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FULL PAPER

Paediatric diagnostic reference levels for common radiological examinations using the European guidelines

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Objective: The purpose of this study was to explore the feasibility to determine regional diagnostic reference levels (RDRLs) for paediatric conventional and CT examinations using the European guidelines and to compare RDRLs derived from weight and age groups, respectively.
Methods: Data were collected from 31 hospitals in 4 countries, for 7 examination types for a total of 2978 patients. RDRLs were derived for each weight and age group, respectively, when the total number of patients exceeded 15.
Results: It was possible to derive RDRLs for most, but not all, weight-based and age-based groups for the seven examinations. The result using weight-based and age-based groups differed substantially. The RDRLs were lower than or equal to the European and recently published national DRLs.
Conclusion: It is feasible to derive RDRLs. However, a thorough review of the clinical indications and methodologies has to be performed previous to data collection. This study does not support the notion that DRLs derived using age and weight groups are exchangeable.
Advances in knowledge: Paediatric DRLs should be derived using weight-based groups with access to the actual weight of the patients. DRLs developed using weight differ markedly from those developed with the use of age. There is still a need to harmonize the method to derive solid DRLs for paediatric radiological examinations.

INTRODUCTION

The need for appropriate radiation safety for children undergoing radiological examinations has been widely recognized.[1–4] Diagnostic reference levels (DRLs) applicable to radiological examination have been promoted as a practical tool to use in the optimization process of medical exposures.[5] Therefore, international radiation safety standards,[6] as well as regional legal requirements,[7] include the concept of DRLs. On a national level, several European countries have applied the concept using the basic strategy of performing national radiation dose surveys for different X-ray examination types and have established national diagnostic reference levels (NDRLs) as recommended internationally,[8] but paediatric examinations have been included only to a limited extent. It is evident that the NDRL concept is more difficult to implement for paediatric examinations due to some basic issues. First, the number of examinations is low compared to that for adults. The time to gather data to determine NDRLs and to derive typical dose values in the clinic to compare with the NDRLs could therefore be significant, and this could restrict the effectiveness of DRLs as a tool. Second, it is more difficult to derive a DRL in paediatric radiology due to the variation in body sizes within this group of patients.[2] Body size has to be taken appropriately into account and a common international methodology should preferably be used in order to derive DRLs on an international level.

The European Commission initiated a project concerning paediatric DRLs,[3] which resulted in guidelines and

European paediatric diagnostic reference levels (EDRLs).[4] The guidelines address the different issues when deriving typical doses as well as DRLs (local, national, or regional). The issue of coping with the different body sizes is addressed and groups based on body weight are recommended. Age is also presented as an additional grouping parameter for the purpose of comparing weight-based DRLs with age-based DRLs. The guidelines define EDRLs for several types of examination. However, at the time of publication, published NDRLs were rare. The current EDRLs are therefore based on a limited number of NDRLs.

Since the publishing of the European guidelines in 2018, some additional NDRLs for paediatric radiology have been published. Two French studies address conventional imaging[9] and CT examinations,[10] and both the UK[11] and Ireland[12] have published NDRLs. According to the European guidelines, weight should be the first choice criterion for grouping (except for head examinations) when defining DRLs. However, it may be beneficial to achieve greater knowledge how weight-based and age-based DRLs compare with each other, which is difficult due to the limited number of published NDRLs. There is still a need to derive and share regional DRLs, as well as national DRLs, using a standardized methodology to further support the concept of DRL in paediatric radiology.

As mentioned, the relatively low number of paediatric examinations makes it more difficult to derive NDRLs, compared to those for adults. The possible advantages were identified of expanding the available patient pool for which a radiation dose survey could be performed in an attempt to derive regional diagnostic reference levels (RDRLs) for Denmark, Iceland, Norway, and Sweden, based on a larger number of X-ray examinations of children.

The aims of this study were: (i) to explore the possibilities to determine RDRLs using the European guidelines; (ii) to compare the outcomes of using weight-based and age-based groups; and (iii) to compare potential regional DRLs with published European and national DRLs.

METHODS AND MATERIALS

The data collection

It was decided to include only those conventional X-ray and CT examinations that were expected to be relatively common in all countries. When specifying examination types to include, the intention was to use clinical indications (Table 1), but anatomical regions are also used in the paper for simplicity. The following examinations were included in the study: conventional imaging of thorax, abdomen, pelvis, and hips/joints and CT examinations of the head, thorax, and abdomen (Table 1). Data were collected at hospitals in Denmark, Iceland, Norway, and Sweden using a web-based collection system and invited hospitals were asked to collect data from at least 20 patients for each examination type. In this study, an upper weight limit of 70 kg was applied, which is lower than the 80 kg indicated in the European guidelines. The age of the patients was limited to less than 16 years, reflecting the age range of patients in some paediatric radiological clinics, but it should be noted that the collection of data was not limited to paediatric clinics. The data collection proceeded over several months during the years 2018 and 2019.

