Pilot Survey of Patient Dose from Computed Tomography in Bulgaria

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Abstract. The number of computed tomography (CT) scanners in Bulgaria increased from 22 in 1996 to more than 160 in 2007. Big variety of scanners of different manufacturers and different generations exists in the country with predominant number of single-slice scanners. Significant part of the scanners is more than 10 years old. This work presents the pilot results from the measurements of CT dose quantities started in 2005 with the aim to spread them to a national survey of CT practice in the country. It was found that different clinical protocols are used for similar examination, resulting in large variations in dose quantities: CT air kerma index varied from 27.1 to 78.4 mGy for head examination, from 8.7 to 28.3 mGy for chest, 11.8 – 30.7 mGy for abdomen and 9.1 – 41.3 mGy for pelvis. The CT air kerma-length product for complete examination was found to vary from 310 to 1254 mGy.cm for head examination, from 215 to 893 mGy.cm for chest, from 265 to 615 mGy.cm for abdomen and from 220 to 761 mGy.cm for pelvis. The analysis demonstrated that the main reasons for found variations are differences in scanning geometry, beam quality, exposure parameters and scanning length.

KEYWORDS: Computed tomography, Patient dose, Computed tomography air kerma index, Computed tomography air kerma-length product

1. Introduction

Modern computed tomography (CT) technologies provide increased quality of diagnostic information due to the reduction in examination time and many new possibilities for post-processing [1, 2]. As a result a tendency exists worldwide in increasing the number of CT scanners and CT examinations. According to the last UNCEAR report from 2000, in the developed countries with first level of health care, CT constituted to 6% of the whole number of radiological examinations with 57 CT examinations per 1000 of the populations against 16 per 1000 worldwide [3]. The increased number of CT examinations together with relatively high individual doses are the reasons for rapidly increase of the collective dose from CT. The report from the United Kingdom states, that only in ten years between 1991 and 2001 "CT has more than doubled its contribution and is now responsible for 40% of the total dose to the population from medical X-rays" [4]. Recently, several generations of multidetector row CT scanners have been introduced in developed countries, resulting in increased contribution to the collective dose, up to 67% in large hospitals in USA [5, 6].

UNCEAR and ICRP publications stress on the substantial variations in the dose to the patient for similar types of CT examination resulting from the use of different CT scanners or application of different imaging procedure or different imaging protocols employed at different imaging centres [3, 7]. Thus, the patient dose surveys performed at a hospital level or even more at a country level are extremely important in providing data for optimisation.

Bulgaria is a country of first level of health care, according to the UNCEAR classification, but the number of CT examinations is still less than the mean number for this group. A strong tendency exists for rapid increase of both the number of the examinations and number of CT scanners. In only ten years the number of CT scanners increased 7 times: from 22 in 1996 to more than 160 in 2007, which is about 2 scanners per 100 000 of population. The review of the national register demonstrates big variety of scanners of different manufacturers and of different generations with predominant number

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of single-slice and only less than ten multi-slice scanners. Significant part of the CT scanners is more than 10 years old and some of them without spiral data acquisition function. The big variety of scanners of different ages and still insufficient standardization of the clinical practice within the country are the reasons to expect big variety of patient doses from these high dose procedures.

This work presents the pilot results from the first measurements of CT dose quantities started in 2005 with the aim to spread them to a national survey of CT practice in the country, as required by the EC Medical Exposure Directive 97/43 [8], introduced in Bulgaria with the Ordinance of the Ministry of Health from 2005 for Protection of the Individuals from Medical Exposure [9]. This regulation introduced Diagnostic reference dose levels (DRL) and assigned their elaboration to the National Centre of Radiobiology and Radiation Protection (NCRRP).

2. Material and Methods

Ten CT scanners routinely used in clinical practice in Bulgarian hospitals was surveyed (Table 1). Most of the CT units were single slice systems and only two of them were multi-slice: one dual-slice system (Siemens Somatom Emotion Duo) and one 16-slice CT units (GE LighSpeed 16). All scanners were from third generation with the exception of the Picker Ultra Z scanner from fourth generation.

