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GLOBAL PAEDIATRIC RADIOLOGY

Setting up regional diagnostic reference levels for pediatric computed tomography in Latin America: preliminary results, challenges and the work ahead

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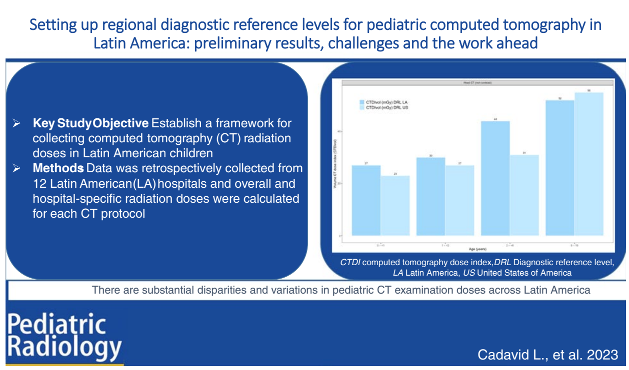
Abstract

We established a framework for collecting radiation doses for head, chest and abdomen-pelvis computed tomography (CT) in children scanned at multiple imaging sites across Latin America with an aim towards establishing diagnostic reference levels (DRLs) and achievable doses (ADs) in pediatric CT in Latin America. Our study included 12 Latin American sites (in Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Honduras and Panama) contributing data on the four most common pediatric CT examinations (non-contrast head, non-contrast chest, post-contrast chest and post-contrast abdomen-pelvis). Sites contributed data on patients' age, sex and weight, scan factors (tube current and potential), volume CT dose index (CTDIvol) and dose length product (DLP). Data were verified, leading to the exclusion of two sites with missing or incorrect data entries. We estimated overall and site-specific 50th (AD) and 75th (diagnostic reference level [DRL]) percentile CTDIvol and DLP for each CT protocol. Non-normal data were compared using the Kruskal-Wallis test. Sites contributed data from 3,934 children (1,834 females) for different CT exams (head CT 1,568/3,934, 40%; non-contrast chest CT 945/3,934, 24%; post-contrast chest CT 581/3,934, 15%; abdomen-pelvis CT 840/3,934, 21%). There were significant statistical differences in 50th and 75th percentile CTDIvol and DLP values across the participating sites ($P<0.001$). The 50th and 75th percentile doses for most CT protocols were substantially higher than the corresponding doses reported from the United States of America. Our study demonstrates substantial disparities and variations in pediatric CT examinations performed in multiple sites in Latin America. We will use the collected data to improve scan protocols and perform a follow-up CT study to establish DRLs and ADs based on clinical indications.

Graphical abstract



Keywords Children · Computed tomography · Patient safety · Dose optimization · Radiation protection · Reference values

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Introduction

Over the past three decades, rapid software and hardware advances in computed tomography (CT) have resulted in improved early diagnosis, disease staging and assessment of treatment response. Hardware innovations have brought faster, wide-array multidetector-row CT scanners capable of sub-second, single-, dual- and poly-energetic exams. Software developments have helped improve dose and image quality optimization with technologies such as automatic tube potential selection, automatic patient centering and positioning and iterative and deep learning–based reconstruction. However, the adoption of new technologies is not uniform, and with wider availability of CT, there are concerns about practice variability, overuse and a lack of optimization of radiation dose. In this context, optimization of scan parameters and radiation doses (especially in vulnerable pediatric patients) has become a strong focus for best medical radiation practices [1, 2]. Judicious use of CT and the application of scanning protocols with "as low as reasonably achievable" (ALARA) radiation doses are the guiding principles for dose reduction and CT optimization in children.

The International Commission for Radiation Protection (ICRP) introduced diagnostic reference levels (DRLs) to promote the optimization of radiation-based medical imaging. DRLs can help identify and mitigate unusually high or low radiation dose outliers for a given imaging procedure. Typically, the 75th percentile (3rd quartile) of the distribution is defined as the DRL value [3]. The achievable dose (AD), representing the 50th percentile of dose distribution, was introduced by the United States (US) National Council for Radiation Protection and Measurements (NCRP) [4]. Since their introduction, several studies have established institutional, local, national and regional DRLs and AD to help optimize radiation doses [5–7]. In 2018, the European Commission summarized existing national DRLs in their report titled "Guidelines for Diagnostic Reference Levels for Pediatric Imaging" [8]. More recently in 2021, the American College of Radiology (ACR) Dose Index Registry (DIR) published the DRLs and AD for the 10 most commonly performed pediatric CT examinations in the US [7]. Although some publications describe local or regional doses in Latin America [9–11], there are no comprehensive, multi-site reports on pediatric CT DRLs from the region.

In this study, we describe our framework for collecting radiation doses for head, chest and abdomen-pelvis CT studies in children from multiple imaging sites with the aim of establishing DRLs for pediatric CT in Latin America.

Materials and methods

This is a multi-institutional retrospective study, which was approved by the ethics committees/institutional review boards of all participating hospitals. The need for informed consent was waived.

All the members of the Sociedad Latinoamericana de Radiología Pediátrica (SLARP) were invited to participate through a web announcement. All institutions that answered the invitation were contacted and instructed to complete a REDCap collection tool. Each site was asked to report on CT examinations in patients <18 years consecutively and without selection, including patient age, sex and weight, number of scan phases, intravenous contrast use (yes or no), tube potential, tube current, gantry rotation time, reconstruction section thickness and pitch. The following dose-related information was also collected: phantom reference size (16 cm or 32 cm), volume CT dose index (CTDIvol) and the dose length product (DLP). The data collection form was then piloted with a small number of cases per site for data quality assessment.

