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FULL PAPER

Local diagnostic reference levels in pediatric CT examinations: a survey at the largest children's hospital in Greece

¹AGAPI PLOUSSI, MSc, ²VASILEIOS SYRGIAMOTIS, MSc, ²TRIANTAFILLIA MAKRI, PhD,
²CHRISTIANA HATZIGIORGI, PhD and ¹EFSTATHIOS P. EFSTATHOPOULOS, PhD

¹2nd Department of Radiology, University General Hospital 'Attikon', School of Medicine, National and Kapodistrian University of Athens, 12462, Athens, Greece

²Department of CT-MRI, Children's Hospital Agia Sophia 11527, Athens, Greece

Address correspondence to: Prof Efstathios P. Efstathopoulos
E-mail: stathise@med.uoa.gr

Objectives: The increased frequency of pediatric CT examinations and the high radiosensitivity of children entail the need to determine DRLs and optimize CT protocols. The aim of the study was twofold. Firstly, to establish pediatric LDRLs according to age and weight for the most common types of CT examinations at the largest children's hospital in Greece. Secondly, to compare LDRLs with European DRLs.

Methods: A total of 756 pediatric patients who underwent head, chest, and abdomen-pelvis CT examinations were included. Patients were categorized into age groups according to the hospital's protocols. All CT examinations were performed using iterative reconstruction algorithm and AEC. LDRLs were determined in terms of 75th percentile of CTDIvol and DLP. Values of LDRLs were subsequently regrouped into weight categories and compared with European DRLs.

Results: Gathering all age groups for head CT examinations and all weight groups for body CT examinations, LDRLs were ranged from (22-68, 2-5, 2-10) mGy in terms of CTDIvol; (317-786, 22-168, 58-425) mGy.cm in terms of DLP per acquisition and (324-838, 42-265, 85-498) mGy.cm in terms of total DLP for head, chest and abdomen-pelvis CT examinations, respectively.

Conclusion: CTDI LDRLs were comparable to European DRLs for head and either comparable or lower than European DRLs for body CT examinations. DLP LDRLs were higher than European DRLs for head and lower for body CT examinations.

Advances in knowledge: Age- and weight-based LDRLs for pediatric CT examinations were established for the largest children's hospital in Greece. Further investigations across the country are required for the establishment of national pediatric DRLs in Greece.

INTRODUCTION

The increased frequency of pediatric CT examinations the last 20 years has raised serious concerns regarding the exposure of pediatric population to ionizing radiation. Larson et al.¹ reported a 4.8 increase in the number of CT examinations of children who visit the Emergency Departments in the USA the period 1995–2008 whereas a study in eight Catalan hospitals showed that the total number of CT scans in children and young adults increased by approximately 50% from 2004 to 2013.² Similarly, a multi-center French study conducted during 2000 to 2006, found a significant increase of about 15% in the use of CT examinations performed in the early childhood with the mean number of CT scans per child amount to 1.6 (range 1–43).³

Recent epidemiological studies have demonstrated an increased cancer risk in children who underwent CT scans.

Pearce et al. showed a positive correlation between radiation dose from brain CT scans in childhood and the incidence of leukemia and brain tumors.⁴ Additionally, Mathews et al. revealed that the overall cancer incidence was 24% greater for people exposed to CT scans in childhood or adolescent than unexposed people.⁵ Although the aforementioned studies have received strong criticism due to the lack of personalized dosimetry and clinical indication ("reverse causation"), in any case, it is of great importance to justify and optimize pediatric CT imaging.^{6,7}

The need for CT optimization is more acute in pediatric population since children have a longer life expectancy and a much higher radiosensitivity with respect to leukemia, thyroid and brain cancer than adults.⁸ In addition, CT optimization is more challenging in children compared

to adults because scan parameters should be adjusted to a wide range of body sizes.