Table 1. Summary of the data collected, number of patients, age, weight, number of images or series, and P_{KA}, $CTDI_{vol}$, and DLP for each patient group

Examination	# hospitals (DK, IS, NO, SE)	Patients (DK, IS, NO, SE)	Age, years median (Q1–Q3)	Weight, kg median (Q1–Q3)	# of images/seq. median min[Q1, Q3]max
Conventional					
Thorax, supine (routine)	13 (6, 1, 2, 4)	239 (93, 66, 27, 53)	1 month (0 – 12 months)	7 (3 – 11)	2 1[1,2]4
Thorax erect (routine)	17 (7, 2, 4, 4)	355 (243, 11, 63, 38)	10 (6 – 13)	32 (23 – 48)	2 1[1,2]4
Abdomen (overview)	18 (6, 2, 3, 7)	346 (40, 18, 111, 177)	5 (1–10)	20 (12 – 31)	2 1[1,2]4
Pelvis (fractures)	15 (7, -, 4, 4)	235 (162, -, 23, 50)	5 (2–10)	20 (13–35)	1 1[1,2]4
Hip/joints (dysplasia)	14 (5, -, 3, 6)	263 (70, -, 57, 136)	6 months (1–14 months)	10 (9–12)	2 1[1,2]4
CT					
CT head (infarct or bleeding)	26 (7, 2, 5, 12)	1212 (264, 6, 204, 738)	7 (2.3–11)		1 sequence (no contrast)
CT thorax, (tumour)	8 (2, -, 4, 2)	121 (19, -, 62, 40)	4 (2–10)	18.5 (12–35)	2 sequences (contrast)
CT abdomen (tumour, infection)	14 (4, -, 5, 5)	207 (30, -, 30, 147)	11 (8 – 13)	38 (27 – 50)	1 sequence (no contrast)

$CTDI_{vol}$, volume of CT dose index; DK, Denmark; DLP, dose–length product; IS, Iceland ; NO, Norway ; P_{KA}, kerma–area product;SE, Sweden. The number of hospitals and patient are also specified for each country; DK, IS, NO and SE.

The patient dose indices, a surrogate for patient doses appropriate for conventional and CT examinations,[13] were collected. That is, for conventional examinations, the air kerma–area product (P_{KA}) for a complete examination was reported together with the number of radiographs per examination. For CT examinations, the dose–length product (DLP) for a complete examination was collected, together with volume CT dose index ($CTDI_{vol}$) registered for the scan sequence giving the highest value. The age and weight of each patient were also collected. Ethical approval was not necessary as patient dose collection to determine DRLs is performed according to national regulations. No sensitive data was collected.

Data were cleaned manually and, if necessary, clarifications were requested from the reporting hospitals, *e.g.* in some cases, the dose index values were not reported with the correct units. It was evident that conventional thorax examinations should be given special attention due to different settings in which these examinations are conducted: younger children are normally X-rayed in a supine position using mobile or conventional X-ray equipment, whereas children older than approximately 5 years of age are usually X-rayed standing upright. Therefore, two examination groups were chosen for thorax conventional X-ray examinations, one called "thorax supine" and the other "thorax erect."

Developing regional diagnostic reference levels

RDRLs were derived using weight-based groups according to the European guidelines. The guidelines recommend specific age-based groups for head examinations, and these were used when calculating RDRLs for CT of the head. Generally, the suggested method to use weight-based groups for setting RDRLs is rather straightforward: the data from the different countries were pooled together in the groups. The RDRL was calculated using the third quartile (75th percentile) of the dose indices in the respective group. For each examination type, the arithmetic mean, median, the first and third quartile of the dose indices, and the mean, median, first and third quartile of the ages and weights, were also calculated for the groups to investigate the data further. The RDRLs derived in this study were compared with published EDRLs and NDRLs for France, the UK, and Ireland.[4,9–12]

