners had single slice with axial and helical modes. The eight hospitals whose scanners are specified above had previously participated in the assessment of current status of effective doses from CT examinations in Libya, and this could be an advantage during the comparative assessment of effective dose. The measurements used in this study were routine CT examinations of head, chest, abdomen, lumbar spine and pelvis. The selected investigations used in this study represent over 90% of the total CT

examinations conducted in Libya today. In order to investigate the effect of exposure related parameters (e.g. kilovoltage (kV), tube current (mA),
exposure time, slice thickness, table increment and number of slices) on patient doses, typical exposure parameters were collected from each hospital participating in the study. Patient data were collected from a minimum number of ten adult patients for each selected CT examination and scanner.

CT dose measurements:

Of interest in this study is the determination of patient dose from CT examinations using the reference dose quantities proposed by the EC. However, these quantities cannot be determined without the knowledge of CT dose index (CTDI). In theory, the CTDI, as a measure of dose from single slice irradiation, is defined as the integral along a line parallel to the axis of rotation (*z*) of the dose profile, *D(z)*, divided by the nominal slice thickness, T, given by EC (1999), Jessen *et al* (1999).

$$CTDI = \frac{1}{T}\int_{-\infty}^{+\infty} D(z)\,dz \qquad (1.1)$$

In this study, CTDI was obtained from a measurement of dose, *D(z)*, along the *z*-axis made in air and phantoms using a special pencil-shaped ionisation chamber (Diados, type M30-316, serial No. 0254, PTW-Freiburg) with a volume of 0.*3* cm^3. The chamber was connected via a 2.5 m cable to a radiation-measuring device (Diados, type 11003, serial No. 1394, PTB Braunschweig.

The calibration of the ionization chamber is traceable to the standards of the German National Laboratory (PTB), and was calibrated according to the International Electrotechnical Commission Standards (IEC) (IEC 1999). The overall accuracy of ionisation chamber measurements was estimated to be ±6%. Since the sensitive length of the pencil ionization chamber is 100 mm, the above expression was modified to read (EC 1999, Jessen *et al* 1999)

$$CTDI_{100} = \int_{-50mm}^{+50mm} \frac{D(z)}{T_T}\,dz \qquad (1.2)$$

Measurements of CTDI in air *(*CTDI100,air*)* and in the cylindrical polymethyl methylacrylate (PMMA) phantoms *(*CTDI100,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 (EC 1999). Unfortunately, the CTDI100,air and CTD100,phantom for CT scanner model Tomoscan M-EG from

JMC were not determined due to malfunction of the scanner. Hence, the missing reference dose quantities for this particular hospital were estimated using normalised CTDI values already established by the ImPACT group (ImPACT 2000).

2.3. Determination of reference dose quantities

The weighted CTDI (CTDIw) to the selected CT examinations in this study was estimated from measurements of CTDI in PMMA phantoms described in the previous section at the centre (CTDI100,centre) and at the periphery (CTDI100,periphery). For the sake of simplicity, from here on, the CTDI100,air, CTDI100,centre and CTDI100,periphery will be abbreviated by CTDIair, CTDIc and CTDIp, respectively. Based on the assumption that higher radiation dose is delivered at the peripheral rather than the central region of the phantom, the *(n*CTDIw*)* was then estimated using the relationship (Shrimpton *et al* 1998, EC 1999, Jessen *et al* 1999)

$$nCTDI_w = \frac{1}{C}\left(\frac{1}{3}CTDI_{100,c} + \frac{2}{3}CTDI_{100,p}\right) \qquad (1.3)$$

where CTDIp represents an average of measurements at four different locations around the periphery of the phantoms. In order to take into account non-contiguous exposure along the *z*-axis, the CTDIw was either divided by pitch (for helical) or multiplied by a packing factor (for axial) to obtain the volume CTDI (CTDIvol). For helical CT scanners, CTDIvol is given by McNitt-Gray (2002), NRPB (2005)

$$\mathrm{CTDI} = \mathrm{CTDI}_w 1\mathrm{Pitch}$$

where pitch is the ratio between table increment per rotation, *I*, and beam width, *t* (EC 1999, McCollough and Zink 1999).

