Radiation exposure in computed tomography: comparison of adult and paediatrics radiology practice in Serbia

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Abstract. There are 90 CT units operating in Serbia, with tenfold increase in the last decade, resulting with annual total of approximately 350000 procedures. The objective of this paper is to assess typical patient dose from adult and paediatric CT examinations. Initially, three hospitals (two general hospitals performing examination of adults and a dedicated paediatric hospital) were enrolled into the study. The hospitals have high workload. Both multi detector CT (MDCT) and single detector CT (SDCT) were included, to represent typical practice in Serbia. Typical patients exposure parameters based on predefined protocol for CT examinations of head, chest, abdomen and pelvis were collected. Data were taken form CT unit displey. This includes exposure parameters and volumetric and weighted CT dose index (CTDI). Dose length product (DLP) was calculated from CTDI values and information on typical scan length. Also, the effective dose was estimated. DLP values were 575 mGy·cm, 310 mGy·cm, 703 mGy·cm and 470 mGy·cm for head, chest, abdomen and pelvic CT respectively in general hospital using SDCT and 325 mGy·cm, 160 mGy·cm, 321 mGy·cm and 140 mGy·cm for the same examination using MDCT. In paediatric hospital these values were 525 mGy·cm, 230 mGy·cm , 385 mGy·cm and 330 mGy·cm. The assessed patients’ doses in terms of CTDI and DLP were well below reference levels and in accordance with surveys from other countries, although the scope for dose reduction through optimisation of the examination protocol was observed.

KEYWORDS: computed tomography, dose, paediatric patients, patient exposure, dose length product

1. Introduction

Computed tomography (CT) is an evolving imaging modality and the most significant diagnostic examination from the radiation protection point of view. The frequency of CT examinations as well as individual dose per examination is increasing rapidly. CT can now be responsible for up to 17% of the departmental workload accounting for 70-75% of the collective dose from medical radiation [1]. The worldwide total number of CT examinations is estimated to 93 millions, corresponding to a frequency of 16 examinations per 1000 inhabitants, with about 11% involving children of age 0-15 [2,3]. The reported increase in request for paediatric CT range from 63% to 92% [1]. This figures reflect the very rapid technological development in CT imagining, i.e. introduction of single detector spiral CT units (SDCT) and multi detector units (MDCT) [4,5]. The number of detectors also affects the dose due to shape of the x-ray beam, referred as “overbeaming” [6,7]. The effect decreases with more detector rows and is less pronounced in 16- and 64-detector machines than 4- and 8-detector machines. Although there is remarkable variation in the number and properties of CT units and examinations increase of collective dose and dose per examination, both in adult and paediatric CT is a general trend [2].

There are 90 CT units operating in Serbia (more than ten 64-detector CT units), with tenfold increase in the last decade, resulting with annual total of approximately 350000 procedures or 45 examinations per 1000 inhabitants. This number is continuously increasing. The frequency of paediatric examination is less than 1% due to technical reasons, but it is likely that number of paediatric examinations will increase in near future. A single CT unit in paediatric hospital is at the moment the only one performing CT examination of children. As a rule, children from all over the country are sent to this hospital for CT examination.

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2. Materials and Methods

2.1. Dosimetry in computed tomography

There is currently much confusion on the use of dosimetric quantities in CT, which is partially driven by rapid development of the CT technologies [8]. Nevertheless, at present, the accepted dosimetry concept in CT is well established and based on the practical dose quantities: weighted CT dose index (CTDI<sub>wp</sub>), volume weighted CT dose index (CTDI<sub>vol</sub>) and dose-length product (DLP) [7-12]. With advent of MDCT, CTDI<sub>vol</sub> has become more relevant. As a quotient of CTDI<sub>wp</sub> and pitch, it account for variation in radiation exposure in the z direction when pitch is not an unity. With use of a spiral SDCT, the CTDI<sub>vol</sub> is equal to CTDI<sub>wp</sub> [4].