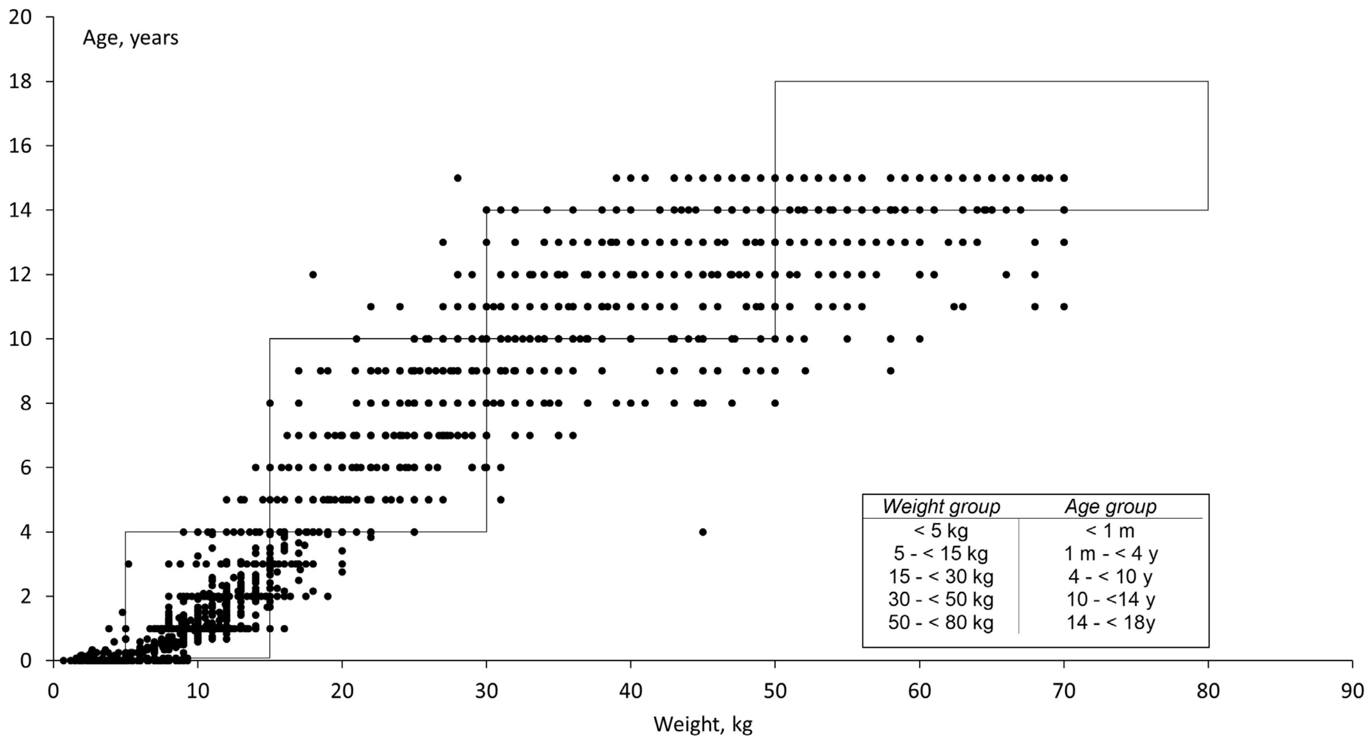
The European guidelines suggest that if age-based groups are chosen wisely, the results are roughly equal to those using weight-based groups, but that the latter is preferred. That is, a typical dose derived for a weight group is roughly valid for the corresponding age group. It has also been argued that this match is good enough to allow the use of either type of group.[14] RDRLs were calculated using the age-based groups specified in Figure 1 and mentioned in the guidelines. The percentage differences between weight-based and age-based RDRLs were calculated.

RESULTS

Data collected

A summary of the collected data is presented in Table 1. Data from a total of 2978 patients from 31 hospitals and 7 examination types were analyzed. The number of patients for each examination varied from 121 (CT thorax) to 1212 (CT head), partially reflecting the number of hospitals submitting data, which varied from 8 (CT thorax) to 26 (CT head). The median age and weight of the patients were lowest for conventional X-ray of thorax, supine (1 month and 7 kg, respectively) and of hips/joints (6

Figure 1. The age distribution depending on weight, all patients included. The lines indicate the recommended weight-based and age-based groups respectively outlined in the embedded table.[8]



months, 10 kg) and highest for conventional X-ray of thorax, erect (10 years, 32 kg) and CT abdomen (11 years, 38 kg).

Cleaning of the data was required. The unit for P_{KA} is not standardised and can thus be different (Gy cm^2, μGy m^2 and cGy cm^2). In several cases, hospitals were contacted to verify the unit.

It was evident from the conventional examinations that some differences in radiological technique existed. Data suggested that for conventional abdomen examinations, the number of radiographs per examination was generally higher in Swedish hospitals; a typical examination in Sweden includes two radiographs. Furthermore, the examination of the hips/joints included one image in Norwegian hospitals, while in Denmark and Sweden, such examinations predominantly included two radiographs. This could result in a systematic differences for P_{KA} per examination between the countries. However, it was not evident that these differences were medically indicated, and therefore RDRLs including data from all countries were derived.