We collected information on the four most common pediatric CT examinations in Latin America from multiple centers in the region. The CT examinations were performed between January 2017 and July 2022. The included protocols were (a) non-contrast head CT, (b) non-contrast chest CT, (c) post-contrast chest CT and (d) contrast-enhanced abdomen-pelvis CT. As recommended for DRL, we requested each participating site to contribute 30 patients in each age group for each type of examination [3].

The age groups for head CT were (a) 0 to less than 1 year, (b) 1 to less than 2 years, (c) 2 to less than 6 years and (d) 6 to 18 years, following methodology from previous reports [7]. The body examinations were based on the ICRP report number 135 [3] and included (a) 0 to less than 1 year, (b) 1 to less than 5 years, (c) 5 to less than 10 years, (d) 10 to less than 15 years and (e) 15–18 years.

Data verification, REDCap survey and statistical analysis

A radiologist (M.K.K.) with 20 years of experience in CT protocol and radiation optimization reviewed the dose input data for potential errors. During this step CTDIvol and DLP from all sites and patients were reviewed. Two sites (one each in Mexico and Perú) with discordant CTDIvol and DLP could not provide the number of acquired phases or scan lengths. Because scan factors including scan lengths can vary across different scan phases, these two sites were excluded from the final analysis.

We collected general information for each participating site, including type of practice (hospital, public, private or outpatient center), scanner model, vendor, number of detector rows and availability of a radiation dose monitoring system. We also collected information on body region-specific choice of scan factors, including method of selecting tube current (fixed tube current for all patients, weight- or size-based fixed tube current or automatic exposure control) and tube potential (fixed tube potential for all patients, weight- or size-based manually selected tube potential or automatic tube potential selection technique) (Supplementary information).

All data were analyzed with Microsoft Excel (Office 365, Microsoft Inc, Boston, MA) and SPSS Statistical Software (SPSS Version 6 IBM Inc, Boston, MA). We estimated overall and site-specific 50th and 75th percentile CTDIvol and DLP for each CT protocol. Non-normal data were compared using the Kruskal-Wallis test. A *P*-value less than 0.05 was considered statistically significant.

Results

Sites, protocols and patient characteristics

A total of 14 sites in 9 countries (4 in Brazil, 2 in Colombia and 1 each in Argentina, Bolivia, Chile, Ecuador, Honduras, Mexico, Panama and Perú) contributed de-identified data. However, during the data verification step, data from the sites in Mexico and Perú were excluded (Fig. 1). Thus, 12 sites from 8 countries constituted the final sample.