There are some shortcomings of using the CTDI, which is the most widely used quantity for CT dosimetry. This quantity is neither related to radiation risk not to noise level, since it only an indication of average dose in the central part of scanned region when slices are contiguous [8]. It does not provide integral dose information, relevant for risk assessment and does not account for patient specific parameters. However, it enables comparisons between scanners, at can be easily measured. Another directly measurable quantity, DLP, is an indicator of overall radiation burden to patient [7]. Furthermore, CTDI and DLP are commonly used quantities to express Diagnostic Reference Levels (DRLs) in CT [11]. DRLs are an optimisation tool in patient protection and permit comparison of the performance of different CT scanners [4].

All CT vendors are now required to display CTDI or even DLP values on the user interface. However, these quantities do not tell anything about actual dose that patient receives. Instead, they are useful information about relative changes that result from alteration of examination parameters and tailoring examination to individual patient. It is worth mentioning that for a given set of parameters, displayed CTDI and DLP will be the same, regardless patient’s size, since these quantities do not reflect the absorbed dose to the body.

In additional to comparison of performance if different CT units and against DRL, there is a need to estimate effective dose for CT procedures, for example, to allow comparison with other types of radiological examinations [9]. It can be done either by using scanner-specific normalised organ dose data for anthropomorphic mathematical phantom [13,14], concept of energy imparted [15] or using age –related conversion coefficients from DLP to effective dose [10].

Effective dose (E) is the most appropriate dose descriptor for assessment of stochastic radiological risk [16]. The effective doses in CT are higher for infants and children than adults for the identical examination protocol [3,15,17,18]. Also, risk for children is higher due to higher radiosensitivity and longer life expectancy. The risk for paediatric patient can be smaller if specific paediatric protocols are used [6,15].

Having in mind a complex relationship between image quality and dose to patient, a number of dose reduction methods are reported in the literature [1,6,19]. The biggest dose saving in CT is when examination is not performed, when multiphase and repeated examinations are avoided and by active designing of the CT protocol. The list of parameters that contribute to radiation dose is: tube current, tube voltage, gentry rotation time, table speed, detector configuration [1,7,19]. Recently, all major CT vendors have made alterations to their equipment aimed to control radiation dose and maintain image quality by age and size adjusted protocols [6].

2
2.2. Data collection

The strategy for the present survey ideally involved the assessment of the CTDI<sub>vol</sub>, CTDI<sub>vol</sub> and DLP for each sequence and examination. Basic parameters of the standard examination protocol for the commonly performed examinations in all radiology departments (head, chest, lumbar spine, abdomen and pelvis) were collected from the scanner display. Protocols suggested by the manufacturer were normally used. The method of data collection from displays was selected, since it has been shown that it is sufficiently accurate in dose audit [shrimpton]. DLP was calculated from each sequence using information on the scan length. For comparison with other types of radiological examinations, effective dose (E) was assessed using suitable conversion coefficients from DLP to E [10].

Initially, three hospitals were involved in this preliminary survey. All hospitals have high workload. Both MDCT and SDCT and adult and paediatric examinations were included to represent typical practice in Serbia. SDCT (Somatom Plus 4, Siemens, Erlangen, Germany), operating in general hospital performing examinations of adults, is not equipped with automatic tube current modulation, while MDCT (Emotion 16, Siemens, Erlangen, Germany) in another hospital has this option. In dedicated paediatric hospitals using SDCT unit (Smile, Siemens, Erlangen, Germany) a specific protocol for children was used.

3. Results and Discussion

Typical examination protocol details for examination of head, chest, abdomen, lumbar spine and pelvis are presented in Table 1. These examination types were selected to cover a wide range of patient doses. The doses in terms of CTDI<sub>vol</sub>, DLP and E are presented in Table 2.

