Dose Reference Levels for Pediatric Thorax CT: Can Image Quality Be Achieved While Maintaining Dose Reduction for Different Body Mass Indices?

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Dose Reference Levels For Paediatric Thorax CT: Can Image Quality Be Achieved While Maintaining Dose Reduction For Different Body Mass Indices?

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ABSTRACT: Organ doses were calculated for diagnostic thorax CT, using data for 573 male Bangladeshi children from 0-10 years old, accounting for age and BMI. We have computed organ doses for an average male adult (170cm*70kg) undergoing a thorax CT examination using the ImPACT dose calculator and constructed ratios of organ dose to CTDIvol as a function of location of organs in the thorax, using a tube voltage of 120 kV for Siemens 64 slice CT scanner. BMIs are modelled as specific diameter water cylinders to obtain the factors for organ doses relative to the organ doses received by a reference adult. Results show that age operates a reduction in absorbed dose by a factor ranging from 0.33-0.79, which are consistent with other reference studies. Conversely, an increase of 1 BMI unit implies an increase in absorbed dose of up to 13%, to maintain the quality standards of diagnostic imaging.

Keywords: Dose Reference Levels, Paediatrics, Thorax CT, Dosimetry

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I. INTRODUCTION

The current Diagnostic Reference Levels (DRLs) are mean values for standard body sizes, which are generally adapted for paediatric patients. In practice, DRLs are higher than necessary in most European countries and there is a wide variation depending on equipment and training. One of the main reasons for this is the complexity of the dose optimization process, while maintaining diagnostic image quality for patients with a wide range of Body Mass Index (BMIs).
It is accepted that radiation dose must be as Low As Reasonably Practicable (ALARP) for younger children due to the risk of radiation-induced cancers, especially leukaemia arising from biological mechanisms such as high cellularity while accepting that image quality for the larger BMIs within this age group requires higher doses.
Since individual organ sizes vary with changes in body size, this is a key issue in countries with a high prevalence of obesity among children. Nevertheless, thorax is an anatomic region where the radiation dose can be significantly reduced due to high contrast between the natural structures such as mediastinal fat and air in the lungs. However, studies that calculate dose as a function of patient size typically use a phantom of 32 cm and, therefore, the availability of studies using real body size data is scarce. This study estimates both contributions of age and BMI to the amount of organ doses for diagnostic thorax computed tomography (CT) accounting for body sizes of 573 male Bangladeshi children from 0 to 10 years old. Indeed, it has been considered that dose estimations grounded on patient size are more accurate and should be used when size information is available (McCollough et al., 2014)

Previous studies. Some studies use x-ray attenuation, expressed in terms of a water-equivalent diameter to describe patient size using cylindrical phantoms for the standard 15 cm long, 16 cm diameter, and 32 cm diameter phantoms, and a 15 cm long, 10 cm diameter cylinder (Huda et al., 2000; Menke, 2005). These studies measure standard CTDI, using 16- and 64-slice CT scanners from GE, Philips, Siemens and Toshiba, across a range of 80-140 kV. They obtain measurements for the16 and 32 cm diameter phantom as a function of the phantom's water-equivalent, through regression models of the CTDI. Furthermore, using CT radiographs and CT images as well as measurement of the patient's lateral dimension using electronic calipers, the authors determined the water-equivalent diameters of chest pediatric patients. Then, scale factors that estimate the dose for a 15cm long phantom having the same water-equivalent x-ray attenuation as the patient were obtained from tables of normalized CTDI, as a function of patient lateral dimension.
Other studies measure 11 anthropomorphic torso phantoms, whose sizes range from newborn to adult, i.e, from LAT dimension 9 cm-39 cm. These studies add tissue-equivalent material on top of some phantoms to account for different body shapes. Exposures to four different CT scanner models (LightSpeed Ultra and VCT from GE Healthcare; and Sensation 16 from Siemens Healthcare) were measured by using a 0.6cc ion chamber and converted to dose to tissue (mGy) using an I-factor of 1.073 mGy [dose] / mGy [air kerma] or 9.37 mGy/R (McCollough et al., 2014)