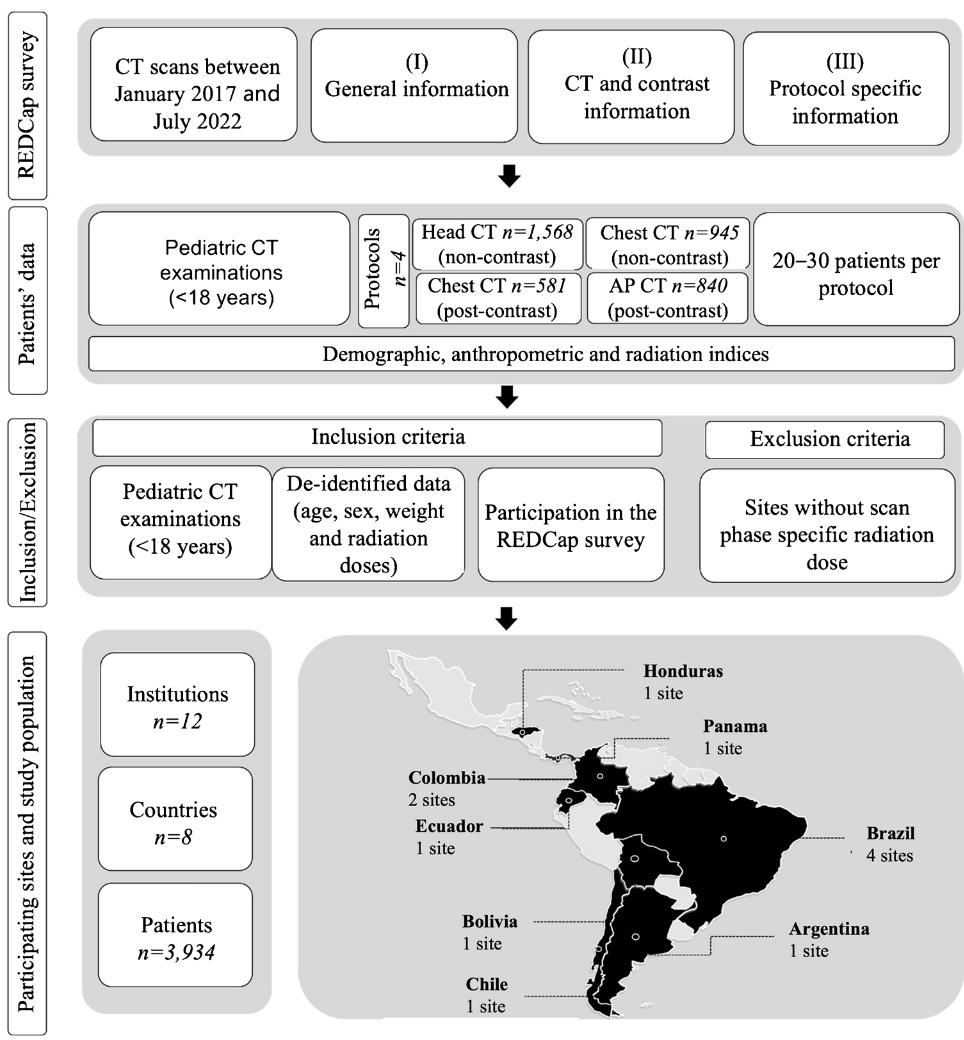

Fig. 1 Flow diagram summarizing the study dates and components of the computed tomography (CT) data received from institutions in Latin America. *AP* abdomen-pelvis

A comparison of overall radiation doses from participating Latin American sites with US-reported doses [7] is summarized in Table 1. There were a total of 3,934 head, chest and abdominal CT examinations (Table 2). There were significant variations in the frequency of protocols used (head CT 1,568/3,934, 40%; chest CT without contrast 945/3,934, 24%; abdominal CT 840/3,934, 21%; chest CT with contrast 581/3,934, 15%) (P<0.001). There were also variations in the age-wise distribution of patients across the participating sites (P<0.001), with most patients belonging to either the 6–18 years group for head CT (885/3,934; 22%) or in the 15–18 years group for chest and abdominal CT (14%) (P<0.001). Regardless of the body region, there were fewer patients aged between 1 and 2 years (126/3934; 3%). There were 1,834/3,934 (47%) female patients.

Body weights for the different age groups were 0–1 year, 6.9±5.3 kg; 1–5 years, 12.7±5.7 kg; 5–10 years, 23.7±9.9 kg; 10–15 years, 43.9±15.3 kg; and 15–18 years, 55.9±18.7 kg.

Scanner and scan factors

Figure 2 summarizes the details of the REDCap survey. Most sites had 64-detector-row multi-detector CT (n=7/12) or 80–320 detector rows (n=4/12); 3/12 sites reported data from two scanners, while most sites (9/12) had only one scanner. Head CT examinations were without contrast in 8/12 sites, with the remaining sites (4/12) often or always acquiring non-contrast images before intravenous contrast administration. For post-contrast chest CT, most sites did not acquire the non-contrast phase (10/12), whereas two sites often or always acquired pre-contrast images. For abdomen-pelvis CT, 4/12 sites acquired non-contrast phase before the post-contrast phase, while the remaining 8/12 sites never or rarely acquired non-contrast phase images.

Vendor-wise 50th and 75th percentile values for CTDIvol and DLP values are summarized in Table 3. There were significant variations in radiation doses across the four CT vendor machines used by the participating sites for the head, post-contrast chest and abdomen-pelvis CT protocols (P<0.001). Such variations were likely related to significant differences in patients' body weights (Table 3) for the non-contrast chest and post-contrast abdomen-pelvis CT examinations and patient age groups for head CT examinations (P<0.001). For chest CT with contrast, there were no significant inter-vendor differences in CTDIvol (P=0.186), although DLP varied significantly (P=0.02).

Table 1 Age-based diagnostic reference levels (DRLs) and achievable doses (ADs) in Latin America and the United States (US) [7]

Examination	Age (years)	CTDIvol (mGy) Latin America		CTDIvol (mGy) US [7]	DLP (mGy cm) Latin America		DLP (mGy cm) US [7]
		DRL (AD)	Range	DRL (AD)	DRL (AD)	Range	DRL (AD)
Head CT (Non-contrast)	0 to <1	27 (20)	3–113	23 (19)	456 (302)	35–1508	344 (267)
	1 to <2	30 (20)	5–113	27 (22)	535 (356)	104–2528	440 (350)
	2 to <6	44 (29)	8–70	31 (25)	813 (527)	120–1650	518 (409)
	6–18	52 (35)	9–77	55 (46)	949 (625)	82–3023	910 (748)
Chest CT (Non-contrast)	0 to <1	4 (2)	0.19–14	3 (2)	81 (39)	3–230	27 (22)
	1 to <5	4 (2)	0.2–24	3 (2)	96 (49)	4–810	49 (35)
	5 to <10	5 (4)	0.3–28	4 (3)	176 (120)	8–743	70 (57)
	10 to <15	8 (5)	0.4–28	5 (4)	294 (172)	9–1828	128 (107)
	15–18	11 (6)	0.9–22	8 (7)	425 (276)	19–1168	257 (202)
Chest CT (Post-contrast)	0 to <1	5 (2)	0.2–13	3 (2)	83 (42)	3–277	31 (23)
	1 to <5	5 (3)	0.2–39	4 (2)	110 (62)	6–916	58 (43)
	5 to <10	6 (4)	0.3–28	4 (3)	167 (107)	9–785	95 (64)
	10 to <15	9 (6)	0.5–47	6 (7)	293 (202)	9–2077	272 (146)
	15–18	12 (8)	0.3–35	11 (14)	412 (305)	13–1846	596 (364)
Abdomen-pelvis CT (Post-contrast)	0 to <1	3 (2)	0.2–42	-	130 (46)	3–386	-
	1 to <5	4 (3)	2–29	5 (3)	160 (103)	9–794	95 (69)
	5 to <10	7 (4)	0.6–46	6 (5)	260 (163)	17–1298	171 (124)
	10 to <15	12 (7)	1–80	9 (8)	418 (292)	39–3027	367 (277)
	15–18	13 (9)	2.5–78	11 (11)	529 (414)	97–2028	510 (408)

