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Research Article

Expansion of Typical Values for Paediatric Patients in Ireland and Comparison with Published DRLs - Experiences of a Single Institution

Andrew Lyons[a], Ali Mohammed Ali[b], Andrew England[a,*], Niamh Moore[a], Rena Young[a], Brid Leamy[c], Winnie Tam[d], Paul Bezzina[e], Napapong Pongnapang[f] and Mark F. McEntee[a]

[a] *Discipline of Medical Imaging & Radiation Therapy, University College Cork, Cork, Ireland*
[b] *Department of Medical Physics, College of Applied Medical Sciences, University of Kerbala, Karbala, Iraq*
[c] *Department of Radiology, Cork University Hospital, Cork, Ireland*
[d] *Department of Radiography, City, University of London, London, UK*
[e] *Department of Radiography, University of Malta, Msida, Malta*
[f] *Department of Radiological Technology, Mahidol University, Bangkok, Thailand*

ABSTRACT

Introduction: To reduce the risks involved with ionising radiation exposure, typical values (TVs) and diagnostic reference levels (DRLs) have been established to help keep radiation doses ‘as low as reasonably practicable. TVs/DRLs provide standardised radiation dose metrics that can be used for comparative purposes. However, for paediatrics, such values should consider the size of the child instead of their age. This study aimed to establish and compare paediatric TVs for chest, abdomen and pelvis radiography.

Methods: Study methods followed processes for establishing paediatric DRLs as outlined by the Health Information and Quality Authority (HIQA). Kerma-area product (KAP) values, excluding rejected images, were retrospectively acquired from the study institution's Picture Archiving and Communications System (PACS). Paediatric patients were categorised into the following weight-based groupings (5 to <15 kg, 15 to <30 kg, 30 to <50 kg, 50 to 80 kg) and stratified based on the examination that was performed (chest, abdomen, and pelvis), and where it was performed (the different X-ray rooms). Anonymised data were inputted into Microsoft Excel for analysis. Median and 3rd quartile KAP values were reported together with graphical illustrations.

Results: Data from 407 X-ray examinations were analysed. For the previously identified weight categories (5 to <15 kg, 15 to <30 kg, 30 to <50 kg, 50 to 80 kg), TVs for the chest were 0.10, 0.19, 0.37 and 0.53 dGy.cm^2, respectively. For the abdomen 0.39, 1.04, 3.51 and 4.05 dGy.cm^2 and for the pelvis 0.43, 0.87, 3.50 and 7.58 dGy.cm^2. Between X-ray rooms TVs varied against the institutional TVs by -60 to 119 % (chest), -50 to 103 % (abdomen) and -14 and 24 %% (pelvis).

Conclusion: TVs in this study follow established trends with patient weight and examination type and are comparable with published literature. Variations do exist between individual examination rooms and reasons are multifactorial. Given that age and size do not perfectly correlate further work should be undertaken around weight-based TVs/DRLs in the paediatric setting.

RÉSUMÉ

Introduction: Pour réduire les risques liés à l'exposition aux rayonnements ionisants, des valeurs typiques (VT) et des niveaux de référence diagnostiques (NRD) ont été établis pour aider à maintenir les doses « au niveau le plus bas raisonnablement possible ».

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* Corresponding author at: Discipline of Medical Imaging & Radiation Therapy, University College Cork, Assert Building, Brookfield Health Sciences Complex, College Road, Cork, Ireland.

E-mail address: aengland@ucc.ie (A. England).

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Les VT/NRD fournissent des doses de rayonnement standardisées qui peuvent être utilisées à des fins de comparaison. Toutefois, en pédiatrie, ces mesures devraient tenir compte de la taille de l'enfant plutôt que de son âge. Cette étude visait à établir et à comparer les VT pédiatriques pour la radiographie du thorax, de l'abdomen et du bassin.

Méthodologie: Les méthodes de l'étude ont suivi les processus d'établissement des NRD pédiatriques décrits par la Health Information and Quality Authority (HIQA). Les valeurs du produit Kerma-Area (KAP), à l'exclusion des images rejetées, ont été obtenues rétrospectivement à partir du système d'archivage et de communication d'images (PACS) de l'institution étudiée. Les patients pédiatriques ont été classés dans les catégories d'âge suivantes (1 mois *à* <4 ans,; 4 *à* <10 ans, 10 *à* <14 ans, 14 à 16 ans) et stratifiés en fonction de l'examen effectué (thorax, abdomen et bassin) et de l'endroit où il a été effectué (les différentes salles de radiologie). Les données anonymisées ont été saisies dans Microsoft Excel pour l'analyse. Les valeurs médianes et du 3e quartile de KAP ont été rapportées avec des diagrammes à barres.