Among the various techniques for optimizing CT protocols (kVp switch, automatic exposure control (AEC), iterative reconstruction algorithms, etc.), diagnostic reference levels (DRLs) have proved to be a valuable and effective tool in the optimization process. The term "DRL" was first introduced by the International Commission on Radiological Protection (ICRP) in 1996⁹ and further guidance was provided in 2001.¹⁰ As determined in the recently published ICRP135,¹¹ DRL "is a form of investigation level used as a tool to aid in optimization of protection in the medical exposure of patients for diagnostic and interventional procedures. It is used in medical imaging with ionizing radiation to indicate whether, in routine conditions, the amount of radiation used for a specified procedure is unusually high or low for that procedure." More specifically, local DRLs (LDRLs) are based on the third quartile (the 75th percentile) value of the distribution of patient doses obtained from radiology departments in a single large healthcare facility or a group of healthcare facilities, for a defined clinical imaging task (*i.e.*, common indication-based protocol) surveyed for standardized patient groupings.¹² On the other hand, National DRLs (NDRLs) are based on the third quartile (the 75th percentile) value of the median (the 50th percentile) values of the distributions of patient doses obtained from a representative sample of radiology departments in the country, for a defined clinical imaging task (*i.e.*, common indication-based protocol) surveyed for standardized patient groupings, whereas European DRLs (EDRLs) are defined as the median (the 50th percentile) value of the distribution of the NDRLs for a defined clinical imaging task (*i.e.* common indication-based protocol) surveyed for standardized patient groupings.¹²

The main objective of DRLs is to ensure that radiation dose is as low as reasonably achievable without compromising diagnostic image quality for a specific imaging task.

The goal of the current study was to establish age- and weight-based LDRLs in pediatric head, chest and abdomen-pelvis CT

examinations performed at the largest children's hospital in Greece and, in addition to compare the LDRLs with the EDRLs as presented in the European Guidelines on DRLs for Pediatric Imaging (RP 185).¹²

METHODS AND MATERIALS

Patient population

The study included a cohort of 756 pediatric patients (under 15 years old) who underwent head, chest, and abdomen-pelvis CT examinations at a dedicated children's hospital from March 2016 to February 2017. Pediatric population was categorized into age groups according to the Department's protocols. Patient-related data including gender, age, weight and height as well as the most common clinical indications for each type of CT examinations were retrospectively collected from the hospital's Picture Archiving and Communication System (PACS) and log-book records. The aforementioned data are summarized in Table 1.

CT data acquisition

All patients were scanned on a 16 multidetector CT (MDCT) (Brightspeed, GE Healthcare, Milwaukee, Wisconsin) with a blend of 60% adaptive statistical iterative reconstruction (ASIR, GE Healthcare, Waukesha, WI, USA) and 40% filtered back projection (FBP). CT examinations were performed using combined AEC technique in both xy and z planes. For each type of examination kV, mAs, slice thickness, rotation time, noise index, and detector configuration were recorded. The scan acquisition parameters are presented in Table 2.

Head CT scans were performed using a 2.5-mm slice thickness from the skull base (including foramen occiput) to cerebellum tentorium and a 5-mm slice thickness from cerebellum tentorium to vertex. For the chest, the scan region was defined from the thoracic inlet to the thoracic diaphragm, whereas for the abdomen-pelvis examinations from the thoracic diaphragm to the pelvic inlet. Noise index, an indicator for the desired image noise level was defined according to the manufacturer recommendations and a previous image quality evaluation from

Table 1. Patient-related data and clinical indications

CT Examination	Age group	Clinical indication	Number of examinations	Number of acquisitions	Male/Female	Age (y)	Weight (kg)	Height (m)
Head	0- < 18 months	Trauma, Tumor, Ventricular size, Headache, Epilepsy	73	78	47/26	0.5 ± 0.5	8.6 ± 8.8	0.7 ± 0.2
	18months- <5y		92	106	58/34	3.2 ± 1.1	14.7 ± 5.4	1.0 ± 0.2
	5-15		316	350	192/124	9.9 ± 3.0	39.2 ± 16.0	1.4 ± 0.2
Chest	0- < 5y	Tumor, Infection, Cystic fibrosis, Injury, Pneumothorax, Anatomic abnormalities	57	84	39/18	2.4 ± 1.6	11.5 ± 5.4	0.9 ± 0.2
	5-15y		156	200	97/59	11.3 ± 3.4	45.4 ± 19.7	1.5 ± 0.2
Abdomen-Pelvis	0- < 5y	Tumor, Injury, Pain, Fever, Infection	20	36	9/11	2.3 ± 1.6	12.9 ± 5.3	0.9 ± 0.3
	5-15y		42	68	16/26	10.4 ± 3.1	41.4 ± 16.7	1.4 ± 0.2

Data are mean value ± standard deviation.

