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COMPARISON BETWEEN MEASURED AND CALCULATED EQUIVALENT DOSES IN CT USING ANTHROPOMORPHIC PEDIATRIC PHANTOMS

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Abstract: Due to the significant increase in pediatric trunk computed tomography (CT) examinations, there is a need for a reliable approach of conducting effective dose estimate for such procedures. The current study is based on two dosimetric anthropomorphic phantoms representing a 1-year and a 5-year old child. Effective and equivalent tissue doses from CT examinations of the trunk were determined by thermoluminescent dosimeters (TLDs) and the CT-Expo software. The results of the two investigated methods show good agreement.

Keywords: computed tomography, pediatric, effective dose, equivalent dose, anthropomorphic phantom

1. Introduction

Computed tomography (CT) examinations are becoming more widespread both for pediatric and adult patients, hence increasing the radiation detriment for the population. Children are the most radiosensitive group, with decreasing radiation risk with the age [1]. In order to assess the radiation risk of pediatric patients undergoing CT examinations, it is necessary to assess the equivalent (*H*) doses and estimate the effective (*E*) dose. One approach for this assessment is to use a dedicated software, such as CT-Expo [2], ImpactDose [3], ImPACT [4]. The currently most accessible of these was the CT-Expo (Sascrad, Germany) software. A simple and practical approach for the calculation of effective dose is based on the volume CT dose index ($CTDI_{vol}$) [5]. However, the conversion coefficients used to determine *E* from $CTDI_{vol}$ for specific body regions are only available for head, neck, thorax, abdomen, and pelvis. Hence, it is complicated to assess *E* for a CT-examination covering several anatomical regions. An alternative is to perform phantom studies for different types of CT examinations, where absorbed doses in radiosensitive organs and tissues are assessed using thermoluminescent dosimeters (TLDs) [6,7,8].
The aim of the current study was to assess the equivalent and effective doses for CT protocols used clinically for pediatric patients undergoing examinations of the trunk. For the 1-year-old and 5-years-old phantoms, equivalent and effective doses determined with TLDs were compared with doses assessed using the CT-Expo software. Conversion coefficients, *k*, from dose length product (*DLP*) to *E* for examination of the trunk were estimated.

2. Material and methods

2.1 Phantoms

The study was conducted using two anthropomorphic phantoms corresponding (Fig.1) to a 1-year-old and a 5-years-old pediatric patient (Riga, Latvia) [9].

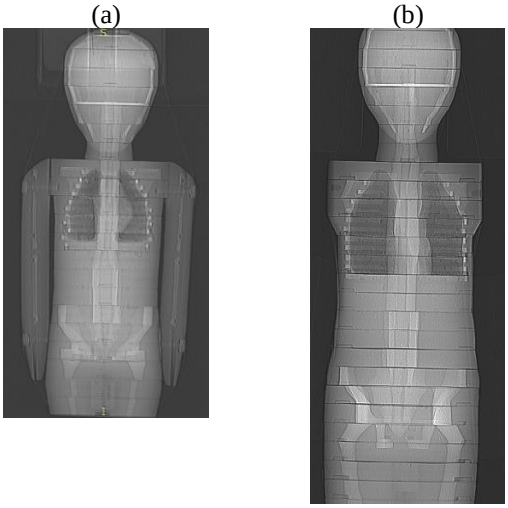

Fig 1. Full body CT 'surview' of the (a) 1-year-old pediatric phantom and (b) 5-years-old pediatric phantom.

The phantoms were filled with 134 and 176 TL detectors of lithiumflouride (LiF) for the 1-year-old and 5-years-old phantom, respectively. The TLDs were positioned in the dedicated holes, corresponding to the locations of the dosimetric relevant tissues and organs (Table 1). Twelve and ten dosimeters were attached externally to the front and side surface of the 1-year-old and the 5-years-old phantom, respectively, to measure the skin dose. Two TLDs were used to measure the background radiation.

Table 1. Tissues and organs of the anthropomorphic phantoms and the corresponding tissue weighting factors, ω_T, according to ICRP Publication 103. The number of TLDs used for each organ of the 5-year-old and 1-year-old pediatric phantoms are provided as well.