Table 1: CT scanners included in the survey

Manufacturer	Model	Generation	Detector rows
SIEMENS	Somatom AR.C	3^{d}	1
	Somatom Emotion	3^{d}	1
	Somatom Emotion Duo	3^{d}	2
GENERAL ELECTRIC	ProSpeed S Fast	3^{d}	1
	HiSpeed CT/e	3^{d}	1
	LighSpeed 16	3^{d}	16
PHILIPS	CT Secura	3^{d}	1
SHIMADZU	SCT 7000TS	3^{d}	1
PICKER	Ultra Z	4^{th}	1
HITACHI	Pronto XE	3^{d}	1

The examinations included in this study were routine CT examinations of head, chest, abdomen and pelvis for adult patient. In order to investigate the effect of exposure related parameter on patient doses, typical exposure parameters for adult patient were collected from each hospital participated in this study.

Two dosimetric quantities were evaluated based on the widely established dosimetry approach: the CT air kerma index for a single slice and CT air kerma-length product for complete CT examination.

CT air kerma index was measured both free in air and in a standard dosimetry CT phantom [10, 11]. CT air kerma index free in air, $C_{a,100}$ is defined as an integral of the CT axial air kerma profile, $K_a(z)$, along the axis of rotation z of the CT scanner over a length of 100 mm, for a single rotation with a single slice divided by the nominal slice thickness T:

$$C_{a,100} = \frac{1}{T} \int_{-50\,mm}^{+50\,mm} K_a(z)\, dz \qquad (1)$$

The integral in equations (1) is called air kerma–length product P_{KL}. For a single-slice scanner CT air kerma index becomes:

$$C_{a,100} = \frac{P_{KL}}{T}, \qquad (2)$$

and for a multi-slice scanner with N slices of thickness T, acquired simultaneously in one rotation (nominal width of irradiated beam NT):

$$C_{a,100} = \frac{P_{KL}}{NT} . \qquad (3)$$

$C_{a,100}$ was measured with a pencil-shaped ionization chamber with an effective length of 100 mm, type TW3009, connected to a electrometer Unidos E (PTW Freiburg, Germany).

CT air kerma index was also measured in standard cylindrical Polymethylmethacrylate (PMMA) dosimetry CT phantoms for head and body, with corresponding diameters 16 cm and 32 cm. In this case the notation $C_{PMMA,100}$ is used. After the recommendations of the European guidelines on quality criteria for CT [12], $C_{PMMA,100}$ was measured at the centre of the phantom, $C_{PMMA,100,c}$ and at four locations around the periphery of the phantom 10 mm below the surface. For particular CT examination weighted CT air kerma index, C_w was calculated from the equation:

$$C_w = \frac{1}{3}(C_{PMMA,100,c} + 2C_{PMMA,100,p}) , \qquad (4)$$

where $C_{PMMA,100,p}$ is average of the four measurements at the periphery.

The second basic dose quantity in computed tomography is ***CT air kerma-length product*** in the standard head or body CT dosimetry phantom for complete examination, $P_{KL,CT}$ [10, 11, 12]. For the examination formed by different sequences j, it was calculated from the formula:

$$P_{KL,CT} = \sum_j {}_nC_{w_j} T_j N_j P_{It_j} , \qquad (5)$$

where ${}_nC_{w_j}$ is the weighted CT air kerma index, normalized to unit tube current exposure–time product; N_j is the number of slices, each of thickness T_j (cm) and tube-current exposure–time product P_{It_j} (mA·s), in a particular sequence j. In a case of helical (spiral) scanning:

$$P_{KL,CT} = \sum_i {}_nC_{w_i} T_i P_{It_i} , \qquad (6)$$

where, for each of i helical sequences forming part of an examination, T_i is the nominal irradiated slice thickness (cm), I_i is the tube current (mA), and t_i is the total acquisition time (s) for the sequence. Quantity ${}_nC_{w_i}$ is determined for a single rotation as in serial scanning.