CT computed tomography, *CTDIvol* volume CT dose index, *DLP* dose length product

Table 2 Age- and protocol-wise distribution of patients across participating sites

Anatomical region	Age (years)	Sites												Total
		A	B	C1	C2	C3	C4	D	E1	E2	F	G	H	
Head computed tomography (Non-contrast)	0 to <1	30	9	42	8	0	3	31	28	29	28	21	28	257
	1 to <2	14	7	11	5	2	33	9	8	11	10	8	8	126
	2 to <6	31	14	22	9	4	33	29	28	21	26	57	26	300
	6 to 18	75	28	84	75	18	86	81	86	88	85	121	58	885
	Total	150	58	159	97	24	155	150	150	149	149	207	120	1568
Chest computed tomography (Post-contrast)	0 to <1	19	2	-	-	-	-	23	30	30	-	2	-	106
	1 to <5	38	5	-	-	-	-	15	30	30	-	3	-	121
	5 to <10	30	2	-	-	-	-	20	30	30	-	1	-	113
	10 to <15	29	1	-	-	-	-	20	30	30	-	3	-	113
	15 to 18	32	0	-	-	-	-	30	30	30	-	6	-	128
	Total	148	10	0	0	0	0	108	150	150	0	15	0	581
Chest computed tomography (Non-contrast)	0 to <1	0	0	20	0	0	1	12	30	30	20	4	-	117
	1 to <5	41	2	22	0	0	3	29	30	30	31	1	-	189
	5 to <10	46	3	25	1	0	6	30	30	30	44	1	-	216
	10 to <15	33	7	24	1	1	3	30	30	30	41	4	-	204
	15 to 18	30	9	4	18	0	4	30	30	30	60	4	-	219
	Total	150	21	95	20	1	17	131	150	150	196	14	0	945
Abdomen-pelvis computed tomography (Post-contrast)	0 to <1	22	2	17	0	-	1	10	7	28	10	5	-	102
	1 to <5	31	1	1	0	-	9	30	30	30	10	13	-	155
	5 to <10	31	2	0	5	-	30	30	30	30	15	14	-	187
	10 to <15	35	3	0	2	-	19	30	30	30	11	13	-	173
	15 to 18	30	0	0	42	-	17	30	30	30	30	14	-	223
	Total	149	8	18	49	0	76	130	127	148	76	59	0	840
Total	597	97	272	166	25	248	519	577	597	421	295	120	3934	

All but one site reported using vendor-specific automatic exposure control techniques for most chest and abdomen-pelvis CT examinations. For chest and abdomen-pelvis CT, 3/12 sites reported the use of a fixed tube potential, while three sites reported using automatic tube potential selection techniques (with variable reference kV of 80, 100 or 120 at the three sites). The remaining sites (6/12) adapted the tube potential based on patient age or weight. Although modal tube potential across the four CT protocols was 120 kV, there were significant differences in tube potential based on patients' age group ($P<0.001$) (Fig. 3).

In addition, radiation doses were significantly higher in institutions with a CT scanner with ≤16 detector rows compared to those with >16 detector rows ($P=0.001$) for all CT protocols.

Volume computed tomography dose index and dose length product

Most sites reported the data using radiation dose monitoring software (10/12), whereas two sites recorded the data manually. There were 5/12 sites that did not have any requirement for recording patient weight at the time of scanning. The 50th and 75th percentile CTDIvol and DLP values in the entire patient group are summarized in Table 4. There were significant statistical differences in 50th and 75th percentile CTDIvol and DLP values across the participating sites ($P<0.001$).

Discussion

Our study shows that the overall and site-specific 75th percentile radiation doses at most Central and South American sites were greater than the corresponding DRLs from the US [7]. We believe that there are several causes for higher than anticipated doses, including older and less efficient scanners, lower adoption of newer dose reduction technologies, incorrect scan factors and lack of dose adjustment according to patient weight and/or age. As noted from Table 4, causes of higher radiation doses varied across sites with some sites (A and B) having

