IMPLEMENTATION OF QUALITY CONTROL MEASUREMENT OF CT SCANNERS IN ESTONIAN HOSPITALS

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Abstract: The purpose of this paper was to perform dose measurements in Computed Tomography (CT) cabinets in three big hospitals in Estonia and compare results to EU reference dose levels for CT (EC DRL). The measured dosimetric quantities are weighted computed tomography dose index ($CTDI_w$) and dose–length product (DLP). Along with dose measurements we performed a comparison of standard routine protocols for most common CT examinations. Measured values show that all three examined CTs meet EC RDLs for chest and abdomen examinations, in terms of radiation dose and examination technique. Only the $CTDI_w$ value for brain examination in West-Tallinn Central Hospital exceeds recommended value by approximately 30%. $CTDI_w$ and DLP values for chest and abdomen examinations on all three scanners are lower than EU recommended levels at least by a factor of 2. Further ways of reducing CT radiation doses and estimation of effective and collective doses to patients are discussed.

Introduction

In worldwide diagnostic radiology practices CT is related to high radiation dose to the patient and contribution of CT examinations to collective dose from medical X-ray is continuously growing [7]. There are many ways to describe and measure radiation dose in CT [11, 14, etc.]. Recently, European Guidelines (EG) on quality criteria for CT [4] were published by the European Commission (EC), in which two dose descriptors, weighted computed tomography dose index (CTDIw) and dose–length product (DLP), were proposed as reference dose levels (RDLs). CTDI can be measured free-in-air ($CTDI_{air}$) on or parallel with the axis of rotation of the scanner, at the centre of a head or body phantom ($CTDI_c$), and 10 mm below the surface of the phantom ($CTDI_p$). $CTDI_w$ is estimated by the following formula:

$$CTDI_w = (\frac{1}{3}CTDI_c) + (\frac{2}{3}CTDI_p) \quad (1)$$

where $CTDI_c$ and $CTDI_p$ represent CT dose index measurements made with a ionization chamber at the centre and periphery of the phantom, respectively [2]. The quantity dose-length product (DLP) which includes the volume of patient (phantom) irradiated in the course of complete examination, is defined as:

$$DLP = \sum_i CTDI_w \cdot T_i N_i \quad (2)$$

where i represents each helical scan sequence forming part of the examination, where T_i is each different slice thickness used in the examination protocol, N_i is the number of T_i slices and $CTDI_{wi}$ is the value of $CTDI_w$ of each particular slice thickness T_i. This translates into a similar equation for helical scanning:

$$DLP = \sum_i CTDI_w \cdot T \quad (3)$$

where i now represents each helical scan sequence forming part of the examination, T is the nominal irradiated slice thickness in cm [2].
The EC have suggested [4] use of normalized weighted CT dose index, nCTDIw, which is expressed as absorbed integral along a line parallel to the axis of rotation z of the dose profile D(z) of a single slice, divided by the nominal slice thickness T. The actual CTDIw is obtained by multiplying with the C (mAs) value used in the hospital and provides the radiation dose from one slice at particular exposure settings:

$$CTDI_w =_n CTDI_w \cdot C \text{ , mGy-air} \quad (4)$$

Comparison of both $CTDI_w$ and DLP values for a specific examination using different scanners and

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protocols will provide information on relative performance [9]

For comparison with EU standards, we used CEC 1998 quality criteria - region-specific normalized coefficients to calculate the risk of a particular examination protocol and to compare it with other CT protocols or different radiological examinations. The purpose of this study was to investigate routine examination protocols utilized in CTs in some largest hospitals of Estonia in terms of imaging technique and radiation dose and to compare results with European Commission reference dose levels (EC RDLs) [4].

Materials and methods

The CT scanners investigated in this study were located in three hospitals in two different cities in Estonia - see Table 1. for details. West-Tallinn Central Hospital has a GE HiSpeed QX/I 4-row helical scanner (GE, Milwaukee, USA), East-Tallinn Central Hospital has a Philips LX 4-row helical scanner (Philips Medical Systems, The Netherlands), and the third has a GE HiSpeed DX/I (GE, Milwaukee, USA) helical scanner. Examinations were categorized as follows: (1) brain; (2) chest; (3) abdomen and pelvis. Examination protocol parameters such as kilovoltage (kV), tube current–exposure time product (mAs), slice thickness *T*, slice increment *I*, window width and window level were taken for standard sized patients. Head examinations on all scanners were performed using axial techniques; standard chest, abdomen and pelvis exams performed using helical protocols. All available technique and equipment parameters were recorded. $CTDI_{air}$ measurements were made free-in-air using a pencil shaped ionization chamber (Model DCT 10 RS Lemo; Barracuda, RTI Electronics AB, Sweden) connected to a radiation measuring device (Barracuda, RTI Electronics AB, Sweden) on the axis of rotation of each scanner. The system was calibrated according to International Electrical Commission standards (IEC) and verified by SSI (Sweden).