Descriptive data

Table 2a shows descriptive data for the conventional examinations. In Table 2b, the corresponding values for CT examinations are presented. Where data are available, the number of patients in each weight group varies from 4 to over 100. It is questionable to derive DRLs based on a limited set of data, so weight groups including fewer than 15 patients were not considered further in this study and no data are shown for such groups. No examination type covers the whole range of weight groups. For all examinations other than conventional thorax supine and abdomen, data are lacking for the lightest weight group (<5 kg) and limited data are present for the heaviest weight group (50–70 kg). The median weight in this latter group is also skewed towards the lower limit of the range and always lower than 60 kg.

Proposed regional diagnostic reference levels

Tables 3 and 4 show the proposed RDRLs for the weight groups and for the age groups for CT head. Tables 3 and 4 also include the published NDRLs from France and the UK as well as values from the European guidelines. The proposed RDRLs are sometimes higher and sometimes lower compared with the EDRLs and the other published NDRLs. The NDRLs from France seem to be somewhat lower compared with the proposed RDRLs. Comparison with DRLs from France may be hampered by the fact that their weight-based DRLs appear to be derived from age-based DRLs. Furthermore, the number of radiographs per examination reported in the study from France seems to be lower compared with the number of radiographs per examinations in this study.

Weight-based *vs* age-based diagnostic reference levels

Figure 1 shows how many of the individuals fall within the weight category proposed for their age. The highest disparity is between the weight groups (10–<15 kg) and (15–<30 kg) and the corresponding age groups (1 month–<4 years) and (4–<10 years), respectively. Approximately, 25% of the children did not fit into the proposed weight group for their age.

Figures 2–4 show the difference between RDRLs derived using weight and age groups, respectively. A negative value represents a higher age-based RDRL compared with the corresponding weight-based RDRL. The difference between the two methods is typically about 20% and is generally larger for conventional examinations.

DISCUSSION

The present study explored the possibility of deriving regional DRLs using weight-based groups as suggested in the European guidelines. The study proposes RDRLs for seven examination types using data from four countries. The definition of examination type using clinical indications was a challenge. It was evident that knowledge about the examinations, *e.g.* yearly frequency data, is important and a systematic definition of the prerequisites for data collection has to precede the actual data survey. The participating hospitals must comprehend the clinical indication(s) and it must be possible to collect data within a reasonable time. During the analysis of the data, it was evident that for the conventional X-ray of the abdomen and hips/joints the methodology was somewhat different in different countries. This study did not try to investigate how the variation in applied technical parameters or methodological differences caused differences in radiation dose: this should be done through collaboration between the clinics, but was out of scope of this study.

This study showed that not enough data could be gathered within a reasonable time period for all of the weight groups, and no examination type could be considered for all of the weight groups. This has to be considered when suggesting NDRLs or RDRLs. This study used an age limit of 16 years and a weight limit of 70 kg. One consequence was that the number of patients in the highest age and weight groups was presumably lower than if limits of 18 years and 80 kg, as in the guidelines, had been used. Our rationale for these limitations was that patients aged 16 years and over are rarely examined in a specialized paediatric radiology department and that patients over 70 kg are expected to be examined with the same protocol as adults, and therefore adult DRLs should apply in most cases. A limitation of the study was the low number of patients included in some weight groups. This is difficult to overcome because the number of examinations of children is low, especially in smaller hospitals. In this study, clinical indications were included and sometimes several indications concerning the same DRL. It is important that the pooled indications are chosen wisely so that the clinical protocols remain similar. This may not be ideal but increases the available amount of data. Because of the low number, data from several hospitals were pooled together to include at least 15 examinations in each weight group, which was not feasible for the vast majority of individual hospitals.

The results, *i.e.* the RDRLs, for weight and age groups differed by up to 55%. The European guideline suggests that the results using weight and age groups are somewhat comparable. The benefits of being able to use age groups have been presented previously[14] and experience suggests that age is a much more readily available parameter compared to weight. However, this study shows

Table 2. a. Conventional X-ray examinations; patient weight, age, and dose indices for the weight groups, respectively. Each parameter is presented with a median (mean) and first; third quartile. The number (#) of patients in each group is also included. Groups with less than 15 patients were not further considered therefore some cells are left blank. b. CT examinations; patient weight, age, and dose indices for the weight groups, respectively. Each parameter is presented with a median (mean) and first; third quartile. The number (#) of patients in each group is also included. Groups with less than 15 patients were not further considered therefore some cells are left blank