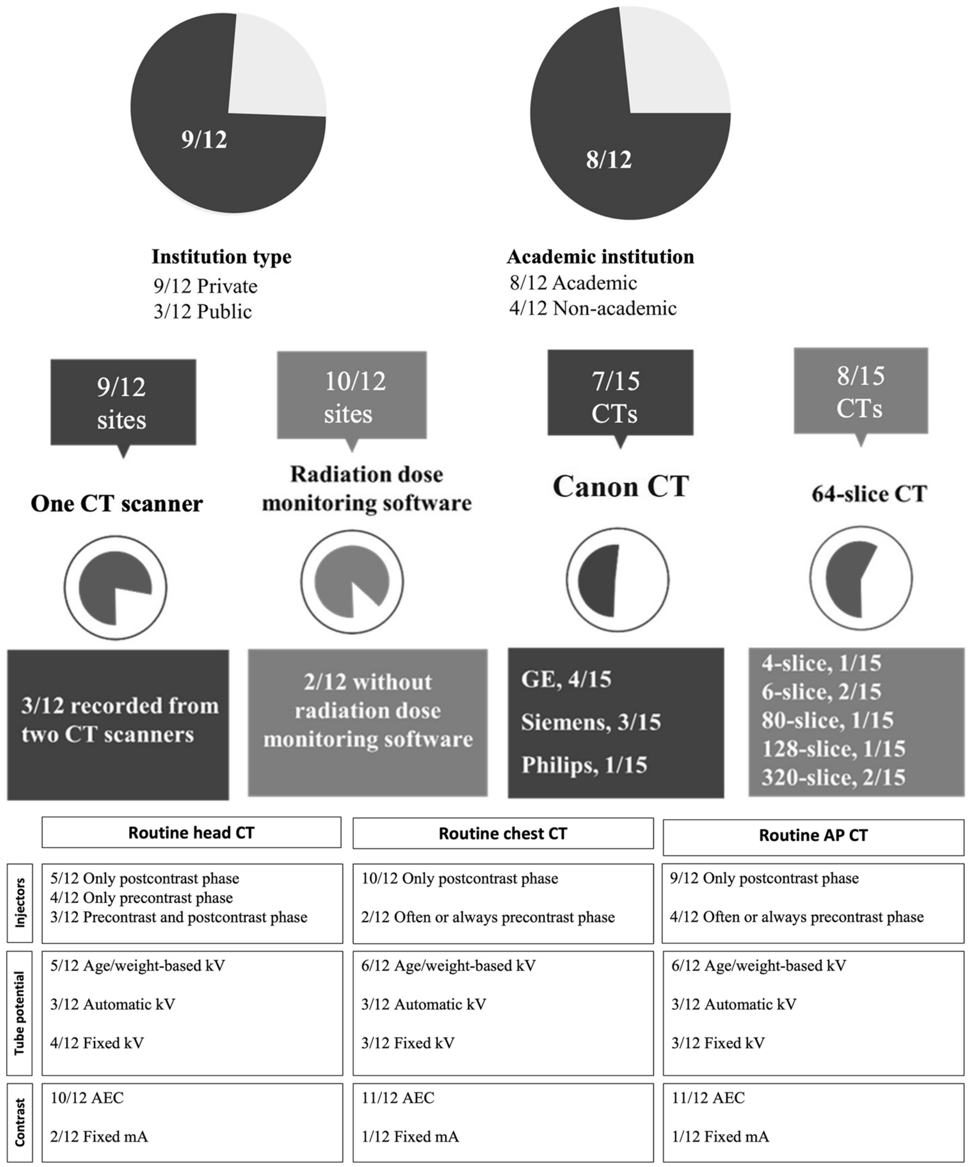

Fig. 2 Summary of the results of the REDCap survey. Scanner model, vendor, number of detector rows and availability of radiation dose monitoring software. *AEC* automatic exposure control, *AP* abdomen-pelvis, *CT* computed tomography, *kV* kilovolt (tube potential), *mA* milliampere (tube current)

disproportionately higher DLP, presumably from longer than necessary scan lengths, and other sites (F and G) with high CTDIvol and DLP likely related to inappropriate selection of scan factors (such as kV and mAs). It is however important to highlight that doses from a few sites with similar technology (2–4/12) were a fraction of the DRLs reported from the US. These sites used low tube potential, automatic tube current modulation and iterative reconstruction techniques to achieve lower radiation doses. Such dose data demonstrate the potential for dose optimization at other sites currently with higher doses.

Pediatric CT dose optimization is challenging, as there is a large variation in body size and composition within and across age groups [7, 12]. In this respect, DRL and AD can help lay the foundation for understanding radiation dose. The clinical indication-based DRLs are superior to body region DRLs as they enable radiation dose optimization in the same body region based on the diagnostic requirements [6]. Therefore, age- or size-based DRLs should ultimately lead toward the clinical indication-based DRLs. A growing number of publications on CT DRLs based on clinical indications have been established [13, 14]. Also, similar studies based on clinical indications to CT DRL [15, 16] and strategies on justification [17, 18] in radiological exams have been applied in Brazil and will contribute to regional DRLs. The European Study on Clinical Diagnostic Reference Levels for X-ray Medical Imaging (EUCLID) project has recently established DRLs for 10 CT clinical indications using data collected from 14 European countries [19].

Table 3 Vendor-based variations in CT radiation doses (CTDIvol and DLP) in terms of diagnostic reference levels (DRLs) and achievable doses (ADs) were related to variations in body weight and/or age of patients

Anatomical region		Canon	GE	Philips	Siemens	*P*-value
Head CT (Non-contrast)	Age (years)	7±5	7±6	13±6	9±6	0.001
	Weight (Kg)	30±21	20±13	40±26	29±19	0.001
	CTDIvol (mGy)	39 (25)	62 (61)	26 (26)	56(30)	0.001
	DLP (mGy·cm)	725 (492)	1123 (1023)	593 (548)	920 (547)	0.001
Chest CT (Non-contrast)	Age	8±6	10±6	14±6	9±5	0.001
	Weight	28±21	-	64±19	30±20	0.001
	CTDIvol	9 (4)	5 (5)	11 (7)	7 (5)	0.001
	DLP	209 (101)	290 (175)	408 (279)	248 (119)	0.001
Chest CT (Post-contrast)	Age	8±6	4±2	-	9±6	0.033
	Weight	29±22	-	-	35±24	0.078
	CTDIvol	8 (4)	5 (3)	-	8 (5)	0.186
	DLP	219 (110)	170 (70)	-	338 (196)	0.023
Abdomen-pelvis CT (Post-contrast)	Age	9±6	10±6	13±6	9±5	0.001
	Weight	32±20	-	60±18	35±21	0.001
	CTDIvol	8 (4)	5 (4)	13 (11)	12 (7)	0.001
	DLP	292 (157)	466 (350)	654 (523)	459 (260)	0.001

CT computed tomography, *CTDI* volume computed tomography dose index, *DLP* dose length product

In our study, we found significant variability in age- and body-region-matched radiation doses among different participating sites, which could be attributed to the differences in scanners and scan factors at different sites. Prior studies from both Europe and Africa have also reported large variations in radiation doses for the same protocols [20–22]. Likewise, a lack of variation in radiation doses for children in different age groups at some sites was disconcerting due to the use of constant, high tube potential (often 120–130 kV) and high tube current.