Tissue or organ	ω_T	Number of TLDs	
		1-year-old	5-year-old
Brain	0.01	4	4
Gonads	0.08	4	6
Stomach	0.12	5	10
Skin	0.01	12	10
Red marrow	0.12	19	29
Lung	0.12	22	28
Brest	0.12	2	2
Bladder	0.04	5	5
Liver	0.04	6	14
Oesop-hagus	0.04	1	6
Bone surface	0.01	25	28
Salivary glands	0.01	2	2
Colon	0.12	10	9
Thyroid	0.04	2	4
Other tissues	0.12	24	29

2.2 Thermoluminescent dosimeters (TLDs)

The tissue and organ absorbed doses were measured using TL detectors of DTG-4 (single-crystal lithium fluoride (LiF) chips doped with Mg and Ti) [10], with a thickness of about 1 mm and a diameter of 4.5 mm. The read-out was performed using a Harshaw (model 2000D) analyzer by first heating the LiF chips in the flow of high purity nitrogen to 340˚C. The annealing was performed at 400˚C for 1 h followed by 100˚C for 2 h. For measurement of the dose equivalent $H_p(0.07)$ for the skin, MKD-B detectors [10] consisting of TTLD-580 (homogeneous composition thermoluminescent material MgB_4O_7 and polyimide resin mark PM-1), with thickness about 10 mg/cm^2 (100 μm) and diameter of 9 mm, were used. The read-out of the MKD-B detectors was performed using a DVG-02TM TLD analyzer, by first heating the detectors to 100˚C and then by 8˚C/s heating to 250 ˚C, for 60 seconds, for signal acquisition. The annealing of these TLDs was performed at 250˚C during 1 h, and after that cooling down to room temperature. Both types of TLDs have an uncertainty of 20% of the acquired signal.

2.3 CT scan

Both of the pediatric phantoms were scanned on a Philips Ingenuity Helthcare (128 slice) CT. The CT protocols applied were the same as clinically used for pediatric patients undergoing examinations of the trunk. To minimize the uncertainties each phantom was exposed 3 times, in helical mode with a pitch of 1.015, using the same parameters. The scan parameters for the 1-year-old and 5-year-old phantoms are presented in Table 2.

Table 2. Pediatric CT protocols used in the study of the both pediatric phantoms.

Parameter	1-year-old	5-year-old
U (kV)	80	100
mAs *	95	95
Collimation (mm)	64×0.625	64×0.625
Time per tube rotation (s)	0.4	0.4
Pitch	1.015	1.015
Scan length (mm)	519	623
$CTDI_{vol}$ ** (mGy)	1.8	3.7
DLP (mGy·cm)	106	408

* *mA modulation was turned off.*
** *$CTDI_{vol}$ was determined for 320 mm diameter PMMA body phantom.*

A 'surview' prior to the examination was acquired for planning of the examination length. The 'surview' dose was not considered while assessing the DLP for the examination.

2.4 Data processing

The TLDs were used for direct tissue and organ doses. The signal from each TLD was corrected by background and was averaged for the three scans. The absorbed dose for a specific tissues (T), D_T, was determined as a mean value from all TLDs in the tissue. Equivalent dose, H_{TLDs} (Table 2), was calculated using the mean absorbed dose deposited in a specific tissue or organ (T), multiplied by a radiation weighting factor, ω_R, from ICRP Publication 103 [11]. The effective dose E_{TLDs} was estimated as:

$$E_{TLDs} = \sum_T \omega_T \left[\frac{H^M_{TLDs}+H^F_{TLDs}}{2}\right] \quad (1)$$

where ω_T is the tissue weighting factor from ICRP Publication 103 (Table 1), H^M_{TLDs} and H^F_{TLDs} are the organ equivalent doses of male and female, respectively.

In addition, the CT-Expo software was also used for calculating the equivalent and effective doses, $H_{CT\text{-}Expo}$ and $E_{CT\text{-}Expo}$. The 'baby' and 'child' age groups were selected in this software for representing the 1-year-old and 5-years-old phantoms, respectively. The equivalent dose assessment was carried out for comparison, but not for estimating radiation detriment.

The relative differences (RD_H and RD_E) was established to compare the both methods. The RD_H was defined as

the ratio of the differences between $H_{CT\text{-}Expo}$ and H_{TLDs} to $H_{TLDs,}$ multiplied by 100%. The RD_E was defined as the ratio of the differences between $E_{CT\text{-}Expo}$ and E_{TLDs} to $E_{TLDs,}$ multiplied by 100%, for both male and female.

3. Results and discussions

The equivalent and effective doses for the pediatric CT examination of the trunk are shown in Table 3. The highest equivalent doses were observed in the thyroid, skin, male gonads and female breast both for the 1-year-old and 5-years-old pediatric phantoms. The equivalent doses assessed by the CT-Expo software have a good agreement with doses estimated by the TLDs but are lower for all tissues and organs except for the bone surface for both phantoms, as well as colon, bladder and female gonads for the 1-year-old phantom. A difference between the both methods of less than 2% in the organ equivalent doses was observed for: stomach, RBM, bladder (1-year-old phantom); bladder, female gonads, colon (5-years-old phantom).

Due to difficulties of determining the absorbed dose in bone surface, RD_H is 178% for the 1-year-old phantom and 166% for the 5-years-old phantom, respectively. This can be explained by the fact that the TLDs used to define the bone surface dose were positioned inside the bone in combination with a limited number of dedicated holes in the phantoms.