$CTDI_c$ and $CTDI_p$ were measured with the ionization chamber in a head phantom using brain examination protocols on corresponding scanners and in a body phantom for chest, abdomen or pelvis examinations. The head phantom was a cylindrical (16 cm diameter, 14 cm length) solid polymetyl metacrylate (PMMA) phantom with five 13.1 mm diameter holes drilled parallel to its long axis, one at the axial centre and four around the perimeter, 90° apart and 1 cm from the edge. Each of the holes must be plugged with a cylindrical solid PMMA rod. The body phantom is similar to the head phantom, with a 32 cm diameter, 14 cm length. $CTDI_w$, DLP were then calculated according to EG (Table 2.) to check for compliance with CT dose criteria.

Table 2: CEC 1998 CT quality criteria

Examination	**1.1.1.1.1.1 Reference dose value**	
	$CTDI_w$ (mGy)	DLP (mGy cm)
Routine head	60	1050
Routine chest	30	650
Routine abdomen	35	800
Routine pelvis	35	600

Results

Table 3: Comparison of CT examination protocols within the following parameters: kilovoltage (kVp), tube current-exposure time (mAs), slice thickness (*T*), increment (*I*) and pitch (*p*)

Exam.	**Scanner**	**kVp**	**mAs**	***T* (mm)**	***1.1.2***	***I* (mm)**	***p***
Head	A	140	200	2 x 2.5	5.0		Axial
		120	160	2 x 5.0	10.0		Axial
	B	120	150	2 x 5.0	10.0		Axial
	C	120	100	5.0	5.0		Axial
Chest	A	120	350	7.5	7.5		1.5
		120	350	7.5	7.5		1.5
	B	120	360	6.5	5.0		1.6
	C	120	200	7.0	7.0		1.8
Abdomen, pelvis	A	120	350	7.5	7.5		1.5
	B	120	360	6.5	5.0		1.6
	C	120	200	7.0	7.0		1.5

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Table 4: Number of slices *N* and irradiation length *L* of examined body region

Examination	[2] **Parameter**		**2.1.1.1 A**	**B**	**C**
Head	*2.1.1.1.1*	*N*	14 + 16 = 30	20	25
	L (cm)		3.25 + 7.50 = 10.75	10.00	12.00
Chest	*N*		28 + 33 = 61	40	40
	L (cm)		20.25 + 24.00 = 44,25	20.15	27.30
Abdomen, pelvis	*2.1.1.1.2*	*N*	33	40	33
	L (cm)		32.00	20.15	22.40

Examinations were performed with parameters kV, mAs, *T* and *I* taken from routine protocols for head (or brain), chest and abdomen (or abdomen + pelvis) examinations at each scanner, for standard sized patients. The kilovoltage parameter was 120 kVp for almost all examinations at all scanners except for 140 kVp value within the 2nd series of brain examination protocol at the scanner A (West-Tallinn Central Hospital). The most variable parameter between scanners was mAs, with the C using the lowest value (100 mAs) at brain examinations and the B using the highest value (360 mAs) at abdomen examinations. In practice scanners A and C may apply lower mAs due to the technique of automatic tube current modulation; ACS-DoseRight technique can be used on the scanner B. Examination protocol details are shown in Table 3.

Table 4 contains values of total number of slices N and irradiation length L for each type of examination. In routine protocols for all three scanners there can be found comparable L for brain, abdomen and chest examinations. But we must take in account that in the case of brain or head examinations scan length is very similar for standard patients and this is usually within 10-12cm. L for chest and abdomen examinations can have a broader range of values (25–40 cm) depending on the size of the thorax.

$CTDI_w$ and DLP were then calculated for each examination, the mean results are shown in Table 5. $CTDI_w$ was calculated for each scanner from an average of three measurements in the head phantom and another three measurements in the body phantom. EC RDLs for $CTDI_w$ and DLP are also found in Table 5. Brain examination was performed only without contrast medium. So, in practice, if the patient is scanned using both methods – with and without contrast -, the radiation dose doubles.

$CTDI_w$ of each examination protocol investigated was below the EC RDL, except for head (brain) examination at the scanner A. Performance of all scanners was satisfactory as far as $CTDI_w$ is concerned. DLP was found to be within proposed EG for brain, abdomen and chest examinations.