Table 2. Acquisition parameters

CT Examination	Age group	Mode	kV	mAs (range)	Slice thickness (mm)	Rotation Time (s)	Noise index	Beam collimation (mm)
Head	0- < 18 months	Axial	100	110–285	2.5/5.0	1	4.37	16 × 1.25
	18months-<5y		120	114–300	2.5/5.0	1	4.37	16 × 1.25
	5–15y		120	129–350	2.5/5.0	1	4.37	16 × 1.25
Chest	0- < 5y	Helical	100	24–109	2.5	0.5	15.86	16 × 1.25
	5–15y		120	24–269	5.0	0.8	16.20	16 × 1.25
Abdomen-Pelvis	0- < 5y	Helical	100	25–40	2.5	0.5	11.57	16 × 1.25
	5–15y		120	25–260	5.0	0.8	16.20	16 × 1.25

experienced radiologists. Different noise indices were selected for the different age groups (different sizes). The use of AEC technique adjusted the tube current according to the predefined noise index and the patient's size. As younger children have smaller structures, a higher image quality (less noise) was determined for smaller children (<5 years) compared to older ones in the body region.

Concerning image quality, all CT examinations had previously been evaluated by one experienced radiologist on a two point scale: 1 = diagnostic, 2 = non-diagnostic (unacceptable).

Radiation dose assessment

According to recent reports and guidelines,^{11,12} both CTDIvol and DLP are recommended quantities for the establishment of DRLs in CT. In the current study, CTDIvol, DLP per acquisition, and total DLP were recorded for each examination from the CT dose report. CTDIvol for head CT examinations was based on the 16-cm-diameter phantom while for body CT examinations (chest and abdomen-pelvis) on the 32-cm-diameter phantom. LDRLs were determined in terms of the 75th percentile of CTDIvol, DLP per acquisition and total DLP. The accuracy of CTDI values was verified during the CT quality control.

COMPARISON WITH EUROPEAN DRLS

According to RP185,¹² EDRLs are presented as age-based data for head CT examinations and as weight-based data for body CT examinations. In an effort to directly compare our LDRLs with the EDRLs, patients were regrouped into the proposed age and weight categories for head and body CT examinations, respectively.

RESULTS

Patient population

Among the 756 pediatric patients included in the study, 459 (61%) were male and 297 (39%) female. Regardless the type of CT examination, the highest number of CT scans was observed in the 5–15 years age group. Head CT was the most frequently requested examination (481 of 756 examinations, 64%) followed by chest (213 of 756 examinations, 28%) and abdomen-pelvis (62 of 756 examinations, 8%). Multiphase examinations (including acquisitions with and without contrast enhancement) were performed in about 22% of children.

The most common clinical indication for head CT examinations included the evaluation of ventricular size in 0- < 18 months age group and head trauma in elder groups. Body CT examinations (chest and abdomen-pelvis) were most frequently requested for evaluation or suspicious of malignancy, regardless of age.

CT data acquisition

All CT images were diagnostically acceptable.

Radiation dose assessment

The proposed rounded LDRLs according to age are summarized in Table 3. It is noted that the measured CTDI values were within 20% of the values reported on the scanner console.

COMPARISON WITH EUROPEAN DRLS

Table 4 displays the proposed LDRLs according to weight in relation to the EDRLs as presented in RP 185.¹² EDRLs values concern a single acquisition.

DISCUSSION

The current study reports LDRLs according to patient age and weight for the most common types of pediatric CT examinations and additionally, provides a straightforward comparison between LDRLs and pediatric EDRLs. National pediatric DRLs for CT examinations have not yet been established in Greece. Therefore, DRLs obtained in this investigation can make a significant contribution to the establishment of national DRLs.

The study provides both DLP per acquisition and total DLP for the entire examination. This is especially important in order to have an estimation of the radiation dose received by patients during CT examinations. For example, two-phase CT examinations (with and without contrast enhancement) were performed in approximately 68% of children underwent abdomen-pelvis CT examinations. Consequently, in these cases, total DLP was approximately double that of DLP per acquisition.