Table 3. The tissue and organs of the 5-years-old and the 1-year-old pediatric phantoms and the corresponding equivalent doses determined by TLDs H_{TLDs} (mSv), equivalent doses assessed by CT-Expo $H_{CT\text{-}Expo}$ (mSv), relative differences between equivalent doses determined by two methods RD_H.

Tissue or organ	1-year-old						5-years-old					
	Male			Female			Male			Female		
	H_{TLDs}	$H_{CT\text{-}Expo}$	RD_H	H_{TLDs}	$H_{CT\text{-}Expo}$	RD_H	H_{TLDs}	$H_{CT\text{-}Expo}$	RD_H	H_{TLDs}	$H_{CT\text{-}Expo}$	RD_H
Brain	4.0	3.6	-11%	4.0	3.6	-11%	7.2	6.5	-10%	7.2	6.5	-10%
Gonads	5.0	4.2	-16%	4.1	4.4	8%	8.8	8.4	-5%	7.1	7.0	-1%
Stomach	4.3	4.3	0%	4.3	4.3	0%	8.1	7.7	-5%	8.1	7.7	-5%
Skin	5.2	3.9	-24%	5.2	3.9	-24%	9.2	7.8	-15%	9.2	7.8	-15%
RBM*	3.8	3.7	-2%	3.8	3.7	-2%	6.9	5.8	-16%	6.9	5.8	-16%
Lung	4.6	4.1	-12%	4.6	4.1	-12%	8.4	7.2	-15%	8.4	7.2	-15%
Breast	-	-	-	5.8	4.0	-30%	-	-	-	8.9	7.9	-11%
Bladder	4.3	4.4	2%	4.3	4.4	2%	7.3	7.3	0%	7.3	7.3	0%
Liver	4.3	4.2	-3%	4.3	4.2	-3%	7.8	7.4	-5%	7.8	7.4	-5%
Oesophagus	5.0	3.8	-25%	5.0	3.8	-25%	8.4	6.7	-20%	8.4	6.7	-20%
Bone surface	4.4	12.3	178%	4.4	12.3	178%	7.8	20.8	166%	7.8	20.8	166%
Salivary glands	4.2	4.1	-3%	4.2	4.1	-3%	8.4	7.6	-9%	8.4	7.6	-9%
Colon	3.7	4.3	15%	3.8	4.3	14%	7.6	7.5	-2%	7.6	7.5	-2%
Thyroid	5.5	4.6	-16%	5.5	4.6	-16%	9.9	8.4	-16%	9.9	8.4	-16%
Other tissues	4.2	3.8	-9%	4.2	3.8	-8%	7.7	6.9	-10%	7.7	6.9	-11%

**Red bone marrow*

In terms of the effective dose assessments, the RD_E equals to -19% and -7% for the male and female 1-year-old phantom, respectively, and -13% and -1% for the male and female 5-years-old phantom, respectively (Table 4). The underestimation of the effective dose was higher for the male phantom used in the CT-Expo software, whereas the agreement for the female phantoms was good.

Conversion coefficients, *k*, from the console DLP (Table 1) to the effective dose were calculated based on the TLD measurement. The results are shown in Table 4. It is important to consider both the *DLP* from the console and size of the PMMA phantom that was used to determine the *DLP*. In our study the $CTDI_{vol}$ and *DLP* were determined for a 320 mm diameter PMMA body phantom.

The results of the current study have a good agreement with the data from the AAPM Report №96 [12] for the 5-years-old phantom but are significantly higher for the 1-year-old phantom.

Table 4. The effective doses estimated by TLDs E_{TLDs} (mSv), and by CT-Expo $E_{CT\text{-}Expo}$ (mSv), *DLP* to E_{TLDs} conversion coefficients, *k* (mSv/mGy·cm) for trunk CT examinations for two groups of pediatric patients for a 320 mm of PMMA phantom. Comparison with the data from the AAPM Report №96 is provided.

Quantity		**1-year-old**	**5-year-old**
E_{TLDs}		4.1	7.5
$E_{CT\text{-}Expo}$	Male	3.3	6.5
	Female	3.8	7.4
RD_E	Male	-19%	-13%
	Female	-7%	-1%
k	This study	0.039	0.018
	AAPM Report №96 [12]	0.028	0.019

4. Conclusions

Comparison of the equivalent and effective doses determined by computational and TLD assessment methods shows good agreement. That validates the use of the CT-Expo software for CT dose assessment. Based on the effective doses estimated with TLDs, conversion coefficients from *DLP* to *E* for CT examination of the trunk for two groups of pediatric patients have been established. The use of conversion coefficients for pediatric CT examinations should be based on correct sized phantoms as there is a potential for underestimation of the effective dose with up to a factor of two. Future studies would be focused on determining the conversion coefficients for other complex CT-examinations and patient age groups.

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