The European guidelines on quality criteria for CT [12] gives reference levels for CT examinations in terms of weighted CT air kerma index, C_w for a single slice in serial scanning or per rotation in helical scanning and CT air kerma-length product, $P_{KL,CT}$ for a complete examination. The International Electrotechnical Commission requires that values of C_w should be displayed on the operator's console of the CT scanner.

In many publications CT air kerma indexes are denoted as *CTDI* and CT air kerma-length product – as *DLP* [2, 4, 12, 13, 14]. The standardized ICRU and IAEA symbols are used in this work [10, 11].

3. Results and Disscussion

Clinical protocols for routine CT examinations of adult patients were collected from all CT scanners surveyed. The main exposure parameters for standard CT examinations of head, chest, abdomen and pelvis are summarised in Table 2.

It was found that different clinical protocols are used for similar examination. For example, in most cases standard head examination was performed in an axial scanning mode with exception of one hospital where spiral scanning sequence was used. The basic body examinations were performed in helical mode with the exception of scanner Siemens Somatom AR.C without helical scanning capabilities.

Table 2: Exposure parameters used in standard CT examination of head, chest, abdomen and pelvis

CT Unit	CT examination	Tube potential, kV	Tube current, mA	Rotation time, s	Slice thickness, mm	Scan length, cm
SIEMENS Somatom AR.C	Head	130	70	3.0	10	12
	Chest	130	50	3.0	10	21
	Abdomen	130	70	3.0	10	24
	Pelvis	130	70	3.0	10	30
SIEMENS Somatom Emotion Duo	Head	130	173	1.5	4.0x2	12
	Chest	130	100	1.0	2	16
	Abdomen	110	160	1.0	5	20
	Pelvis	130	160	1.0	5	20
SIEMENS Somatom Emotion	Head	130	150	1.5	8	16
	Chest	130	100	0.8	8	29
	Abdomen	130	150	0.8	10	23
	Pelvis	130	150	1.0	10	26
GE ProsPeed S Fast	Head	120	80	1.5	5/10	13
	Chest	140	160	1.5	10	22
	Abdomen	120	160	1.0	10	22
	Pelvis	120	120	1.5	10	28
GE HiSpeed CT/e	Head	120	100	2.0	7	11
	Chest	120	130	1.0	7	25
	Abdomen	120	157	1.0	10	23
	Pelvis	120	160	1.0	7	21
GE LighSpeed 16	Head	140	165	2.0	2.5x4	16
	Chest	120	225	0.6	5.0x2	24
	Abdomen	120	300	0.6	5.0x2	30
	Pelvis	120	300	0.6	5.0x2	30
SHIMADZU SCT 7000TS	Head	130	160	1.0	5	12
	Chest	130	200	1.0	7	32
	Abdomen	120	160	1.0	7	25
	Pelvis	120	160	1.0	7	25
PHILIPS CT Secura	Head	140	120	2.0	5	15
	Chest	120	260	0.7	5	25
	Abdomen	140	240	0.7	7	20
	Pelvis	120	160	1.0	7	18
PICKER Ultra Z	Head	130	200	1.0	8	12
	Chest	130	100	1.5	8	16
	Abdomen	130	150	1.0	8	20
	Pelvis	130	120	1.5	8	12
HITACHI Pronto XE	Head	120	175	2.0	5	12.5
	Chest	120	200	1.5	10	19
	Abdomen	120	200	1.0	10	22
	Pelvis	120	200	1.0	10	25

Typical values of tube voltage used were in the range from 120 kV to 140 kV; lower value of 110 kV was used in one hospital for the routine examination of abdomen. It is evident from the Table 2 that large variation in tube current-time (mA.s) values for the same examination exists among scanners.