Our study revealed that multiphase CT examinations (before and after contrast administration) constitute 22% of the total CT examinations and 68% of abdomen-pelvis CT examinations. As children are at higher risk of developing radiation-induced cancer compared to adults and they are often undergo multiple examinations using ionizing radiation,¹³ multiphase CT

Table 3. 75th percentile of CTDIvol, DLP per acquisition, and total DLP for each type of CT examination according to age

CT Examination	Age group	Number of exams	Number of acquisitions	75 th percentile		
				CTDIvol _a (mGy)	DLP per acquisition (mGy.cm)	Total DLP (mGy.cm)
Head	0- < 18 months	73	78	27b/23c	337	409
	18months-<5y	92	106	49b/35c	589	622
	5-15 y	316	350	68b/46c	778	828
Chest	0- < 5y	57	84	2	40	58
	5-15y	156	200	4	128	147
Abdomen-Pelvis	0- < 5y	20	36	2	67	132
	5-15y	42	68	3	131	237

CTDIvol: CT volume index, DLP: Dose Length Product

^aCTDIvol for head CT examinations was based on the 16-cm-diameter phantom and for body CT examinations on the 32-cm-diameter phantom

^bCTDIvol using a slice thickness of 2.5mm

^cCTDIvol using a slice thickness of 5.0 mm

examinations should be avoided in pediatric population. If additional evaluation of a lesion is required, alternative non-ionizing techniques such as ultrasound or magnetic resonance imaging (MRI) should be considered.

The comparison of DRLs in pediatric imaging is a challenging task, primarily due to the lack of standardization in patients

grouping (different categories based usually on age or weight, and different bands). So far, the most common classification of grouping pediatric patients is based on a set of five age groups (0, 1, 5, 10, and 15 years).¹² However, since children cover a wide range of body sizes even kids of the same age categorization of pediatric population according to weight is considered more representative. The recently published RP 185¹² recommends

Table 4. 75th percentile of CTDIvol, DLP per acquisition, and total DLP for each type of CT examination according to weight compared with the EDRLs.¹²

CT Examination	Group	Number of exams	Number of acquisitions	Current study			EDRLs ¹²	
				CTDIvol _a (mGy)	DLP per acquisition (mGy.cm)	Total DLP (mGy.cm)	CTDIvol _a (mGy)	DLP per acquisition (mGy.cm)
Head	0- < 3 months	40	43	27b/22c	317	324	24	300
	3 months - < 1y	-	-	-	-	-	28	385
	1- < 6y	158	177	50b/36c	596	631	40	505
	≥6y	283	314	68b/46c	786	838	50	650
Chest	<5kg	10	16	2	22	42	1.4	35
	5- < 15kg	32	48	2	41	61	1.8	50
	15- < 30kg	52	67	2	44	61	2.7	70
	30- < 50kg	57	69	3	86	110	2.7	115
	50- < 80kg	49	64	5	168	265	5.4	200
Abdomen-Pelvis	<5kg	-	-	-	-	-	-	45
	5- < 15kg	11	21	2	58	85	3.5	120
	15- < 30kg	18	30	2	78	149	5.4	150
	30- < 50kg	21	37	3	116	226	7.3	210
	50- < 80kg	10	14	10	425	498	13	480

CTDIvol: CT volume index, DLP: Dose Length Product

^aCTDIvol for head CT examinations was based on the 16-cm-diameter phantom and for body CT examinations on the 32-cm-diameter phantom

^bCTDIvol using a slice thickness of 2.5mm

^cCTDIvol using a slice thickness of 5.0 mm

^dno available data due to the small patient sample size (<10 patients)

that head CT protocols should be determined based on patients' age and body CT protocols based on patients' weight, as presented in Table 4. Comparison of DRLs must be conducted between the same patient groupings. If this is not feasible and until the implementation of weight-based protocols in clinical routine, age-based DRLs can be compared with weight-based DRLs using weight-to-age equivalent data.¹² Nonetheless, this approach introduces uncertainties.

An alternative methodology to present and compare DRLs, mainly for limited sample sizes, is by providing a DRL curve, which presents DLP (or CTDI) as a function of the patient age or weight. For the comparison of LDRLs with the DRL curve, instead of presenting discrete age or weight bands, one can use a small number of patients (*e.g.*, 10 patients) regardless age or weight and insert these data points on the DRL curve. If the majority of the points lie under the curve then DRLs are not exceeded.¹² Jarvinen *et al*¹⁴ have proposed DRLs for pediatric body CT examinations as DRL-curves.