Running brain examination on the GE QX the value was slightly above the EC RDL due to the higher value of $CTDI_w$, within the almost the same short L in comparison with the other scanners. All chest DLP were sufficiently under EG of 650 mGy cm, except for GE QX, where it was within 631.63 Gy cm, which is within the reference level. Since RDLs act as parameters to help identify relatively poor or inadequate use of technique, the exposure settings and the extent of the scan should be further investigated to lower the dose without affecting image quality. Clarke et al [2] and Tsapaki V. [10] presented CTDIw and DLP results for the same examinations. Their results have a broad range of values, and one of the reasons is the larger number of scanners included in the study.

V Tsapaki et al's values were well within proposed EG for both $CTDI_w$ and DLP, apart from chest DLP on one of examined scanners exceeded the EC RDL. For chest examination, Clarke et al's scanned volume length (range 13.4–28.7 cm) was generally lower than in the our study range 20–45 cm), which seems to have great implication for DLP. Verdun et al [15] presented DLP results for standard abdominal examinations in the range 421–904 mGy cm. Range of DLP value in our abdominal protocols was lower (208-338 mGy cm) and not as broad as at Tsapaki et al's (278–582 mGy cm), probably because our scanning length was 20–32 cm, which is shorter than the scanning length of 38 cm presented in Verdun's study and very close to results reported by Tsapaki et al.

Table 5: Mean weighted computed tomography dose index ($CTDI_w$) and dose–length product (DLP) results compared with European Guidelines (EG)

Examination	[3] **Quantity**		[4] **A**		**4.1.1.1 B**	**C**	**EG**
Head	4.1.1.1.1	$CTDI_w$ (mGy)	4.1.1.1.2	96.18, 65.72	42.9	47.7	60
	DLP (mGy cm)		336 + 525.74 = 862.36		429.00	572.4	1050
Chest	$CTDI_w$ (mGy)		12.48		14.0	12.6	30
	DLP (mGy cm)		631.63		282.10	343.98	650
Abdomen	4.1.1.1.3	$CTDI_w$ (mGy)	4.1.1.1.4	7.67	14.0	15.1	35
	DLP (mGy cm)		208.54		282.10	338.24	800

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Discussion

CT examinations on head or brain appear to have the highest DLPs among examined CTs, and also have a higher than EG $CTDI_w$ criteria. The large irradiation volume of investigations seems to be an important factor since CTDIw is within RDLs. Reducing the extent of the scan as much as possible, without missing any vital anatomical regions, could be a first step to lower DLP and effective dose to patient *E* [3].

Furthermore, reducing mAs of the examination protocol is also important, especially for patients who are thinner than the standard sized patient. W. Kalender et al. 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 study indicate that the lowest mAs can be used without affecting diagnosis, despite of the fact that images may be noisier. A number of other scanning parameters can be easily adjusted for lower doses and better images, very good source for that we have found in W. Kalender references [8].

As far as the other examinations (brain, abdomen and chest) are concerned, the protocols utilized in observed hospitals have $CTDI_w$ and DLP values that are well within EG dose criteria. This is encouraging, since the most important aspect of radiation protection is to have the amount of dose absorbed by the patient as low as reasonably achievable, provided that this does not affect image quality and precise diagnosis [13].

The $CTDI_w$ and DLP values found for each CT canner will be used as a local reference level for each examined hospital. It is important that CT RDLs should be monitored at certain time intervals to constantly assure optimization of the procedure. Furthermore, all examination protocols performed in each hospital will be investigated in terms of technique and radiation dose and compared with EG RDLs, since they appear to be a very useful tool in assessing standard CT performance [11].

To compare radiological examinations in terms of radiation risk, taking into account the relative radiosensitivities of body regions involved, it is necessary to estimate effective dose E, which is the sum of the products of organ doses and corresponding weighting factors [1]. Shrimpton et al [12] calculated E from CTDI measurements using Monte Carlo conversion coefficients. Organ doses can also be measured using TLDs inside and at the surface of phantoms [6, 10, 15]. There are a number of other methods and software applications for evaluating E dose from CTDI parameters can be found in literature [5, 6]. And this can be the next project in the field of CT dose evaluation and monitoring in our country.

Conclusion

First CT QC tests were successfully performed in three largest hospitals of Estonia where we have evaluated $CTDI_w$ and DLP values with further comparison to European Guidelines quality criteria, which showed good correlation with EU normatives; compared routine head, chest and abdomen CT protocols. Today there are no RDLs for *E*. However, since *E* provides a direct estimation of radiation risk and is useful for comparison with other radiological examinations, it should be always evaluated.

However, diagnostic reference dose values should not be applied locally on an individual patient basis, but rather to the mean dose observed for representative groups of patients. For the establishment of national reference doses, all of about 10 CT scanners in Estonia should be monitored with thorough investigation of routine CT exam protocols. We hope this will be the goal of our next study.

Having carried out this survey, now we have the knowledge base and possibilities for reducing dose to patient and improving the quality of CT images at minimal dose.

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