The main implication of our study pertains to the need for optimization based on the substantially higher 75th percentile

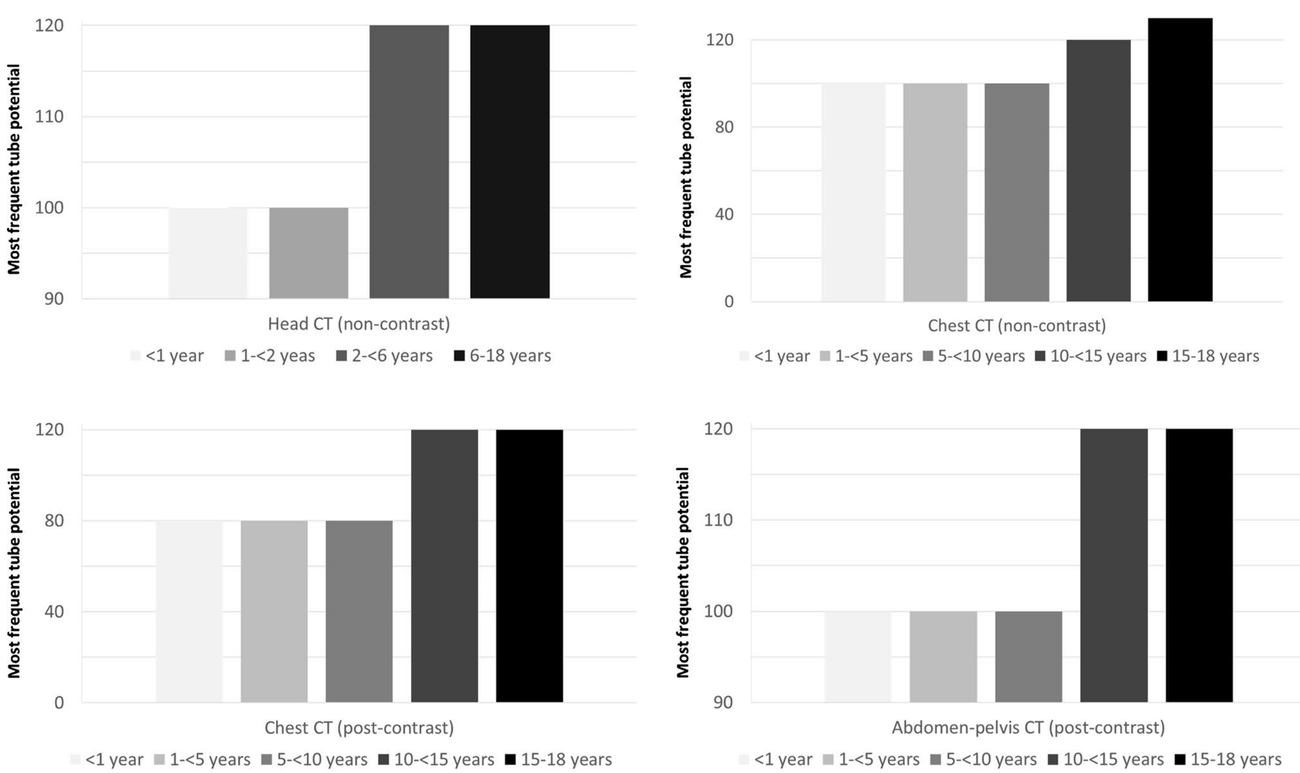

Fig. 3 Bar graphs show the tube potential (values represent kV) for different age and protocol groups (all group comparison, $P<0.001$). Post-contrast chest computed tomography (CT) had the lowest tube potential, while 100–120 kV was the most frequent for other CT protocols

Table 4 Age- and protocol-wise achievable doses (ADs) and diagnostic reference levels (DRLs) for patients across participating sites in Latin America