Weight group	[<5 kg]	[5–<15 kg]	[15–<30 kg]	[30–<50 kg]	[50–<70 kg]
a.					
		Thorax, supine			
# patients	104	128			
Weight, kg	3 (3.1) 2.4; 3.9	10 (9.9) 8; 12			
Age, years	0 (0.03) 0; 0	2 (4.8) 1; 5			
P_{KA}, Gycm^2	0.008 (0.014) 0.005; **0.013**	0.029 (0.031) 0.015; **0.040**			
		Thorax, erect			
# patients			137	131	84
Weight, kg			22 (21.9) 19; 25	36 (37.6) 32; 43	57.5 (57.8) 53; 63
Age, years			6 (6.3) 5; 7	11 (10.9) 9.5; 13	14 (13.8) 13; 15
P_{KA}, Gycm^2			0.018 (0.021) 0.009; **0.028**	0.028 (0.038) 0.013; **0.050**	0.061 (0.088) 0.034; **0.097**
		Abdomen			
# patients		96	134	75	28
Weight, kg		10 (10) 8; 12	20.9 (21) 17.4; 25	35 (36.8) 31.3; 42	52 54.8 50; 58.5
Age, years		0.7 (1.0) 0.2; 1.1	6.0 (5.5) 4.0; 7.8	10.0 (10.7) 9.3; 12	13 (12.8) 11; 14
P_{KA}, Gycm^2		0.039 (0.058) 0.025; **0.073**	0.140 (0.204) 0.050; **0.237**	0.232 (0.395) 0.092; **0.534**	0.566 (0.942) 0.208; **1.54**
		Pelvis			
# patients		87	104	49	42
Weight, kg		11 (10.7) 9; 13	20 (20.4) 16; 24	39 (38.1) 32; 43	54 (55.8) 51; 60
Age, years		0.9 (1.2) 0.2; 1.9	5 (5.6) 4; 7	11 (10.9) 9; 13	14 (13.4) 12; 15
P_{KA}, Gycm^2		0.023 (0.034) 0.012; **0.041**	0.060 (0.104) 0.034; **0.130**	0.185 (0.240) 0.083; **0.330**	0.425 (0.501) 0.237; **0.646**
		Hip/joints			
# patients		234	23		
Weight, kg		10.0 (10.1) 8.9; 12.0	15.5 (16.2) 15; 17.5		
Age, years		1 (1.2) 0.9; 2.0	2.9 (2.7) 2.0; 3.4		
P_{KA}, Gycm^2		0.022 (0.034) 0.011; **0.048**	0.047 (0.063) 0.023; **0.088**		
b.					
		CT thorax			
# patients		34	38	24	17
Weight, kg		10.4 (10.4) 9; 12.4	18.8 (20.7) 17; 24.8	36 (37.8) 34; 40.2	55 (57.2) 51; 63
Age, years		1.4 (1.5) 1.0; 2.1	4.5 (5.6) 4; 7.8	10.5 (10.3) 8.8; 11.5	13.0 (13.0) 13; 14
CTDI, mGy		1.0 (1.9) 0.75; **1.2**	1.3 (1.5) 1.1; **1.6**	1.7 (2.0) 1.6; **2.4**	2.6 (3.1) 2.1; **3.0**
DLP, mGycm		18.8 (35.0) 14.4; **25.3**	30.9 (38.6) 24.7; **41.4**	42.4 (54.5) 39.3; **64.7**	93.0 (103.1) 62.9; **103.0**
		CT abdomen			

(Continued)

Table 2. (Continued)

Weight group	[<5 kg]	[5–<15 kg]	[15–<30 kg]	[30–<50 kg]	[50–<70 kg]
# patients			60	82	57
Weight, kg			23.8 (23.5) 20.8; 27.0	40 (39.8) 34; 45	58 (58.7) 53; 64
Age, years			7.0 (7.2) 10; 13	11.0 (11.1) 10; 13	14 (13.3) 13; 14
CTDI, mGy			1.8 (2.1) 1.5; **2.6**	2.7 (2.8) 2.0; **3.4**	4.2 (4.3) 3.1; **5.0**
DLP, mGycm			70.5 (78.7) 52.8; **91.7**	115.5 (120.8) 80.5; **150.3**	189.2 (201.1) 153.8; **247.0**
Age groups	**[0–< 3 months]**	**[3 months–< 1 years]**	**[1–< 6 years]**	**[>=6 years]**	
		CT head			
# patients	101	102	304	704	
Age, years	0.1 (0.1) 0.1; 0.2	0.5 (0.5) 0.3; 0.8	3.6 (3.3) 1.8; 4.3	11.2 (10.7) 8.2; 13.2	
CTDI, mGy	22.8 (22.8) 20.0; **27.5**	22.8 (23.7) 20.0; **27.3**	25.9 (27.4) 22.8; **30.7**	31.8 (33.7) 26.0; **38.7**	
DLP, mGycm	361 (365) 318; **403**	363 (365) 306; **398**	433 (454) 382; **516**	555 (589) 469; **679**	

CTDI, CT dose index; DLP, dose–length product; P_{KA}, kerma–area product.

that comparisons of weight-based and age-based DRLs should be made with great caution.