Résultats: Les données de 407 examens radiologiques ont été analysées.

Pour les catégories d'âge précédemment identifiées (1 mois *à* <4 ans, 4 *à* <10 ans, 10 *à* <14 ans, 14 à 16 ans), les valeurs VT pour le thorax étaient de 0,10, 0,19, 0,37 et 0,53 dGy.cm^2. Pour l'abdomen, elles étaient respectivement de 0,39, 1,04, 3,51 et 4,05 dGy.cm^2 et pour le bassin de 0,43, 0,87, 3,50 et 7,58 dGy.cm^2. Entre les salles de radiologie, les VT varient par rapport à la VT institutionnelle de -60 à 119% (thorax), -50 à 103% (abdomen) et -14 à 24% (bassin).

Conclusion: Les VT de cette étude suivent les tendances établies en fonction de l'âge du patient et du type d'examen et sont comparables à la littérature publiée. Il existe des variations entre les différentes salles d'examen et les raisons sont multifactorielles. Étant donné que l'âge et la taille ne sont pas parfaitement corrélés, il conviendrait de poursuivre les travaux sur les VT/NRD basés sur le poids.

Keywords: Diagnostic reference levels; Radiation protection; Paediatric; Dose area product; ALARA

Introduction

Medical ionising radiation is one of the greatest factors influencing human exposure to radiation [1]. The rise in the use of ionizing radiation is of particular concern with regard to the paediatric population [2]. Children are up to ten times more sensitive to the effects of radiation than adults [3], due to their increased tissue radiosensitivity, increased cumulative lifetime radiation dose and longer lifetime in which to manifest the effects. As a result, children are more likely than adults to develop radiation-induced cancers, or as future parents, at increased risk of passing on radiation-induced genetic abnormalities [4]. There is, therefore, a need to ensure effective radiation protection for children undergoing radiological imaging [5,6].

To help manage radiation exposure, the International Commission on Radiological Protection (ICRP) [7] and the European Council Directive 2013/59/Euratom Basic Safety Standards (BSS) [8] have recommended that diagnostic reference levels (DRLs) are established at a European, national, and local levels for all medical examinations using radiation. The European Commission (EC) has established regional or 'European' DRLs (EDRLs) [9]; nationally government bodies are responsible for establishing national DRLs (NDRLs) [10], and the local DRLs (LDRLs) [11] are determined by a group of geographically local institutions [12]. A relatively new term '*typical values*' has been advocated for a single healthcare facility consisting of several imaging rooms [13]. Differences between *typical values* (TV) and LDRLs are distinguished by whether data are collected from a single (TV) or multiple facilities (LDRL) in a local area.

The clinical use of DRLs and TVs can help radiographers to optimise their practice [12,13]. When properly educated, practitioners can use TVs to evaluate radiation dose while maintaining an awareness of image quality versus diagnostically acceptable image quality [14]. Paediatric DRLs and TVs are of vital importance since there is also growing evidence that the frequency of diagnostic imaging examinations is increasing in children [15-17].

In Ireland, the Health Service Executive (HSE) defines paediatric patients as any patient aged from 0 to 16 years old [18], however for the purposes of DRLs in Europe this extends up to 18 years old [6]. It is the duty of all medical professionals who work with paediatric patients to protect this vulnerable group, and to comply with all regulations. In terms of paediatric radiography, children must be protected, and any radiation delivered by medical exposures is minimalistic and complies with ALARP (as low as reasonably practicable) principles [19].

Chest radiography (CXR) is one of the most common procedures performed, accounting for 47 % of paediatric X-ray examinations [20]. The anteroposterior (AP) pelvis X-ray is the second most performed X-ray examination, accounting for a further 31 % of paediatric X-ray examinations [20]. Abdominal radiography (AXR) is the third most performed paediatric X-ray examination being 6.3 % of all paediatric examinations [21]. In was, therefore, deemed necessary to develop TVs for paediatric CXR, AXR and AP pelvis X-ray examinations at the study institution.