An additional weakness in comparing DRLs is that in some pediatric studies, CTDIvol is based on the 16-cm-diameter phantom for both head and body CT examinations.¹² As a consequence, the comparison of DLP and CTDI with previously published DRLs is direct for head examinations; however, it becomes more difficult for body examinations.

In the current study, patients were categorized into age groups according to the Hospital's protocols and, subsequently regrouped into weight categories to compare with EDRLs in a straightforward way. According to our results, for head CT examinations, CTDIvol LDRLs values are comparable with EDRLs (above or slightly below depending on slice thickness), whereas DLP LDRLs values are higher than EDRL values, indicating that higher scan lengths used in our study. For chest CT examinations, CTDIvol LDRLs are comparable within significant figures with EDRLs while for abdomen-pelvis CT examinations CTDIvol LDRLs are lower than EDRLs. In terms of DLP, LDRLs values are below the EDRLs for both chest and abdomen-pelvis CT examinations. In an effort to reduce radiation exposure in children undergoing head CT studies, an optimization process, based on the age categories proposed by RP 185¹², is already being conducted in our Department.

The latest reported pediatric DRLs in Greece were published about a decade ago by Yakoumakis *et al*.¹⁵ The study based on cylindrical phantoms, included 12 hospitals and the three most frequently performed CT examinations (brain, thorax and abdomen). The authors found that for the 5-year-old children category, DLP was 650, 336, and 840 mGy/cm for brain, thorax, and abdomen CT examinations, respectively, whereas for the 10-year-old children category, DLP recorded 975, 578, and 1120 mGy/cm, respectively. Although the comparison with previous

published data from our country would be interesting, the different patient grouping makes it difficult to perform.

Along with the patient grouping, RP 185¹² proposed also a methodology for the establishment of pediatric DRLs, providing in detail all dosimetric quantities and technical parameters required for the establishment of DRLs. According to the guidelines,¹² CTDIvol and DLP are the basic DRL quantities. CTDIvol and DLP should be determined for a 32 cm phantom for body CT examinations and for a 16 cm phantom for head CT examinations. The use of size-specific dose estimates (SSDE) is also encouraged for body CT examinations.

DRLs should be evaluated taking into consideration the image quality. Image quality and number of acquisitions are strongly associated with the specific imaging task. Therefore, it is of significant importance the establishment of DRLs based on clinical indication. UK and Finland have already proposed indication-based DRLs.^{14,16} In addition, Wagner *et al*,¹⁷ in a newly published article, presented national DRLs for neuro-pediatric CT examinations based on medical indication.

The establishment, use, and regular review of DRLs for radiodiagnostic examinations is also highlighted in the new Basic Safety Standard Directive 2013/59 Euratom.¹⁸ Studies have shown that the collection of DRLs on periodic basis facilitates the optimization process. More specifically, Roche *et al*¹⁹ found that DRLs for adult CT examinations were approximately 35% lower in relation to the latest recorded DRLs, whereas Shrimpton *et al*²⁰ demonstrated a 10–40% reduction in pediatric CT DRLs comparing with previous values.

CONCLUSION

The implementation of DRLs is considered an efficient tool for the management of radiation dose and the optimization of CT protocols. The regrouping of patients into weight categories allowed a direct comparison with the EDRLs. For head CT examinations, CTDIvol LDRLs were comparable with European DRLs (higher or lower depending on slice thickness), whereas DLP LDRLs exceeded the corresponding European DRLs. For body CT examinations, CTDIvol LDRLs were either comparable or lower than European DRLs and DLP LDRLs were below the European DRLs. In an attempt to reduce radiation doses in head CT examinations and comply with the guidelines,¹² we have already started to modify the Department's CT protocols according to the proposed patient grouping and the clinical indication, as well. Although multiphase CT examinations should be avoided in children, the record of both DLP per acquisition and total DLP is essential in order to have an estimation of the patients' radiation exposure and cancer risk. Since pediatric DRLs are not currently available in Greece, further investigations should be conducted across the country to establish national pediatric DRLs.

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