In this study, the DLP (in mGy cm) for the selected CT examinations per hospital was determined by multiplying the values of CTDIw or CTDIvol obtained according to equations (3) and (4), respectively, by scan length, *L*, defined elsewhere (Shrimpton *et al* 1991). For a body region of *i* scan sequences, each with scan length *L*, the DLP could be calculated from the relationship (EC 1999, Jessen *et al* 1999):

$$DLPl_{Axial} = \sum_{t}^{n} CTDI.T.N.C (1.4)$$

In order to evaluate how well the hospitals under study are performing in terms of minimization of risks associated with CT imaging, it was further useful to compare mean effective dose to patients among scanners. This was done by estimating the effective dose using the normalized values of effective dose for DLP (*E*DLP), defined as the quotient E/DLP, given by EC (1999)

$$E = (E\mathrm{DLP})_{\mathrm{region}} x\mathrm{DLP} \qquad (1.5)$$

where *E*DLP is the normalised value appropriate to general regions of the patients (head, neck, chest, abdomen, pelvis and trunk) provided by EC (1999), Jessen *et al* (1999). The mean estimated effective doses per CT examination per hospital using *E*DLP values were further compared with previous estimated effective doses using CTDIair measurements and conversion coefficients (NRPB-R250) derived from Monte Carlo (MC) techniques (Jones and Shrimpton 1993, ImPACT 2000).

Results and discussion

CT scanning protocols:

The mean values and related statistics of scanning parameters conducted in each hospital for CT examinations (head, chest, abdomen, lumbar spine and pelvis) were analyzed and the results of the analysis are presented in tables 1 and 2.

Reference dose levels from CT Examination

Table 1. Details of CT scanning protocols for a given examination employed by each participating hospitals

Hospital	CT examination	Applied potential (kV)	Exposure setting (mA s)	Slice width (mm)	Table increment (mm)
TMC	Head	120	220, 280	10, 5	10, 5
	Lumbar spine	120	340	3	3
	Chest, abdomen, pelvis	120	280	10	10
TCH	Head	120	220, 280	10, 5	10, 5
	Lumbar spine	120	420	3	3
	Chest, abdomen, pelvis	120	280	10	10
PCH	Head	120	60	10, 5	10, 5
	Lumbar spine	120	60	5	5
	Chest, abdomen, pelvis	120	60	10	10
MCH	Head	120	160, 200	10, 5	10, 5
	Lumbar spine	120	200	3	3
	Chest, abdomen, pelvis	120	100	10	10
FCH	Head	120	360	8, 5	8, 5
	Lumbar spine	120	360	3	5
	Chest, abdomen, pelvis	120	280	8	12
ZAC	Head	130	249, 315	5, 3	5, 3
	Lumbar spine	130	200	3	4
	Chest, abdomen, pelvis	130	125, 158	10	15
JMC	Head	120	200	7, 3	8, 4
	Lumbar spine	120	480	3	3
	Chest, abdomen, pelvis	120	160	10	15
JCH	Head	120	275	10, 5	10, 5
	Lumbar spine	120	550	3	3
	Chest, abdomen, pelvis	120	385	10	10

Table 2. The average number of slices (N) and scan length (L) per examination used by each hospital (N1 - number of slices for lower part of brain, N2- number of slices for upper part of brain)

Examination	Parameters	TMC	TCH	PCH	MCH	FCH	ZAC	JMC	JCH
Head	N_1 (mm)	20 × 5	13 × 5	34 × 5	6.4 × 5	22 × 5	30 × 3	21 × 3	16 × 5
	N_2 (mm)	19 × 10	17 × 10	9 × 10	12 × 10	14 × 8	28 × 5	15 × 4	17 × 10
	L (cm)	28.4	19.8	25.9	14.7	22.2	13	20.6	24.5
Chest	N	48.5	31	41	47.3	59.4	51.8	65.7	45.3
	L (cm)	48.5	31	41	47.3	59.4	76.1	97.5	45.3
Abdomen	N	48.5	40.7	58	61	72.5	63	76.2	62.7
	L (cm)	48.5	40.7	58	61	85.8	93.5	112.9	62.7
Lumber spine	N	37	22	27	27	40	51	27	25
	L (cm)	11.1	6.5	13.3	8.1	19	20	8.1	7.5
Pelvis	N	46	38.5	—	48.7	72.7	61	54.7	—
	L (cm)	46	38.5	—	48.7	86.4	72.4	76.6	—

With the exception of one hospital with 130 kV, all the hospitals used CT scanners rated 120 kV. Since the manufacturers fix this parameter, the choice of kV should be made during procurement planning phase. From the table, it is evident that large variation of mA s values for a given examination exists among scanners. For example, the mA s values per hospital varied by up to a factor of six for CT examinations of head, chest, abdomen and pelvis, respectively, while those for CT examination of lumbar spine varied by up to a factor of nine.