A third group of studies study the effects of patient size on organ dose for CT exams using Monte Carlo simulations. One study uses 8 voxelized phantoms, representing a range of sizes from newborn to large adult (from 15-33 cm), including both males and females (Zankl et al., 2005). The scan length simulated for each Multi-detector CT scanners model, using the "equivalent source" method (Turner et al., 2010) is proportional to the scan length typical for each body size.
Organ doses were obtained using the Multi-detector CT approach (DeMarco et al., 2005) on the Monte Carlo N-Particle eXtended (v2.7.a) radiation transport code; While another study performs the dose simulation using a GE Lightspeed 16 scanner, with a tube voltage ranging 80 -140 keV, with 9.8 mm of added AI filtration, on cylindrical phantoms (Zou and Boone, 2008). The SIERRA Monte Carlo code system was developed to compute dose to extremely long cylinders of water, PMMA, and polyethylene, with diameters of 1-50 cm, accounting for 22 increments (Turner, 2011). The Monte Carlo code determined air kerma values for the 16 cm and 32 cm PMMA phantoms. The dose in water (or tissue) was computed as a function of cylindrical diameter and was divided by the CTD y measured in air.

II. MATERIAL AND METHODS

We use the ImPACT dose calculator based on Monte Carlo simulations to compute organ doses for an average male adult (170cm*70kg) undergoing a thorax CT examination. Using a tube voltage of 120 kV for Siemens 64 slice CT scanner, we construct ratios of organ dose to CTDIvol as a function of location of organs in the thorax.
In addition, we investigate the dose distributions in water cylinders simulating patients undergoing diagnostic thorax CT. Different BMIs are modelled as different diameter water cylinders in order to obtain the corresponding factors for organ doses in paediatric patients undergoing thorax examinations relative to the organ doses received by a reference adult.

The X-ray attenuation of a patient is expressed in terms of a water cylinder having the same x-ray absorption. BMIs are modelled as different diameter water cylinders to obtain the correspondent factors for organ doses to paediatric patients.

The area of the cylinder (*Aw)* can be represented in terms of attenuation values:

$$AW = \sum \left(\frac{CT\ (x,y)}{1000} + 1 \right)^{\alpha} * A_{pixel} \qquad (1)$$

Where, A_{pixel} *is* the area of a pixel in the CT image, CT(x, y) is the CT number of a voxel and α is the weight of the linear attenuation coefficients relative to water. We assume linear dependence, i.e., that α=1.

Aw can be calculated using the mean CT number within a region of interest (ROI). The ROI should be large enough to include the entire patient cross section, but not include irrelevant objects [e.g., patient table].

$$AW = \frac{1}{1000}\overline{CT\ (x,y)_{ROI}} * A_{ROI} + A_{ROI} \tag{2}$$

Where, $\overline{CT\ (x,y)_{ROI}}$ is the mean CT number in the ROI and A_{ROI} is the total area of the ROI

The diameter of cylinder (*Dw*) can be calculated from the mean CT number in an ROI containing that cylinder

$$DW = 2\sqrt{\left(\frac{1}{1000}\ \overline{CT\ (x,y)_{ROI}} + 1\right) + \frac{A_{ROI}}{\pi}} \tag{3}$$

The mean CT number is calculated using automatic segmentation algorithms. The average dose for each *Dw of* water cylinders was calculated using MCNP5.

Water cylinders of diameters ranging between 12 and 23 cm were used to simulate patients measuring between 9.80 and 21.63 cm (Table 1).