The aim of the study was to establish TVs for paediatric X-ray examinations of the chest, abdomen and pelvis at a single institution and compare them to previously published data.

Methods

Methods used in this research were derived from the HIQA 'Guidelines for developing DRLs' and is the standardised method for every clinical setting in Ireland. Given that the establishment of TVs/DRLs is a legal requirement by HIQA, for-

Table 1
Summary of the study inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Paediatric patients between the ages of 1 month to 16 years.	Combined chest and abdomen images obtained on a single image receptor.
Images with adequate image quality, as determined by review of the radiology report (none identified within the study sample).	Pelvic radiographs which had been extended to include distal femora.
	Supplementary images (e.g., bases views for CXRs; cross-kidney views for AXRs).
	Examinations undertaken as a mobile, including patients < 1 month old (neonates).

Table 2
Proposed paediatric TVs for the study institution, including individual rooms.

			dGy.cm^2				
				X-ray Room			
Examination	Weight group	n	TV	ED-1	ED-2	GEN-1	GEN-2
Chest	5 - <15kg	41	0.10	0.19	0.22	0.07	0.05
	15 - <30kg	43	0.19	0.25	0.37	0.14	0.07
	30 - <50kg	41	0.37	0.35	0.44	0.37	0.40
	50 – 80kg	41	0.53	0.68	0.65	0.46	0.46
Abdomen	5 - <15kg	39	0.39	0.53	0.79	0.19	0.35*
	15 - <30kg	40	1.04	1.15	1.04	0.80	0.57
	30 - <50kg	31	3.51	3.50*	1.88	4.00*	12.00*
	50 – 80kg	13	4.05	23.31*	5.470*	3.13*	2.42*
Pelvis	5 - <15kg	28	0.43	0.45	0.48	1.33*	0.40*
(single view)	15 - <30kg	33	0.87	0.79	0.75	0.88*	0.95*
	30 - <50kg	34	3.50	3.50	4.33	4.07	1.79*
	50 – 80kg	23	7.58	17.87*	6.65	6.31*	7.78*

mal ethics committee approval for this project was not necessary and followed similar reports [22,23]. The study setting is a large teaching tertiary hospital that caters to patients across the South/South-West of Ireland. The study hospital has a large Emergency Department (ED) which is equipped with two digital X-ray rooms.

For each examination (CXR, AXR and AP pelvis), across four X-ray rooms (ED-1, ED-2, GEN-1 & GEN-2), a minimum of ten patients [24] from each weight-based category (1 month to <4 years, 4 to <10 years, 10 to <14 years and 14 to 16 years) were selected by a study researcher from PACS (Table 1). Examinations included represented the most common examinations performed for which radiation dose assessment was feasible, also those with the highest patient radiation doses were given preference [20,21,25]. Given that this was a retrospective study only age was available via interrogation of the institution's PACS. To overcome this, the EC has given approximate age groups that correspond to the weight groupings used for establishing TVs/DRLs [9]. The ages of included participants were thus converted to weight-based values [26].

Data were captured over the minimum period of time to access sufficient data and where there were no changes to imaging equipment or clinical protocols. The kerma-area product (KAP) for each examination was entered on a Microsoft Excel spreadsheet (Microsoft Inc, Redmond, WA) in dGy.cm^2.

Data analysis

Typical values (TVs) were established by calculating the *median* value whereas recommendations for local / national / international DRLs were made using the 3rd quartile value. TVs together with their comparators were also depicted graphically.

Results

The calculated TVs are presented in Table 2 and illustrated in Fig. 1.

In order to compare our study findings against published references, the most recent national and European DRLs for these examinations are summarised in Table 3. To compare TVs reported in this study with NDRLs [24] and EDRLs [9], the weight groups, as per HIQA and EU recommendations, must be considered (Table 3).