Table 1. Details on the typical CT scanning protocol for a given examination types in each hospital under the survey

<table>
<thead>
<tr>
<th>Hospital</th>
<th>CT examination</th>
<th>Tube potential [kV]</th>
<th>Tube loading [mAs]</th>
<th>Slice width [mm]</th>
<th>Pitch</th>
</tr>
</thead>
<tbody>
<tr>
<td>GH-MDCT</td>
<td>Head</td>
<td>130</td>
<td>220</td>
<td>5.0</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Chest</td>
<td>130</td>
<td>113</td>
<td>5.0</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>Abdomen/Lumbar spine</td>
<td>130</td>
<td>90</td>
<td>5.0</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>130</td>
<td>150</td>
<td>5.0</td>
<td>0.8</td>
</tr>
<tr>
<td>GH-SDCT</td>
<td>Head</td>
<td>140</td>
<td>170</td>
<td>5.0</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Chest</td>
<td>140</td>
<td>160</td>
<td>5.0</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>Abdomen/Lumbar spine</td>
<td>120</td>
<td>200</td>
<td>5.0</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>140</td>
<td>506</td>
<td>3.0</td>
<td>1.5</td>
</tr>
<tr>
<td>PH-SDCT</td>
<td>Head</td>
<td>120</td>
<td>100</td>
<td>5.0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Chest</td>
<td>120</td>
<td>100</td>
<td>5.0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Abdomen/Lumbar spine</td>
<td>120</td>
<td>80</td>
<td>5.0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>120</td>
<td>120</td>
<td>2.0</td>
<td>1</td>
</tr>
</tbody>
</table>

As an indication of an integral dose to patients, DLP values were 575 mGy·cm, 310 mGy·cm, 703 mGy·cm and 470 mGy·cm for head, chest, abdomen and pelvic CT respectively in general hospital using SDCT and 325 mGy·cm, 160 mGy·cm, 321 mGy·cm and 140 mGy·cm for the same examination using MDCT. In pediatric hospital these values were 525 mGy·cm, 230 mGy·cm, 385 mGy·cm and 330 mGy·cm.

Effective doses were estimated for adults and for children of age 1, just for comparison to doses for adult patients. However, to obtain more realistic dose estimates for children, it is necessary to account for specific patient weight, scan length and imaged anatomy. Since radiation risk is higher for children, special efforts are needed to tailor clinical practice using size-specific protocols. It has been reported that effective doses to paediatric patients could be 2.5 – 10 times lower than adult’s dues to the adaptation of tube current [15].
Inherent differences in the design of CT equipment lead to large variations between scanner models in assessed dose for standard adult examination protocol and acceptable image quality. Spiral CT offers the ability to adjust the slice reconstruction interval. The use of higher pitch and tube current modulation are the major methods for balancing patient dose and image noise level, as presented in Table 1 and Table 2. The factors that affect the dose are scanner related, operator related or patient related. The first two are can be controlled either by manufacturers or by operators, while the last one cannot be easily controlled. However, the examination protocol must be related to the situation.

Table 2. Results of dose assessment for various CT examination types in three hospitals. European DRL [11] are given in the final columns

<table>
<thead>
<tr>
<th>Hospital</th>
<th>CT examination</th>
<th>CTDIvol [mGy]</th>
<th>DLP [mGy cm]</th>
<th>E [mSv]</th>
<th>Reference levels CTDIw [mGy]</th>
<th>DLP [mGy·cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>GH-MDCT</td>
<td>Head</td>
<td>13</td>
<td>325</td>
<td>1.0</td>
<td>60</td>
<td>1050</td>
</tr>
<tr>
<td></td>
<td>Chest</td>
<td>6.4</td>
<td>160</td>
<td>2.2</td>
<td>30</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>Abdomen/Lumbar spine</td>
<td>11</td>
<td>321</td>
<td>4.8</td>
<td>35</td>
<td>780</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>8.0</td>
<td>140</td>
<td>2.1</td>
<td>35</td>
<td>570</td>
</tr>
<tr>
<td>GH-SDCT</td>
<td>Head</td>
<td>23</td>
<td>575</td>
<td>12</td>
<td>60</td>
<td>1050</td>
</tr>
<tr>
<td></td>
<td>Chest</td>
<td>18</td>
<td>310</td>
<td>4.3</td>
<td>30</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>Abdomen/Lumbar spine</td>
<td>21</td>
<td>703</td>
<td>11</td>
<td>35</td>
<td>780</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>14</td>
<td>470</td>
<td>7.1</td>
<td>35</td>
<td>570</td>
</tr>
<tr>
<td>PH-SDCT</td>
<td>Head</td>
<td>21</td>
<td>525</td>
<td>4.4</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td></td>
<td>Chest</td>
<td>9</td>
<td>230</td>
<td>6.0</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td></td>
<td>Abdomen/Lumbar spine</td>
<td>11</td>
<td>385</td>
<td>12</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>13</td>
<td>330</td>
<td>9.9</td>
<td>/</td>
<td>/</td>
</tr>
</tbody>
</table>

