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THE ESTABLISHMENT OF COMPUTED TOMOGRAPHY DIAGNOSTIC REFERENCE LEVELS IN PORTUGAL

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The aims of this study were to investigate the frequency of Portuguese computed tomography (CT) examinations, identify protocol application and establish diagnostic reference levels (DRLs). CT departments ($n=211$) were surveyed nationally (June 2011–January 2012) and CT protocol information and dose data were collected, as were retrospective age-categorised paediatric CT data from three national paediatric centres. The proposed national CT DRLs ($CTDI_{vol}$) for adults were 75, 18, 14, 18, 17, 36, 22, 27 and 16 mGy for head, neck, chest, abdomen, pelvis, cervical, dorsal, lumbar and joints, respectively. The levels for paediatric head and chest examinations were as follows: 48 and 2 mGy (newborns), 50 and 6 mGy (5 y olds), 70 and 6 mGy (10 y olds) and 72 and 7 mGy (15 y olds). A limited number of current paediatric protocols aligned to recommended international age categorisations. Portuguese DRLs were generally higher than European recommendations, suggesting potential for optimisation. The need for greater standardisation of age-categorised paediatric protocols was identified.

INTRODUCTION

According to Report 160 of the National Council on Radiation Protection, the average radiation dose resulting from medical exposure increased 7-fold in 26 y (1980–2006)⁽¹⁾. In 2009, computed tomography (CT) accounted for 17 % of all radiological examinations but was responsible for 66 % of the collective effective dose in the USA. In the UK, CT is responsible for 47 % of the collective effective dose and in Germany, for 60 %⁽²⁾.

Multislice CT (MSCT) technology continues to evolve, facilitating clinical diagnosis and provides more efficient treatment, offering improved image quality and faster image acquisition⁽³⁾. However, if not used correctly, MSCT technology can increase the average radiation per examination⁽⁴⁾. The existence of risk to patients following exposure during CT examinations remains controversial⁽⁵⁾. The lifetime attributable risk of a fatal cancer from all causes is 22.8 %, whereas that associated with ionising radiation exposure from a typical CT is ~ 0.05 %⁽⁶⁾. The literature published with respect to radiation risks associated with CT examinations varies; however, the majority of authors recognise the cumulative population risk of increased incidence of cancer secondary to radiation exposure⁽⁷⁾.

The level of radiation dose received by patients undergoing CT examination depends on a number of factors, in particular the protocol used and equipment settings for the individual examinations^(8, 9). If the As Low As Reasonably Achievable principle is not

followed and techniques are not appropriately adjusted, especially to the patient size, the risk of potential radiation effects increases⁽¹⁰⁾.

Diagnostic reference levels (DRLs) are particularly useful in areas where considerable individual or collective dose reduction may be achieved especially for high-dose examinations such as CT and fluoroscopy procedures⁽¹¹⁾. In practice, DRLs are a percentile point (75th) on the observed distribution of radiation to patients. However, the main purpose of DRLs is maintaining awareness of radiation protection at local levels, and the identification of abnormally high doses. Establishing DRLs and comparison to national values can facilitate dose audit and improve patient radiation protection, by promoting a reduction in dose levels without compromising image quality or patient care. The principal aim of optimisation is achieving a narrower dose distribution, with lower mean and 75th percentile values⁽¹²⁾. The establishment of DRLs needs to encompass both adult and paediatric examinations as cell biology reactions differ between the two groups⁽¹³⁾.

The risk of cancer in children caused by radiation exposure is approximately two to three times higher than that in adults because children are particularly susceptible to the effects of ionising radiation, with ten times more neoplastic potential compared with an adult⁽¹⁴⁾. Current research recommends that specific protocols be tailored for paediatrics and that overscanning and multi-phase scanning must be avoided⁽¹⁵⁾.

Portuguese paediatric patients are classified from 0 to 18 y old⁽¹⁶⁾. Because of the large variation in size between a newborn and an 18 y old, patient demographics such as weight, height and AP diameter vary tremendously. This is an important factor and requires full consideration in the formulation of imaging protocols relevant to paediatric cohorts⁽⁷⁾, as the European guidelines on quality criteria for diagnostic radiographic images in paediatrics recommend⁽¹⁷⁾ and international DRL papers evidences^(18–21).

The frequency of radiological examinations for adults was established in Portugal in April 2012⁽²²⁾. The current legislation does not fully account for advancing CT technology, and concerns are focused in licensing of private radiology centres⁽²³⁾. Currently, there is no documented evidence related to Portuguese CT practice with respect to protocols and how these are applied; this remains a serious concern⁽²²⁾. National CT DRLs are yet to be established, despite being required by international regulations since 1997⁽²⁴⁾. Neither is there any national data on the frequency of paediatric CT examinations or similar national DRLs and information as to how protocols are applied across different age groups for paediatric imaging. This lack of information regarding CT dose values hinders any comparison with international literature and is an obvious deficit regarding the CT exposure-associated risks in Portuguese children and adults.