The choice of mA.s settings depend mainly on specific characteristics of CT system and partly on differences in clinical protocols. For scanners operated in auto dose reduction mode with automatic tube current modulation, the average values of tube current or mA.s during the modulation is presented in the table and that value was used in dose calculation. The higher variations in current-time product were found for standard head examination (from 120 to 350 mAs) and for chest examination (from 80 to 300 mAs), and less for abdomen and pelvis – from 120 to 210 mAs and from 150 to 210 mAs, respectively.

Routine CT examination of head, chest, abdomen and pelvis were performed with slice thickness in the range from 5 mm to 10 mm; at only two CT scanners 2 mm slice thickness is used as a standard chest protocols to achieve better resolution.

Rotation times were in the ranges of 1 – 3 s for standard head examinations and 0,6 s – 3 s for body examinations. The long rotation time used for standard chest examination at one of the oldest CT systems Siemens Somatom AR.C (3 s) may cause image artifacts because of the tissues movement during the scanning process.

Significant variation of scanning length was found among hospitals for the same examination. The mean values of scan length with the minimum and maximum values in parentheses are presented in Table 3, as well as typical values from the German survey [2].

Table 3: Comparison of scan length for typical CT examination in this study and in German survey

CT Examination	Scan Length, cm	
	This study	German survey [2]
Head (routine brain)	13.1 (11.2 – 16.0)	12
Chest	22.8 (16.0 – 31.5)	27
Abdomen	22.9 (20.0 – 30.0)	42 (total abdomen)
Pelvis	23.5 (12.0 – 30.0)	24

The mean values of scanning length for head CT examination in this study were in the ranges from 11.2 cm to 16.0 mm, 16.0 – 31.5 cm for chest, 20.0 – 30.0 cm for abdomen and 12.0 – 30.0 cm for pelvis. These large variations were mainly due to the differences in slice thickness and number of slices used in different protocols. The highest variation was found for chest examination; with maximum to minimum values differed by factor of 2. The mean scan length for head and pelvis examinations were similar to the typical values from the German survey, while for chest and abdomen they were lower.

Results for $C_{a.100}$ and C_w for selected head and body examinations are presented in Table 4. With asterisks are marked the values of C_w estimated from $C_{a.100}$ values with “phantom factors” published in the literature [2]. In the table are also presented calculated values for $P_{KL,CT}$ using C_w.

Large variations of $C_{a,100}$ and C_w for a specific examination were found among the CT units included in this study. Measured mean values of $C_{a,100}$ for head examination were in the range 39.4 – 112.8 mGy, while for body examinations they were 25.9 – 111.5 mGy. Similar variations were found for the values of C_w. Mean values of C_w for head and chest CT examinations were from 27.1 to 78.4 mGy and from 8.7 to 28.3 mGy, respectively, while those for abdomen and pelvis were 11.8 – 30.7 mGy and 9.1 – 41.3 mGy, respectively. The large variation for identical examination were mainly attributed to different scanner design and differences in exposure parameters among CT units, i.e. tube voltage, mA.s and exposure time, focus to axis distance, filtration.

Values of C_w for head examination performed with multi-slice systems were higher than with single-slice scanners. The reason is the wider collimator settings used to compensate for the penumbra effects, especially when smaller slice thicknesses are used [1, 2]. Another reason for the higher C_w is the higher value of mA.s used in this examination in order to reduce the image noise when examination is performed with thin slice thickness.

Table 4: Measured dose quantities for standard CT examinations with different CT scanners.