Table 3. Comparison of scan lengths for some common CT examinations between this study and published values from Greece and Italy

	Scan length (cm)								
	Libya			Greece			UK		
CT examination	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Head	13.0	28.4	21.1	13.0	15.0	14.3	8.9	18.6	12.9
Chest	31.0	97.5	55.8	17.0	25.0	20.7	12.0	31.9	23.3
Abdomen	40.7	112.9	70.4	18.0	25.0	22.0	12.0	31.4	22.7
Lumbar spine	6.5	20.0	11.7	7.0	15.0	12.1	4.5	12.0	8.6
Pelvis	38.5	86.4	61.4	15.0	23.0	20.4	9.9	23.5	16.9

The variations would be expected if the protocols were designed to yield a uniform CTDI at the isocentre when focus to axial distance varies between scanner types (see table 3) (Olerud 1997). This is due to the fact that the radiation intensity varies as the inverse of the squared distance between the source of the radiation and the patient. Of great concern is the significant variation of mA s values for the CT scanners of the same model for a given CT examination, such as CT scanners at TMC and TCH.

From table 2, it is evident that significant variations exist among hospitals for given examinations. For example, the mean scan length per hospital varied up to a factor of three for CT examinations of chest, abdomen and lumbar spine, respectively. These variations were largely caused by different scanning protocols (e.g. slice thickness, number of slices and use of contrast) employed by the hospitals. Large scan length was mainly attributed to the use of contrast media, since this procedure in most cases involves a repeated scan of the same scan length (i.e. with and without contrast materials) (Gray 2001). However, when medically appropriate, the large scan length can be reduced by eliminating pre-contrast scans. For example, JCH was found to have small scan length for CT examinations of chest, abdomen and pelvis relative to other hospitals because of using a scan sequence with contrast only. In order to compare the scan length among nations, the minimum, maximum and mean values of scan length per examination from this study, and published values from Greece and UK

are presented in table 3 (Papadimitriou *et al* 2003). From the table, the mean scan length per examination for CT examinations of head, chest, abdomen and pelvis in this study were higher by factors of 1.5–3.2 and 1.6–3.6 than published values in the literature from Greece and UK, respectively. For the remaining CT examination of lumbar spine, the mean scan length in this study was comparable to the published values in the literature for Greece and Italy by factors of 0.97 and 1.4, respectively. The higher mean values of scan length per examination observed in this study relative to the published values from Greece and UK might be attributed to the use of a large number of slices and multiple scans without and with contrast media. In view of these results, reduction of irradiation to the point where the vital anatomical region is just covered would be among the strategies that can be used to reduce patient dose.

Recommendations for future work

In view of the observed wide variations of doses among hospitals and high mean values of DLP per examination for almost all hospitals relative to the proposed RDLs, it is evident that further studies are needed in order to optimise the scanning protocols, in particularly those related to scan length, so that the mean values of CTDIw and DLP are below the proposed.

There are a number of observed parameters that are in great need of optimisation. These include optimal selection of exposure settings (i.e. kV, mA, exposure time, slice thickness) based on clinical indication and patient variation; restricting the number of slices to the region of clinical interest; use of contrast materials only to optimise diagnostic yield etc (Shrimpton *et al* 1991, Olerud 1997, Gray 2001). However, in order to achieve these, the following steps were considered. First, each of the participating hospitals in this study has been informed of the dose levels associated with their scanner examination practices and requested to compare their dose levels with the proposed RDLs. The results and recommendations of this study will be sent to the Ministry of Health, Libyan Atomic Energy Commission (regulatory authority) for further action. Second, a national workshop will be initiated for all CT personnel users i.e. referring physicians, radiologists and CT technologists. The workshop will provide adequate education on the potential risks associated with the high radiation dose delivered to patients from CT examinations, the influence of CT scanning parameters on patient radiation doses and image quality required for accurate diagnosis, and systematic evaluation of radiological procedures according to the basic principles of justification and optimization as recommended by the ICRP 60 (ICRP 1991, Olerud 1997, Gray 2001). Understanding of these factors will help to balance between patient doses and the corresponding image quality required for accurate diagnosis for a given type of examination. As a follow-up to the workshop, a second phase of the study on optimization of radiation dose strategies will be implemented to reduce CT doses to a level as low as reasonably achievable in order to ultimately establish the national reference dose levels from CT examinations.

Conclusions

The assessment of radiation dose to patients from CT examinations in Libya according to the proposed EC guidelines has been investigated. In this study, the mean values of CTDIw and DLP for a given examination varied significantly between hospitals. This was largely influenced by different scanning parameters and types of scanner used among hospitals. The mean CTDIw values per examination among hospitals were generally below the proposed RDLs, suggesting that most of the scanners operate at optimum exposure settings. On the other hand, the mean DLP values for almost all examinations for all except one hospital were above the proposed RDLs, suggesting that most of hospitals use larger scan length than needed for a given examination. The mean scan lengths used in Libya were higher by a factor of up to three than reported values from literature for Greece and UK. The observed great variations of CTDIw and DLP among hospitals and relatively high values of DLP are evidence that radiation protection to patients from CT examinations is not fully optimised. It was concluded that future studies to minimise the dose without affecting image quality are needed in order to achieve the required level of dose for establishment of the national RDLs from CT examinations in Libya. 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.

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