As presented in Table 1, section thickness commonly used is slightly higher than 7-10 mm, as recommended in European protocol [16262]. Also, this protocol recommends pitch values of 1 for the smaller lesions and 1.5 for the larger lesions, to achieve acceptable image quality. Pitch values obtained here are, however, lower than recommended. As presented in Table 2, the CT doses in terms of CTDI and DLP were well below reference levels and in accordance with surveys from other countries [11,20-22]. Wide variation in doses indicates that there is a scope for dose reduction. Immediate action is possible by proper selection of the section thickness, increased pitch and reduced the scanned volume.

Due to very limited sample, it is not possible to bring the general conclusion on the difference between SDCT and MDCT. Other survey results pointed out that these differences are significant and that DRL should be set separately for these two technologies at least of the examinations of adults [10]. In addition, it is necessary to obtain separate DRL for children due to large variation in size whithing the different age groups. More representative values of radiation risk magnitude can be obtained exclusively by taking into account variation in patient size.

This survey is an initial input for assessment of CT doses in Serbia, since this issue has never been raised before. Standard examination protocols provide the basic framework for the typical practice, although the extended survey should be oriented towards individual patients in order to assess variation among them and towards establishment of national DRL. This is especially relevant for further optimisation studies. In all hospitals enrolled into the survey the operators were not aware about magnitude of patients’ doses in CT and possibilities for dose reduction.

4. Developments in computed tomography dosimetry

In recent ICRU Report 74, several application-specific quantities have been described for measurements, including those used for CT dosimetry [16]. These are: CT air kerma index free-in-air, as integral of the CT axial air kerma profile along the axis of rotation of the CT scanner for single rotation with a single slice divided by the nominal slice thickness. CT air kerma index in the standard CT dosimetry phantoms, defined similarly to CK but for air kerma profile inside the Perspex head or body phantom instead in air and weighted CT air-kerma index (analogue to definition of CTDIw).
Further, CT air kerma-length product is an integral of the air kerma free-in-air over a line parallel to the axis of rotation of a CT scanner, analogue to DLP.

At present, the use of CT as a medical imaging procedure has increased tremendously in recent years, spurred in part by the rapid scanning capabilities of modern multi-slice CT scanners, up to 256 detectors and cone beam CT units with flat panel detectors [5, 23,24]. With this increase in utilization, the radiation dose to patients associated with modern CT has become a larger concern. Measurement of above mentioned conventional quantities mainly relies on the use of pencil ionization chambers designed to have uniform response along the entire length of the sensitive volume. In the view of technical developments in CT, particularly large volume scanning, basic measurements using a 10 cm long detector will be most probably inadequate in the future [6].

5. Conclusion

It is apparent that radiation protection issues in CT are extremely complex and they have become even more complicated with the introduction of MDCT. Commonly, radiologists are not aware about magnitude of patients’ doses in CT and possibilities for dose reduction. Protocol suggested by the manufacturer is normally used. As the number of units and examinations is increasing in Serbia, the training of operating staff is of utmost importance.

Extended survey should be performed on the national scale, resulting with setting of national DRL. Also, the efforts should be made to train the operators and to increase their awareness about dose management and magnitude of patient doses in CT, especially for paediatric patients.

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