This work sets out to ascertain the most commonly performed CT examinations and protocols for both adults and paediatric patients in Portugal. Average CT doses were collected and analysed to allow the calculation of Portuguese CT DRLs. Resultant values are then compared with corresponding European levels.

MATERIALS AND METHODS

Dosimetry survey

To facilitate planning of the national dose survey, firstly the government structure and clinical institution demographics were reviewed. The Portuguese health system is divided into five regional health administrations (ARS). These agencies ensure the efficiency of health care and manage the human and technical resources. To formulate a contact list, the five Portuguese ARS were contacted, requesting the name and contact details of the institutions with CT systems. Four major CT manufacturers (General ElectricTM, PhilipsTM, SiemensTM and ToshibaTM) were also contacted to assist in compilation. A list of institutions nationally was created, and ethical approval to distribute a questionnaire survey was received from the appropriate hospitals Ethical Commissions, according to the dispositions of the National Ethics Commission for Health Sciences, official government advisor⁽²⁵⁾.

The survey aimed to firstly gather the specifications for CT equipment and usage data to include: the

number of CT scanners per institution, type of equipment and specific technical detail, e.g. number of slices. Information related to the governance of quality control and the frequency of CT examinations was also sought. The second aspect of the survey was to facilitate a detailed review of currently employed imaging protocols and the collection of typical CT doses for standard patients. Institutions were also asked to define their paediatric protocols with regard to patient demographics (weight and age).

The survey was based on European Guidelines, RPI54^(26, 27) and securely delivered over the internet. The survey was composed of eight closed questions for hospitals with adults, and for institutions with paediatric protocols, a further six questions were included. To promote the survey nationally, a Joomla-based technology website was designed (<http://www.joanas.eu>), thus providing participants with information regarding the research aims and updates.

A pilot test was carried out with two university-affiliated teaching centres of excellence. Senior CT radiographers were asked to participate in the study by completing the pilot survey online and encouraged to feedback comments. In June 2011, the national survey commenced. Radiography managers were contacted using both standard and electronic mail and were given the choice of participating using either the electronic or hardcopy questionnaire format. Follow-up communication was issued three weeks into the survey and the survey process remained active for 7 months, in order to encourage an increased response rate.

DRLs were calculated by rounded 75th percentile of CTDI_{vol} and DLP values and Student's *t*-test (for *Independent Samples*), with a confidence interval of 95 %, was used to compare public and private CT dose values. The significant level was set to $p < 0.05$.

Paediatric dose levels

Taking into account the low number of paediatric protocols supplied and the variability with which paediatric age categorisation is currently applied across Portuguese centres, it was not possible to define DRLs from the national survey owing to lack of adequate data points.

In order to establish paediatric DRLs, dose data were collected in three dedicated regional, public paediatric centres, in Portugal each one representing geographic regions of Portugal. In 2011, the paediatric centres of excellence performed ~80 000, 142 000 and 100000 paediatric consultations, respectively⁽²⁸⁾. Radiology directors were contacted in each of the three clinical sites, and all agreed to participate. Ethical approval to commence the proposed study was granted by the governing government institutions.

To determine the most frequently performed paediatric CT examinations, in each of the three centres, analysis of examinations listing from a one period

(2011) was reviewed. These data were accessed using the Picture Archiving and Communication System/Radiology Information Systems in each of the three paediatric centres.

The quality assurance records of the CT imaging suites were inspected to confirm the CT scanners had undergone appropriate Quality Control tests. In addition, the CTDI value of each scanner was verified, using a CTDI phantom; polymethylmethacrylate with a density of 1.19 g cm^{-3} , and an ionisation chamber of the quality control kit *RaySafe Xi*, with a valid calibration and quality control (QA) certificate. A further aim of the research was to pursue optimisation of practice for paediatric examinations once DRLs were established; therefore QA conformity required manufacture confirmation. The most common CT protocols were recorded from the CT scanner pre-sets and confirmed with the relevant specialist CT radiographers.

Retrospective data collection was performed to calculate paediatric DRLs owing to the lack of data supplied in the national survey. Information on patient gender, CT dose index (CTDI_{vol} —mGy) and dose length product (DLP—mGy cm) was collected for head and chest CT examinations, for specific ages (newborns, 5-, 10- and 15-y olds)^(18–21), with a minimum of 15 patients within each age category/examination deemed acceptable⁽¹²⁾.

ANOVA statistical testing with *Post Hoc* Test (Student–Newman–Keuls test) was used to identify significant differences ($p < 0.05$) between centres and age groups, with a confidence interval of 95 %.