The median difference between RDRLs developed in this study and existing EDRLs and NDRLs was 23% and 22%, respectively, for conventional examinations, with the single largest percentage difference being 75% for European RDLs and 100% for national. The corresponding values for CT examinations were 48% and 23%, respectively. The values in this study were sometimes higher in some cases and lower in other, and there does not appear to

Table 3. Proposed RDRLs derived in this study, EDRLs, and NDRLs from France and Ireland concerning conventional X-ray examinations

	RDRL	EDRL	NDRL, France	NDRL, Ireland
Chest, supine	**Gycm2**	**Gycm2**	**Gycm2**	**Gycm2**
<5 kg	0.013	0.015		0.009
[5–<15 kg]	0.040	0.022	0.015	0.017
Chest, erect				
[15–<30 kg]	0.028	0.050	0.035	0.022
[30–<50 kg]	0.050	0.070		0.050
[50–<70 kg]	0.097	0.087		0.070
Abdomen				
[5–<15 kg]	0.073	0.150	0.060	0.063
[15–<30 kg]	0.237	0.250	0.220	0.100
[30–<50 kg]	0.534	0.475		0.286
[50–<70 kg]	1.54	0.700		0.457
Pelvis				
[5–<15 kg]	0.041			0.039
[15–<30 kg]	0.130	0.180	0.110	0.111
[30–<50 kg]	0.330	0.310	0.580	0.412
[50–<70 kg]	0.646			0.800
Hips/joints				
[5–<15 kg]	0.048			
[15–<30 kg]	0.088			

EDRL, European diagnostic reference level; NDRL, national diagnostic reference level; RDRL, regional diagnostic reference level.

Table 4. Proposed RDRLs derived in this study, EDRLs, and NDRLs from France, Ireland and the UK for CT examinations

	RDRL	EDRL	NDRL, France	NDRL, Ireland	NDRL, UK[b]
		DLP, mGycm			
CT head					
[0–< 3 months]	403	300		239	350
[3 months–< 1 year]	398	385		376	350
[1–< 6 years]	516	505	450	536	650
[>=6 years]	679	650	530	742	860
CT thorax					
[5–<15 kg]	25	50	29/20[a]	81	
[15–<30 kg]	41	70	43/36[a]	99	
[30–<50 kg]	65	115		166	
[50–<70 kg]	103	200		131	
CT abdomen					
[15–<30 kg]	92	150	92	168	
[30–<50 kg]	150	210	170	210	
[50–<70 kg]	247	480		397	
		CTDIvol, mGy			
CT head					
[0–< 3 months]	28	24			25
[3 months–< 1 year]	27	28			25
[1–< 6 years]	31	40	22		40
[>=6 years]	39	50	26		60
CT thorax					
[5–<15 kg]	1.2	1.8	1.5/1.1[a]		
[15–<30 kg]	1.6	2.7	1.5/1.4[a]		
[30–<50 kg]	2.4	3.7			
[50–<70 kg]	3.0	5.4			
CT abdomen					
[15–<30 kg]	2.6	5.4	2.3		
[30–<50 kg]	3.4	7.3	3.6		
[50–<70 kg]	5.0	13			

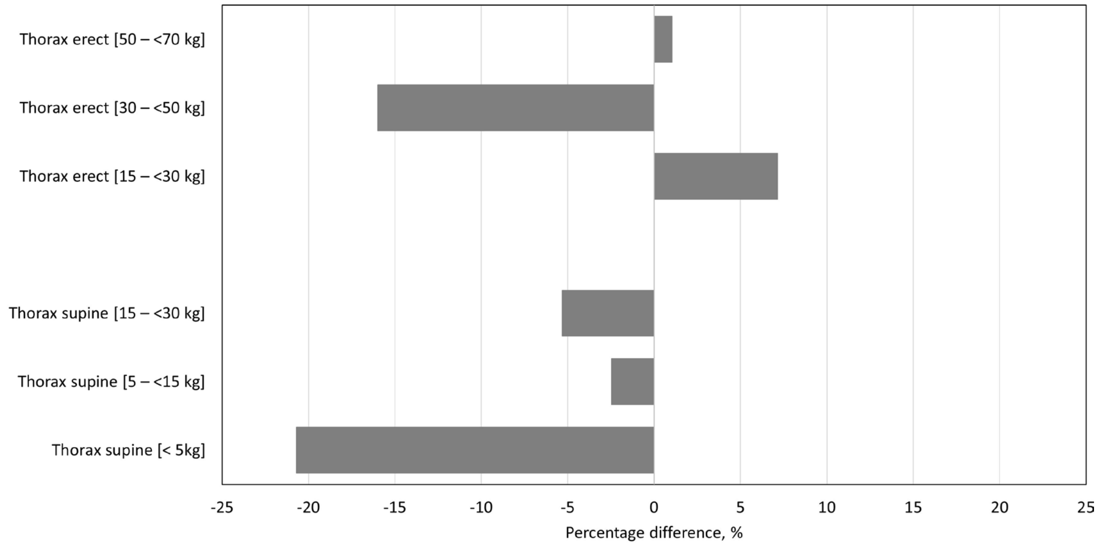
CTDI, CT dose index; DLP, dose–length product; EDRL, European diagnostic reference level; NDRL, national diagnostic reference level; RDRL, regional diagnostic reference level.
[a]France, CT chest: with contrast (mediastinum/lung).
[b]UK, trauma.

