PATIENT DOSES CALCULATED FOR ANY COMPUTED TOMOGRAPHY SCANNER

Kiryl Viarenich, Victor Minenko, Semen Kuten, Arkady Khrutchinsky

Institute for Nuclear Problems, Belarusian State University, Minsk, Belarus

Abstract

Various models of Computed tomography scanners have different radiation output, fan angle and radius of X-ray tube trajectory and other characteristics. A huge database of conversion coefficients is needed to calculate organ doses from any CT scanner. These coefficients can be calculated by computer simulation of exposure from CT scanner. A new approach to estimate organ doses was introduced based on the fact that conversion coefficient calculated for different CT scanners have very similar values for the same X-ray tube voltage.

1. Introduction

Currently there are over a hundred models of CT scanners being used worldwide. They all have various parameters of radiation beam including fan angle of X-ray beam, radius of X-ray tube trajectory, inner characteristics of X-ray tube (anode angle, inherent filtration). These parameters all impact the resulting radiation dose to patient. Identical CT scanners can still give various doses, however a measured X-ray output metric exists to account to this: CTDI. The relation of patient dose to CTDI will be constant for a given CT scanner. This relation is known as conversion coefficient and is widely used as a basis for dose estimation. A catalogue of conversion coefficients was calculated by Jones and Shrimpton [1]. This catalogue was calculated for a stylized «mathematical» phantom, which describes the human body using simple geometry shapes (planes, spheres, cylinders etc.). The calibration coefficients were gathered in extensive arrays. Each element of the array was a coefficient representing the dose from a 5 mm slice being exposed to X-ray beam. After that the sum of these coefficients was calculated and multiplied by the measured CTDI. These arrays were calculated for 23 various combinations of CT scanners, X-ray radiation filters and X-ray tube voltages. Despite the fact that these values are outdated, they were included into a dedicated MS Excel book ImpaCT, which was continuously updated and maintained by IMPACT group. Version 1.0.4 of ImpaCT was released in 2011. These conversion coefficients were continued to be used for other CT scanner models not necessarily identical to the original models.

The relation of CTDI measured in cylindrical phantom to CTDI measured free-in-air ($CTDI_{air}$) is called factor P_B and P_H (for body and head phantoms respectively). If these value for any CT scanner is equal to previously calculated, then old conversion coefficients can be used to estimate the doses from the new CT scanner.

2. Materials and methods

To establish the method described in introduction we performed a calculation of all necessary dosimetric quantities for Toshiba Aquilion ONE scanner. The human body was simulated using reference phantoms published in ICRP Publication 110 [2]. Monte-Carlo simulation was based on MCNPX 2.6 code [3]. Dynamic source was simulated using method based on [4]. Source subroutine of MCNPX was modified to simulate the exposure from a CT scanner. For each position of scanning plane the positions of X-ray tube were sampled along a circle of given radius. Depending on the starting position of each particle the vector of propagation was uniformly sampled in the beam. Fan angle of the beam is 49,2°. In target angle of the beam corresponds to 1 cm slice. Source spectrum was generated for high voltage 100 kV [4]. The shape bowtie filter was also simulated and in our case it was "Medium-M" and taken from [4].

The resulting doses to organs and tissues and effective dose were calculated based on recommendations of Publications 103 and 116 of ICRP [5,6]. Most distinct tissues to simulate are active marrow and endosteum. Their size is much smaller than the size of voxels in the phantom. Therefore according to [6] the dose to active marrow was calculated using the following formula:

$$D_{skel}(AM)=\sum_{x}\frac{m(AM,x)}{m(AM)}D(SP,x) \tag{1}$$

where $m(AM, x)$ is the mass of active marrow in bone x, $m(AM)$ is the total mass of active marrow in the skeleton. $D(SP, x)$ is the dose to trabecular spongiosa.

For example, the mass of active marrow in pelvis of adult female phantom is 157,5 g. The total mass of active marrow is 899,1 g.

Dose to endosteum (formerly called bone surface) was calculated using the formula similar to (1).

Calculation of each slice was performed for $2\cdot10^5$ starting histories. The statistical error caused by Monte-Carlo method was around 1% for organs in the direct beam.

As doses in MCNPX are calculated per source photon, CTDI was also calculated in the same conditions. Because exposure of both head and the rest of the body were simulated, two values of CTDI were determined: for head cylinder phantom (diameter 8 cm) and body phantom (diameter 16 cm).

The resulting array of doses calculated in MCNPX was processed using Wolfram Mathematica computer algebra system.

3. Results

The dependence of slice-by-slice conversion coefficients for effective dose is shown in figure 1. Each slice was 1 cm thick. The values from 0 to 20 cm were related to CTDIw measured in head phantom, the resting values were related to $CTDI_w$ measured in body phantom. Conversion coefficient to lungs multiplied by their respective weight factor (0,12) is shown. Conversion coefficient to breast multiplied by weight factor (0,12) added to the conversion coefficient to lungs is shown.