Protocol	Age (years)	Radiation	A	B	C1	C2	C3	C4	D	E1	E2	F	G	H
Head CT (non-contrast)	0 to <1	CTDIvol[a]	27 (26)	45 (43)	10.4 (10)	20 (14.2)	-	20.3 (20)	18 (15.7)	15.7 (15.3)	8 (7.3)	62 (59)	57.5 (55.4)	25.1 (25.1)
		DLP[b]	456 (394)	862 (793)	183 (165)	460 (308)	-	395 (395)	295 (256)	301 (284)	130 (112)	1010 (985)	805 (805)	388 (327)
	1 to 2	CTDIvol	34.5 (27)	46 (43)	10 (10)	14.2 (11.8)	14 (12)	30 (20.3)	18 (15.9)	15.7 (15.3)	20 (8.6)	62.4 (17.8)	57.5 (57.4)	30.1 (24.3)
		DLP	898 (578)	862 (852)	210 (184)	311 (248)	255 (201)	490 (375)	317 (285)	312 (292)	317 (143)	1148 (317)	920 (920)	474 (388)
	2 to 6	CTDIvol	39 (35)	45 (45)	12.9 (12.1)	26 (25)	37 (29)	44 (44)	25.3 (21.8)	16 (15.4)	12 (10)	62.5 (52)	57.3 (56.2)	35 (35)
		DLP	741 (617)	931 (897)	299 (245)	590 (555)	959 (473)	813 (769)	468 (394)	332 (318)	204 (164)	1149 (1055)	1036 (920)	559 (559)
	6 to 18	CTDIvol	54 (38.8)	46 (45)	24 (19)	26 (26)	45 (34)	51.4 (45.9)	35.5 (31.3)	25 (16.3)	18 (16)	62.4 (62)	57.4 (56.7)	39.7 (38.6)
		DLP	1103 (671)	993 (888)	474 (394)	598 (558)	955 (667)	949 (871)	674 (585)	562 (375)	311 (271)	1134 (1115)	1036 (959)	842 (811)
Chest CT (non-contrast)	0 to <1	CTDIvol	-	-	1 (1)	-	-	1 (1)	2 (1)	7 (4)	1 (1)	4 (3)	5 (5)	-
		DLP	-	-	20 (11)	-	-	16 (16)	35 (23)	89 (57)	15 (13)	82 (81)	117 (87)	-
	1 to <5	CTDIvol	10 (10)	2 (2)	1 (1)	-	-	3 (2)	3 (2)	5 (4)	1 (0)	3 (3)	5 (5)	-
		DLP	227 (159)	36 (32)	20 (13)	-	-	51 (34)	61 (40)	91 (74)	17 (7)	136 (49)	101 (101)	-
	5 to <10	CTDIvol	10 (10)	4 (4)	3 (2)	6 (6)	-	3 (2)	4 (3)	7 (6)	1 (1)	5 (5)	5 (5)	-
		DLP	269 (181)	159 (90)	78 (59)	181 (181)	-	77 (56)	134 (80)	147 (120)	20 (17)	290 (177)	94 (94)	-
	10 to <15	CTDIvol	16 (14)	5 (5)	5 (4)	6 (6)	4 (4)	5 (4)	8 (7)	11 (8)	3 (2)	5 (5)	13 (12)	-
		DLP	616 (406)	617 (406)	618 (406)	619 (406)	620 (406)	621 (406)	622 (406)	623 (406)	624 (406)	625 (406)	626 (406)	627 (406)
	15 to 18	CTDIvol	15 (12)	6 (4)	16 (9)	13 (8)	-	4 (4)	9 (9)	18 (13)	4 (4)	5 (5)	8 (7)	-
		DLP	513 (397)	208 (145)	581 (341)	443 (312)	-	232 (160)	403 (343)	426 (309)	150 (131)	– (325)	271 (256)	-
Chest CT (post-contrast)	0 to <1	CTDIvol	6 (5)	2 (2)	-	-	-	-	2 (2)	6 (5)	1 (0)	-	5 (5)	-
		DLP	164 (75)	40 (40)	-	-	-	-	36 (29)	100 (79)	12 (6)	-	89 (86)	-
	1 to <5	CTDIvol	10 (5)	4 (3)	-	-	-	-	2 (2)	6 (4)	1 (0)	-	8 (8)	-
		DLP	234 (105)	70 (70)	-	-	-	-	50 (36)	110 (77)	14 (10)	-	363 (304)	-
	5 to <10	CTDIvol	7 (6)	6 (4)	-	-	-	-	5 (3)	7 (6)	1 (1)	-	6 (6)	-
		DLP	209 (155)	320 (183)	-	-	-	-	170 (110)	149 (123)	29 (16)	-	156 (156)	-
	10 to <15	CTDIvol	17 (7)	6 (6)	-	-	-	-	7 (7)	12 (9)	3 (2)	-	9 (6)	-
		DLP	535 (227)	283 (283)	-	-	-	-	265 (225)	333 (242)	141 (75)	-	609 (293)	-
	15–18	CTDIvol	9 (4)	-	-	-	-	-	11 (9)	17 (13)	5 (4)	-	9 (8)	-
		DLP	365 (162)	-	-	-	-	-	454 (393)	431 (349)	255 (161)	-	529 (345)	-

Table 4 (continued)