be any systematic difference. In view of the overall statistical uncertainty, the actual RDRLs adopted in regulations should be presented with fewer significant figures than those given in this study.

In this study, the RDRL was derived for a complete examination. In previously published studies, it is not clear whether this approach was applied. It is plausible that derived DLRs include one radiograph even if a standard examination includes more. The purpose of including all projections is that both methodological and technical differences are included in the DRL concept. Clinics then have the opportunity, not only to scrutinize technological differences (*e.g.* tube voltage and filtration), but also methodological differences, as well as the number of radiographs or CT sequences per examination. Following this reasoning, examinations that include retakes should not be excluded, and if a significant number of retakes are performed this could affect the typical dose derived. This could be a benefit to the DRL system because technological differences to some extent could be revealed using phantoms.

The European guidelines[11] emphasize that a system should be in place to judge whether image quality is adequate for the diagnosis according to the indication of the examination. In

Figure 2. The difference, %, between derived RDRLs using weight-based and age-based groups for conventional thorax examinations. Negative values indicate that using weight-based groups results in a lower RDRLs compared with using age-based groups. RDRL, regional diagnostic reference level.



this study, it was assumed that such a system was in place in the participating hospitals. Is has been suggested that image quality should be part of the DRL system and a so-called acceptable quality doses should be derived.[15] This system was later clinically used and evaluated[16] using image quality scoring criteria developed for paediatric CT.[17] With this approach, doses from patient examinations with suboptimal image quality are excluded before the typical values are derived.

Other countries may have published NDRLs for internal use, but these are hard to find. Additional studies to those previously mentioned have been published.[18–21] However, these NDRLs are for age groups or weight groups different from those proposed in the European guidelines. In a recent study performed in the USA,[22] DRL was determined for several CT examinations. However, as information about patient weight was not available in the study, age groups were converted to weight groups. This present study shows the difficulties in comparing DRLs based on weight and age groups. Therefore, the values established in this study have not been compared with the other studies.

In general, comparisons with the published data were hampered by a lack of information about whether the given values related to a complete examination or to a single radiograph or CT

Figure 3. The difference, %, between derived RDRLs using weight-based and age-based groups for conventional abdomen, pelvis, and hips/joint examinations. Negative values indicate that using weight-based groups results in a lower RDRLs compared with using age-based groups. RDRL, regional diagnostic reference level.