Discussion

The *typical values* (TVs) obtained in this study, for each examination and for each weight group, were calculated using based on previously recorded patient age, as per international guidelines [26]. However, many commentators have suggested that age may not be an appropriate descriptor for dose analysis. A recent publication by Almén and colleagues (2021) [27] demonstrated the differences when determining LDRLs using weight and age. Work by Almén and colleagues (2021) [27] showed that the DRLs obtained using age had, for certain examinations, a percentage difference up to 55 % against those based on weight. Using the European Guidelines supports the relationship between weight and age, however, approximately 25 % of patients will reported as not fitting the expected weight categories for their age [1]. It would, therefore,

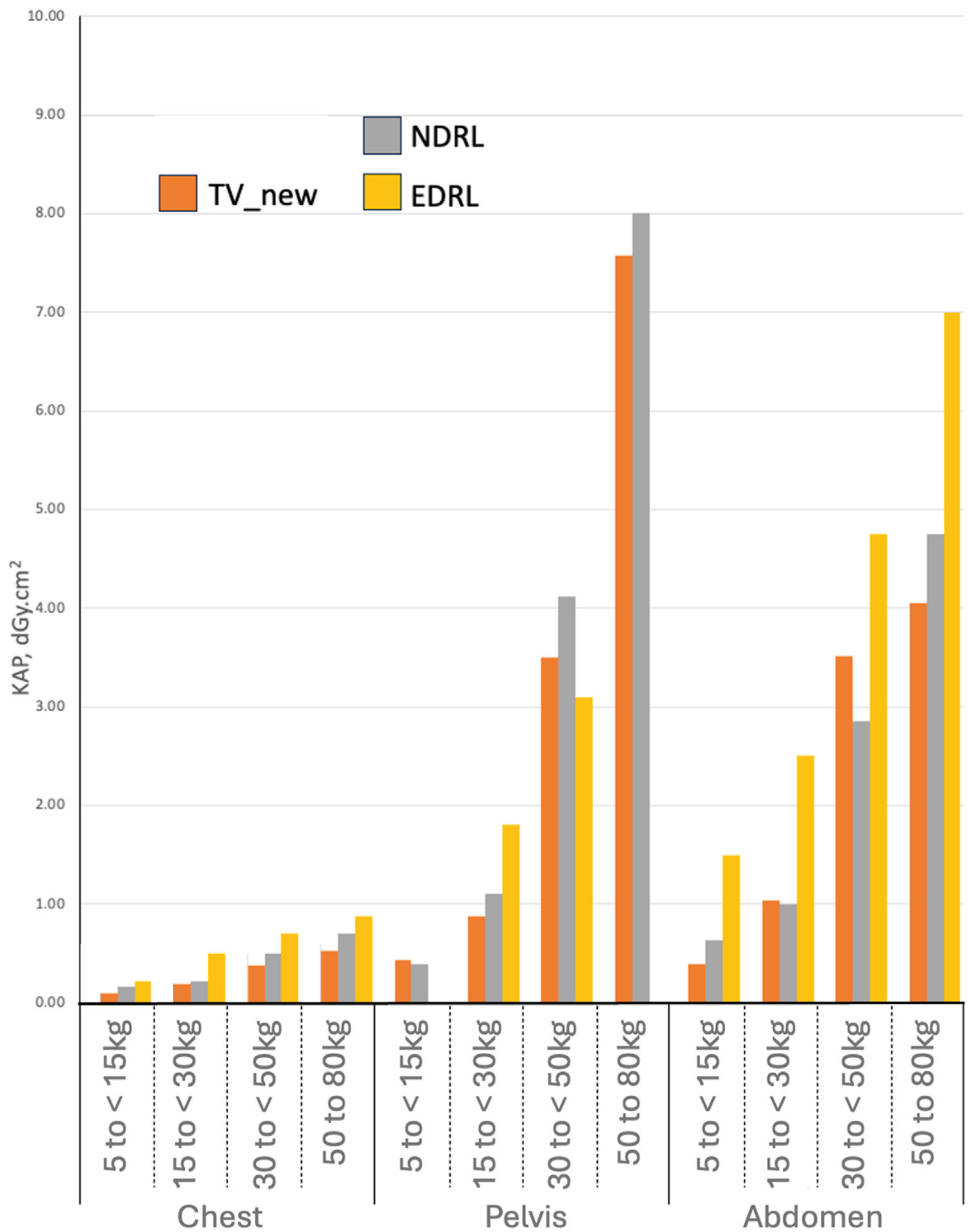

Fig. 1. Bar chart comparison of new TVs together with the corresponding NDRLs [24] and EDRLs [9].