Protocol	Age (years)	Radiation	A	B	C1	C2	C3	C4	D	E1	E2	F	G	H
Abdomen-pelvis CT (post-contrast)	0 to <1	CTDIvol	9.3 (4)	2 (1.5)	0.94 (0.76)	-	0.8 (0.8)	-	1.5 (1.19)	18 (6.4)	1.8 (0.85)	2.97 (2.95)	4.12 (3.51)	-
		DLP	164 (68)	40 (40)	77 (33)	-	16 (16)	-	46 (41.5)	362 (184)	43.5 (20)	136 (136)	113 (111)	-
	1 to <5	CTDIvol	14 (4)	5 (5)	1.59 (1.59)	-	1.3 (1.2)	-	3.82 (2.76)	5.1 (3.9)	1 (0.62)	3 (2.98)	5.67 (4.4)	-
		DLP	426 (156)	170 (170)	168 (168)	-	60 (43)	-	141 (110)	140 (104)	28 (21)	214 (211)	194 (139)	-
	5 to <10	CTDIvol	13 (4.4)	46 (25)	-	11 (10.8)	2.6 (2)	-	12 (10)	7.6 (6.45)	1.8 (1.1)	3.07 (3)	14 (7.94)	-
		DLP	780 (310)	536 (238)	-	1109 (827)	267 (199)	-	374 (297)	396 (321)	219 (141)	408 (406)	798 (541)	-
	10 to <15	CTDIvol	8 (7)	10 (5)	-	14 (13)	5 (4)	-	14 (8)	11.4 (8.55)	4 (3)	5 (4.5)	14 (11)	-
		DLP	505 (267)	-	-	654 (525)	409 (201)	-	578 (493)	463 (372)	284 (236)	480 (466)	916 (686)	-
	15–18	CTDIvol	17 (7)	-	-	12 (10)	4.2 (3.2)	-	13 (10)	12.7 (10.6)	6 (4.75)	4.9 (4.7)	17.8 (11.5)	-
		DLP	505 (267)	-	-	654 (525)	409 (201)	-	578 (493)	463 (372)	284 (236)	480 (466)	916 (686)	-

CT computed tomography, *CTDIvol* volume CT dose index, *DLP* dose length product

[a]in mGy, [b]in mGy·cm

radiation doses associated with pediatric head, chest and abdomen-pelvis CT in Latin America. Therefore, instead of accepting and labeling these "outlier" doses, we recommend that participating sites use the 50th percentile doses (considered "achievable doses") in our study as the target for optimization. The median doses in our study are closer to the DRLs from the US [7]. In the short term, we intend to continue to collect and monitor dose data following protocol optimization at various sites. This study reports on the initial efforts of what has become a communication network among participating sites, which we hope will ultimately help establish regional and continental body region- and age/size-specific pediatric CT DRLs across Latin America. To this end, SLARP has established a radiation protection committee and working groups to further this work and the education of members. Our study represents the first step towards forming a team of key stakeholders across Latin America and obtaining initial dose data. We provided separate written reports and online didactic advice to the sites with high radiation dose levels after the data analysis step, with an emphasis on limiting scan phases and the need for using a proper size-based low tube potential (kV) and automatic exposure control technique. We shared the experience on dose optimization from external sites as well as those with lower doses in the current study. Higher radiation dose does not provide additional diagnostic information but increases the risk from unnecessary radiation in vulnerable children. All sites indicated their willingness to optimize scan protocols and radiation doses for children undergoing CT.

Since the higher-than-anticipated doses relative to those from the US led to our choice of not using the collected data for establishing "flawed" DRLs across the region, the primary implication of our study lies in the importance of optimizing radiation dose through awareness, training and protocol optimization. To meet that goal, we formally presented and personally communicated the entire cohort results as well as results with each site. We offered external expertise to the sites with substantially higher doses than the DRLs from the US. We received positive feedback from all participating sites along with an encouraging willingness of sites with higher doses to modify their scanning practices.

Our study demonstrates that collaborations can bring personnel and effort to accomplish data collection despite the limitations in technological automation, funding and dedicated personnel. However, the exclusion of two sites from our study due to recording errors underscores the value of automation through dose registries [7] which require both funding and resources. The American College of Radiology (ACR) Dose Index Registry (DIR) initiative in the US is a prime example of how automated radiation dose collection from several hundred sites can help establish patient size and body region–based DRLs and ADs for both children and adults [23]. Such initiatives have led to a decrease in CT radiation doses despite an overall increase in the use of CT in the US [24]. Another implication of our study is identifying the usage patterns for specific scan factors across the participating sites. We noted a higher tube potential (120–130 kV rather than 70–100 kV) for small children and chest CT examinations, particularly in sites with higher radiation doses, which were notified accordingly.

There are limitations to our study. First, the distribution of contributed datasets across participating sites and age groups varied based on the use of CT in children. Second, as noted above, we did not target the development of clinical indication-based DRLs or AD. Third, our study is prone to errors associated with manual dose recording instead of automated radiation dose recording software, which is uncommon in the region. Fourth, the clinical indications and justification for CT are important aspects of pediatric radiation dose optimization and were not assessed in our study. Fifth, we acknowledge that the doses from individual participating sites might not reflect doses or scan practices across the entire country or region. Finally, although we requested 30 patients per protocol and per age group, some sites did not meet this target; such sites or data were however not excluded from the study. We compared our doses to the US [7] levels and not with other luminary reports such as from Europe, since our age and weight groups did not match with the other reports [8]. Finally, although the initial intent of our project was to define body-region and age-specific DRLs, we could not accomplish this objective due to the reasons discussed above. Our multi-site, international study highlights issues related to improper scan factors and a lack of optimization of radiation doses at most sites in Central and South America. We have planned scan protocol modifications across several sites and the collection of new dose data to establish DRLs and achievable dose levels for different body regions and patient sizes/ages.

In conclusion, our multicenter study highlights the disparity in radiation protection in Latin America. Multiple factors such as improper scan factor usage, multiphase protocols and legacy scanners without modern dose reduction techniques contributed to the higher DRLs and AD compared to the same parameters in the US. The SLARP and its allies, the Colégio Brasileiro de Radiologia (CBR) and Latin Safe will, in the near future, propose a detailed plan to reduce the gap and improve radiation protection policies, including efforts to establish clinical indication-based DRLs.

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Data Availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflicts of interest None

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