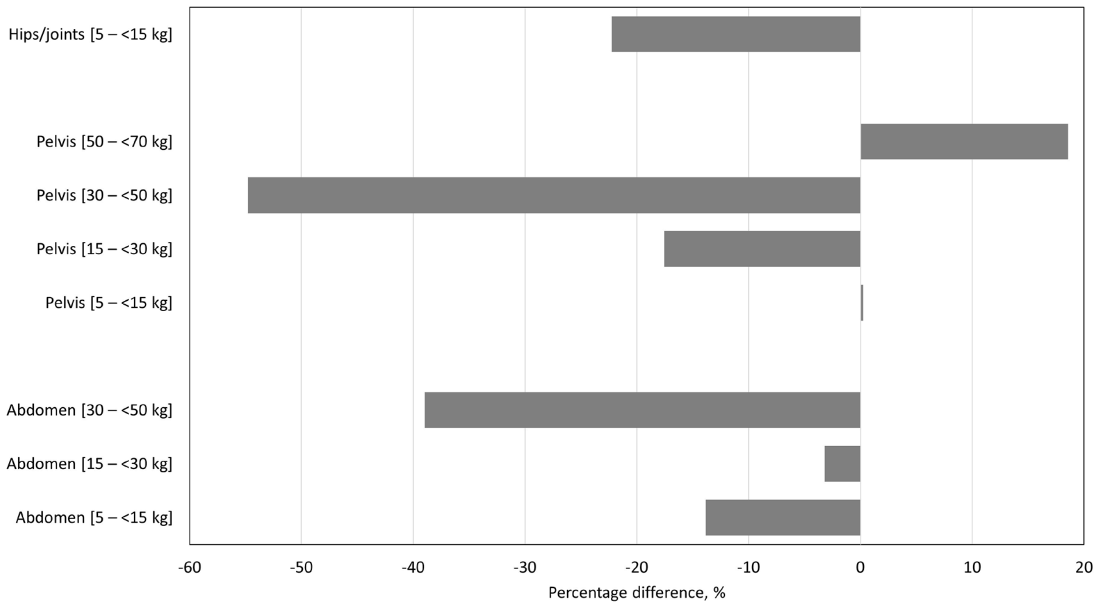
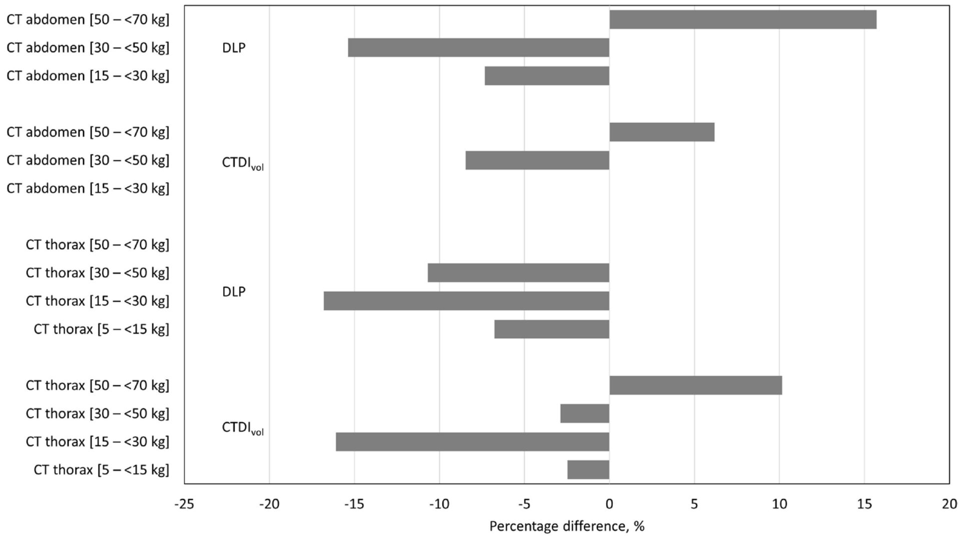


Figure 4. The difference, %, between derived RDRLs using weight-based and age-based groups for thorax and abdomen CT examinations. Negative values indicate that using weight-based groups results in a lower RDRLs compared with using age-based groups. RDRL, regional diagnostic reference level.



sequence. Some published NDRLs gave the same DRL for both thorax anteroposterior and thorax posteroanterior, although the different projections indicate substantial technological differences. Furthermore, it was not clear if patient weight data were collected and used, or only age data collected and the DRL subsequently presented for weight groups. These differences and ambiguities made comparisons difficult.

In this study, collection of data was limited to specific clinical indications. The drawback of including clinical indications is that it requires considerably longer time to collect data and even collecting sufficient data for predefined indications for adult examinations has proven to be a challenge.[23] A recent paediatric study performed in Greece[24] confirms the difficulties in collecting a substantial amount of data for a single clinical indication. A more detailed comparison between the hospitals participating in this study could be valuable in order to explain the differences, but this was out of scope of this study.

In the future, it is expected that the data from the examinations, and more generally about the patients, could be more efficiently collected using dose management systems.[25] Increased data availability in healthcare can support data-driven quality assurance in radiology including the use of the DRL system.

CONCLUSIONS

This study proposes RDRLs for seven paediatric radiological examinations for the weight groups suggested in the European guidelines. It is evident that the development of DRLs is facilitated by a detailed knowledge of examination frequencies and examination methodology in paediatric radiology. Despite the inclusion of several countries in the study, collection of a sufficient patient data was a challenge.

Approximately, 25% of patients did not match the expected weight groups for their age, using the correspondence between weight and age intervals suggested in the European guidelines. The RDRLs based on weight groups and age groups differ, by up to 55%. It is advisable to collect weight data when deriving DRLs and derive weight-based DRLs.

There were differences between the regional DRLs developed in this study and existing published European and national DRLs. In this study, RDRLs were derived for complete examinations, and the patients' weights were collected. This has not been done in all studies, which make comparison with the EDRLs and other published NDRLs ambiguous.

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