TABLE 1- Body measurements by age

Age	ED1	WE1	ED2	WE2
0	9.80	12	10.39	13
1	13.27	15	13.67	16
5	16.12	19	17.15	20
10	19.60	22	21.63	23

Notes: ED is the effective diameter; WE is the water equivalent. Source: own calculations

We obtain the radiation dose distributions inside the water cylinder using MCNP5. The depth dose distribution along the x-ray beam central axis was normalized to free-in-air air kerma (AK) that is incident on the phantom. Scattered radiation within the water cylinders- but outside the directly irradiated region- was normalized to the dose at the edge of the radiation field. We also have determined the total absorbed energy to the directly irradiated volume and indirectly irradiated volume and investigated it as a function of x-ray tube voltage and phantom size.

III. RESULTS AND DISCUSSION

Table 2 provides the ability to estimate the effective diameter as a function of patient age.

TABLE 2- Effective Dose chest CT, accounting for changes in body size

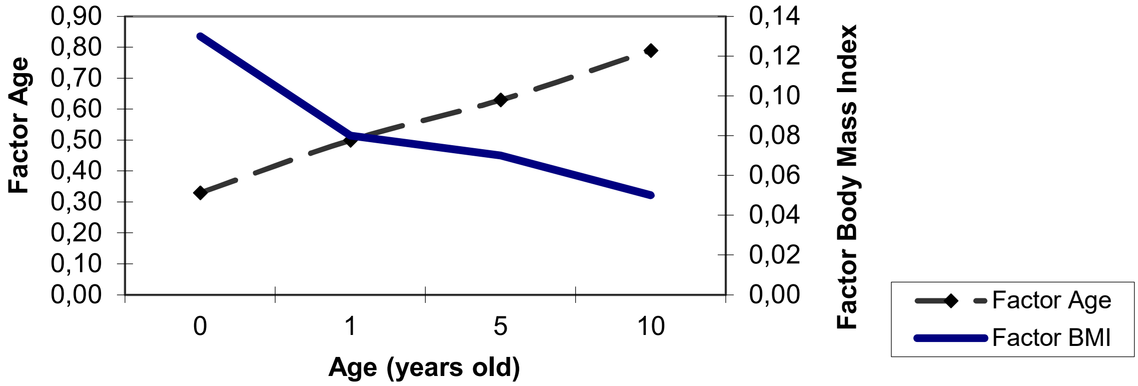
Age	ED1	Factor Age	ED2	WE1	WE2	ΔED
Adult	1.72					
10	1.36	0.79	1.41	12	13	0.05
5	1.08	0.63	1.15	15	16	0.07
1	0.86	0.50	0.94	19	20	0.08
0	0.57	0.33	0.70	22	23	0.13

Notes: ED is the effective diameter; WE is the water equivalent. Source: own calculations

The results show that age operates a reduction in absorbed dose by a factor ranging 0.33 to 0.79, which are consistent with the results of other reference studies.

Conversely, an increase of 1 BMI unit implies an increase in absorbed dose up to 13% in order to maintain the required image quality. Figure 1 combines the results regarding the factor *age* and factor *body mass index*. The relationship between these two factors are inverse

FIGURE 1- Effective dose (mSv), according to age and BMI factors in diagnostic thorax CT



Source: Own elaboration

These results are recommended to be used by the radiologists and or medical physicists working at an institution. However, our results were obtained using a tube voltage of 120 kV for Siemens 64 slice CT scanner. Any change in these parameters may drive to other results.

Limitations. This paper describes a method to *estimate* patient dose from CTDI, that is reasonable for use in thorax CT. However, applying the conversion factors, in practice, may cause errors. For example, due to magnification issues, if the lateral dimension is determined from the CT radiograph, a patient closer to the x-ray source will project a larger image than if positioned farther from the x-ray source.

IV. CONCLUSION

MCNP5 provides a potent tool to analyse the absorption and transmission of x-ray energy in phantoms that represent patients undergoing Radiological procedures. This characteristic allows for a systematic investigation of the relationship between patient dose and diagnostic image quality, and thereby keep patient doses As Low As Reasonably Achievable (ALARA). These findings encourage the construction of Dosimetry Tables for body mass indices within age groups.