CT scanner	CT Examination	$C_{a.100}$, mGy	C_w, mGy	$P_{KL,CT}$, mGy.cm
SIEMENS Somatom AR.C	Head	62.5	49.2	591
	Chest	46.5	18.6	392
	Abdomen	62.3	25.4	609
	Pelvis	62.5	25.4	761
SIEMENS Somatom Emotion Duo	Head	96.7	70.6*	847
	Chest	38.4	13.4*	215
	Abdomen	38.2	13.2*	265
	Pelvis	57.6	20.2*	204
SIEMENS Somatom Emotion	Head	67.0	40.1	641
	Chest	26.4	8.7	250
	Abdomen	35.7	15.7	361
	Pelvis	44.4	15.5	404
GE ProsPeed S Fast	Head	42.5/36.3	31.4/22.8	310
	Chest	106.3	27.6	608
	Abdomen	55.2	14.4	316
	Pelvis	36.1	10.4	291
GE HiSpeed CT/e	Head	44.7	33.1	371
	Chest	30.5	9.6	235
	Abdomen	36.1	17.8	271
	Pelvis	40.8	11.8	247
GE LighSpeed 16	Head	112.8	78.4	1254
	Chest	34.0	14.1	338
	Abdomen	44.1	18.1	542
	Pelvis	44.1	18.1	542
SHIMADZU SCT 7000TS	Head	44.0	39.6	475
	Chest	58.0	28.3	893
	Abdomen	41.9	18.4	463
	Pelvis	41.9	18.4	463
PHILIPS CT Secura	Head	59.2	44.4	666
	Chest	33.6	13.4	336
	Abdomen	44.4	17.8	336
	Pelvis	31.3	12.1	220
PICKER Ultra Z	Head	58.7	30.1	361
	Chest	66.9	20.8	333
	Abdomen	94.2	30.7	615
	Pelvis	111.5	41.3	496
HITACHI Pronto XE	Head	85.1	54.4	680
	Chest	71.1	25.5	485
	Abdomen	48.4	17.5	386
	Pelvis	48.4	17.5	239

Measured values of C_w and $P_{KL,CT}$ were compared with the European dose reference levels (DRL) [12], which were adopted as national reference dose levels [9]. The summary of the results is presented in Table 5.

Table 5: Mean values (min-max) of C_w and $P_{KL,CT}$ from this survey and corresponding European dose reference levels (DRL)

CT Examination	This study		European DRL	
	C_w, mGy	$P_{KL,CT}$, mGy.cm	C_w, mGy	$P_{KL,CT}$, mGy.cm
Head	47 (27.1 –78.4)	620 (310 –1254)	60	1050
Chest	18 (8.7 – 28.3)	405 (215 – 893)	30	650
Abdomen	18 (11.8 – 30.7)	416 (265 – 615)	35	780
Pelvis	18 (9.1 – 41.3)	406 (220 – 761)	35	570

It was found that for most of CT units included in the study C_w are below the European DRLs with several exceptions. For head examination both multi-slice units were found to exceed the European DRL of C_w. For body examinations only one CT scanner (PICKER Ultra Z) demonstrated value of C_w higher than European DRL for routine pelvis examination. The possible reason might be the specific characteristics of this fourth generation CT scanner.

Large variations in $P_{KL,CT}$ were found among different CT scanners for similar examinations: from 310 to 1254 mGy.cm for head examination, from 215 to 893 mGy.cm for chest, from 265 to 615 mGy.cm for abdomen and from 220 to 761 mGy.cm for pelvis (Tables 4 and 5). The reasons for that were already discussed differences in scanning length, scanning geometry and beam quality.

The comparison between values of $P_{KL,CT}$ from this study and European DRL for head CT examinations shows that DRL were exceeded in only one multi-slice CT scanner; for chest and pelvis examination only one scanner was found to have values higher than DRL; values for abdomen examinations were below the DRL.

4. Conclusion

This study summarised the basic clinical protocols for head, chest, abdomen and pelvis CT examinations from ten Bulgarian hospitals and corresponding measured basic dosimetric quantities. The values of CT air kerma index for a single slice and CT dose-length product for complete examination found to vary significantly between hospitals. This was influenced by different CT scanner geometry, scanner generation and scanning parameters used among hospitals.

It was evident from this pilot survey of only ten CT rooms that high potential for optimisation of CT examinations exists as well as standardisation of protocols at a national level.

The present survey served as a basis for developing standardized protocol for a national survey of CT practice throughout the country that was initiated this year with representative number of CT systems in Bulgaria.

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