Table 3
Summary of paediatric TVs, NDRLs [24] and EDRLs. [9].

Examination	Weight group	TV	NDRL [24]	EDRL [9]
Chest	5 - <15kg	0.10	0.17	0.22
	15 - <30kg	0.19	0.22	0.50
	30 - <50kg	0.37	0.50	0.70
	50 – 80kg	0.53	0.70	0.87
Pelvis	5 - <15kg	**0.43**	0.39	
	15 - <30kg	0.87	1.11	1.80
	30 - <50kg	**3.50**	4.12	3.10
	50 – 80kg	7.58	8.00	
Abdomen	5 - <15kg	0.39	0.63	1.50
	15 - <30kg	**1.04**	1.00	2.50
	30 - <50kg	**3.51**	2.86	4.75
	50 – 80kg	4.05	4.75	7.00

Dose values reported in the table are in dGy.cm^2, values in bold indicate values which exceed either published NDRLs [24] or EDRLs [9].

be optimal to directly measure patient weight when conducting dosimetric studies. It is important to acknowledge that in a paediatric hospital this would not be possible for all children examined.

For CXRs, the TV (0.10 dGy.cm^2) for 5 to <15 kg was 0.07 and 0.12 dGy.cm^2 lower than the NDRL and EDRL, respectively. Similarly, the TV for the other three CXR weight groups was lower than the NDRL / EDRL (Table 3). Such differences may reflect the greater frequency of paediatric chest X-ray examinations and tight adherence to protocol optimisation for this anatomical area. For pelvis X-ray examinations, no EDRL was available for children who weight 5 - <15 kg and 50–80 kg. In all instances, except the categories 5 to <15 kg and 30 - <50 kg, the TV was lower than the corresponding NDRL / EDRL. For the 5 to <15 kg weight group, the TV was very slightly 0.04 dGy.cm^2 higher than the NDRL. For the 30 - <50 kg weight group the TV was 0.40 dGy.cm^2 higher than the EDRL. Such an increase is likely to be multifactorial and similar for other TVs which were higher than NDRLs/EDRLs. For AXRs, only TVs for 15 - <30 kg and 50–80 kg weight groups were higher than the NDRL (0.04 and 0.65 dGy.cm^2, respectively). Higher TVs may again reflect the relatively low frequency of examinations for some patient groups and also differences in imaging equipment and patient characteristics, for example body habitus or underlying pathology [12]. Clinical indications [28] could also play a role with some examinations regarding higher levels of detail, for example the investigation of suspected pelvis and hip fractures.

Comparison with existing TVs/DRLs

Our new TVs (Table 3) are for the 5 to <15 kg weight group were equivocal. For the remaining weight groups new TVs were lower (0.19, 0.37 and 0.53 dGy.cm^2). Differences between X-ray room technology i.e. computed versus digital radiography, frequency of paediatric imaging examinations undertaken and the availability of pre-set anatomical exposure factors may have caused these variations.

It should be noted that there are some limitations to the work reported. For some examinations, in some X-ray rooms, there was less than 10 patients worth of data available for analysis. At the study institution radiography as a limited role in paediatric examinations, other than when examining the chest and the skeletal systems. It should be noted that this feature is likely to be institution specific and not necessarily indicative of global imaging trends. Results, were less than 10 data points, were available should be treated with caution as the generation of DRL values could be prone to outlier effects. Such situations have been clearly identified in the data analysis. It should also be noted that age categories have been mathematically converted into weight categories using previously published guidance. As previously specified this has limitations and future studies should aim to capture and report TVs/DRLs using actual patient weight data. We, therefore, opted to provide weight categories based on an age conversion. We do accept that the age and weight do not always follow a linear correlation [26] and thus this area would warrant further research.

Conclusion

The median KAP for each examination, for each age group, for each X-ray room was compiled and presented as local TVs. The majority of TVs were below published NDRLs and EDRLs. Certain groups exceeded the previous national, and international standards. This suggests that the study hospital was largely compliant with the national and European standards and is promoting the ALARP principles. Dose constraints are an important element of an institution's radiation protection strategy and work with TVs/DRLs should be a continual feature of departmental practices and as previously stated should consider the individual weights of paediatric patients. Given the compliance of TVs for chest radiography, it might be worth focusing dose optimisation strategies on less frequent X-ray examinations.

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