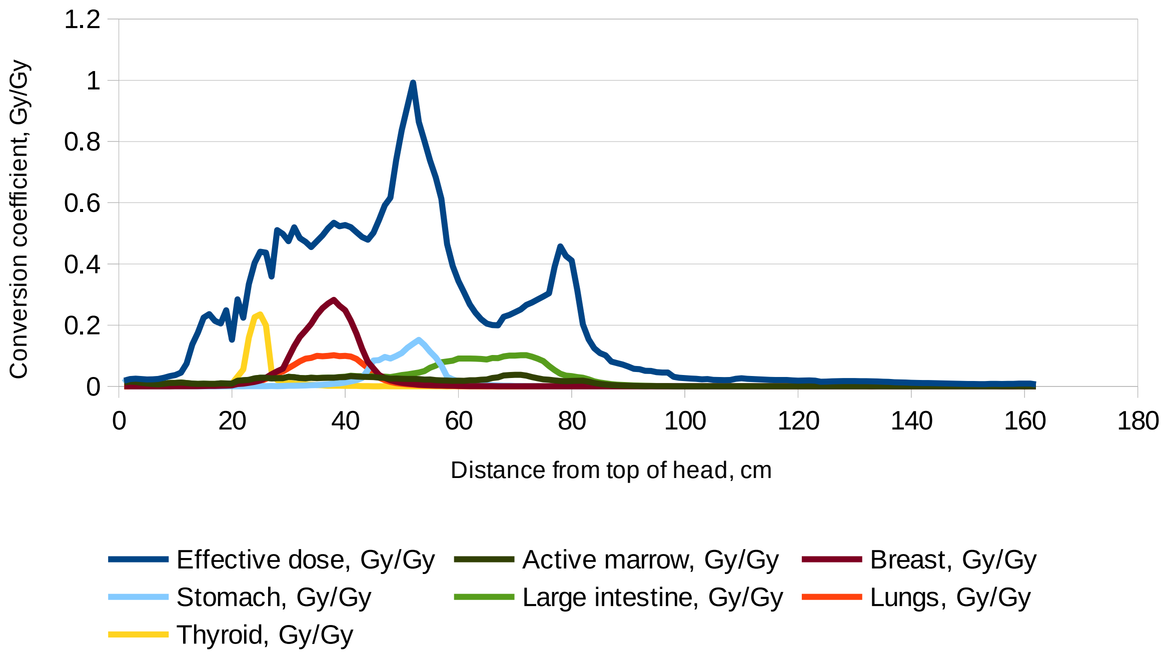

Figure 1: Conversion coefficients for effective dose for slices along the height of the patient. Conversion coefficients to six most sensitive organs and tissues multiplied by their respective weight factors are shown.

The results of calculation of CTDI for head phantom are shown in Table 1. Due to importance of each value number of starting histories for calculation of each CTDI value was $1.5 \cdot 10^7$.

Table 1 – CTDI values measured in body phantom and free-in air.

№	Quantity	Value, Gy/photon
1.	$CTDI_c$	$7,49 \cdot 10^{-17}$
2.	CTDI (3 o'clock)	$2,49 \cdot 10^{-16}$
3.	CTDI (6 o'clock)	$2,22 \cdot 10^{-16}$
4.	CTDI (9 o'clock)	$2,51 \cdot 10^{-16}$
5.	CTDI (12 o'clock)	$2,49 \cdot 10^{-16}$
6.	$CTDI_w$	$1,86 \cdot 10^{-16}$
7.	$CTDI_{air}$	$9,34 \cdot 10^{-16}$

In this case factor P_B is equals 0,2 which corresponds to the values measured in GE Max 640 CT scanner at 120 kV [7].

4. Discussion

As can be seen from Figure 1 the effective dose is rather non-homogenous quantity. The highest peak is at the distance 41 cm from top and is caused predominantly by so called remainder, the highest dose in this slice is to stomach. Lungs and breast are responsible for the major part of effective dose in chest region.

As seen from Figure 1, the conversion coefficient is always lower than 1. Therefore, $CTDI_w$ can be used for conservative estimation of effective dose during computed tomography examinations.

Doses estimated for computed tomography have several sources of uncertainties. The geometry of the beam is almost always unknown. The vertical positioning of patient relative to the CT scanner axis is somewhat arbitrary. These and other possible sources of errors have to be studied in further research.

5. Conclusions

To estimate doses from any given CT scanner one requires a database of only limited number of conversion coefficients. Measurement of computed tomography dose index free-in-air and in phantom provide an opportunity to estimate the dose to the patient.

References

1. Jones D G and Shrimpton P C 1991 Survey of the practice in the UK: Part 3. Normalized organ dose calculated using Monte Caro techniques National Radiological Protection Board NRPB R-250.
2. ICRP, 2009. Adult Reference Computational phantoms: ICRP Publication 110. Ann. ICRP 39 (2)
3. Waters L. MCNPX User's Manual, Version 2.6.0. Report No LA-CP-07-1473 (Los Alamos National Laboratory) (2008).
4. Ghita M. Computer Simulations to Estimate Organ Doses from Clinically Validated cardiac, neuro, and pediatric protocols for multiple detector computed tomography scanners (A dissertation). University of Florida, 2009. - 176 p.
5. ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103 / Ed. J. Valentin. // Ann. ICRP 37 (2-4).
6. ICRP, 2010. Conversion Coefficients for Radiological Protection Quantities for External Radiation Exposures // Ann. ICRP. Vol. 40, Issues 2-5, P. 1-258.
7. Bongartz G. European guidelines on Quality criteria for computed tomography. EUR 16262. Brussels: EU, 1997.

Реферат.

У разных моделей КТ сканеров отличаются радиационный выход, угол пучка и радиус траектории рентгеновской трубки и других характеристик. Для оценки органных доз от любого КТ сканера нужна огромная база данных с конверсионными коэффициентами. Эти коэффициенты могут быть рассчитаны путем компьютерного моделирования облучения от КТ сканера. Новый подход к оценке органных доз был предложен на основании того факта, что конверсионные коэффициенты, рассчитанные для различных компьютерных томографов имеют очень близкие значения при одинаковом напряжении на рентгеновской трубке.