RESULTS

The national survey was forwarded to 211 institutions identified as delivering a CT clinical service; however, 12 institutions were confirmed as closed prior to the commencement of the survey. Eight private institutions declined participation. Of the remaining 191 centres, 41 responses (21 %) were obtained (Figure 1), which comprised of 55 % of the public institutions and 10 % of private institutions nationally. The responses are summarised by region in Table 1. Detailed CT protocols from 41 institutions were made available for 44 adult and 16 paediatric examinations for different body regions and age categorisations.

National CT equipment specifications

The majority of centres (88 %) reported having a single CT scanner installation, four institutions having two (10 %) and one institution confirming four active CT scanners. The average age of the CT scanners was found to be $6 (\pm 5 \text{ y})$; however, nine were installed prior to 2000; six, post 2010 and a further six, post

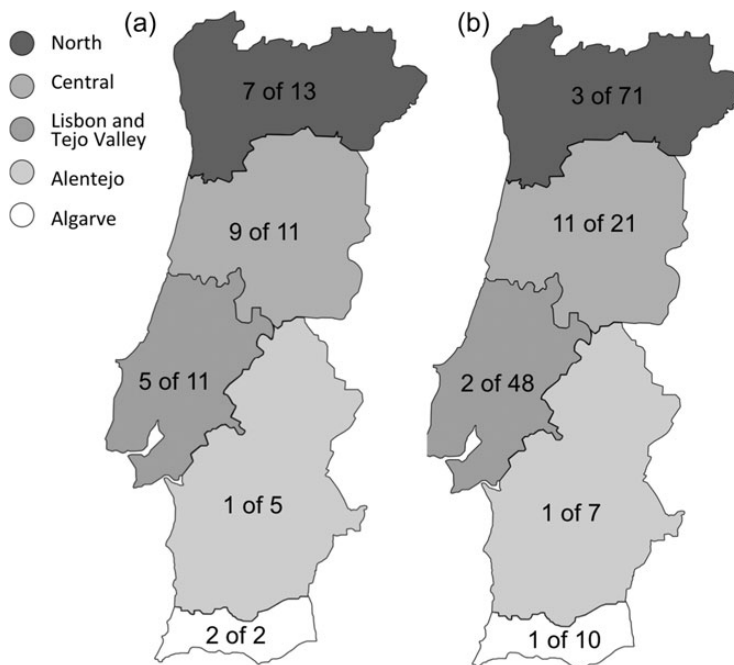


Figure 1. Summary map of National CT survey responses, per Portuguese regional health administrations. (a) Public institutions; (b) private institutions.

Table 1. Summary of Portuguese ARS-documented CT institutions ($n=211$) and clinical centre response to the CT questionnaire.

ARS (regional health administration)	Public		Private		Closed	Total	
	Institutions	Responses	Institutions	Responses		Institutions	Responses
North	13	7	79	3	8	84	10 (12 %)
Central	11	8	22	11	1	32	19 (59 %)
Lisbon and Tejo Valley	11	5	51	2	3	59	7 (12 %)
Alentejo	5	1	7	1	—	12	2 (17 %)
Algarve	2	2	10	1	—	12	3 (25 %)
Total	42	23	169	18	12	199	41 (21 %)

Table 2. The number of CT examinations in 2010, for different body regions, adult and paediatric examinations.

Anatomic region	Head	Neck	Chest	Abdomen	Pelvis	Column	Joints	Total
Adult								
Institutions	24	24	24	24	24	24	23	31
Number CT per year	96 688	5829	45 510	53 245	36 467	43 313	9977	440 294
Paediatric								
Institutions	2	2	2	2	2	2	2	2
Number CT per year	1585	67	851	603	423	134	192	6394

2008. The most frequently used vendors are SiemensTM (41 %) and General ElectricTM (32 %). Alternate manufacturers included: PhilipsTM (14 %) and ToshibaTM (11 %), whilst NeusoftTM maintains one clinical site. The most common CT scanner type was identified as the 16-row multidetector scanner (41 %).

In general, CT quality control was reported to be performed by the equipment manufacturer (68 %), with 13.6 % of institutions utilising an alternate quality control company, 6.8 % using local medical physics and the remainder (11.4 %) did not respond to the question.

Frequency of CT examinations

Head, chest and abdomen CT examinations were identified as the most commonly performed adult procedures (Table 2). Approximately 17 % of the public institutions and 33 % of the private did not provide information regarding the number of CT exams performed per year, whereas 18 % of the public and 17 % of the private institutions did forward information but with a degree of variability regarding the categorisation of anatomical regions.

The majority of respondents (68 %) stated paediatric imaging was not performed in their centre, of those undertaking paediatric examinations, 5 % employed modified adult protocols, whereas 27 % of centres used specific paediatric protocols. The frequency of paediatric CT examinations is summarised in Table 2 for clinical centres A and B. Hospital C did

not differentiate between adult and paediatric examinations and thus was omitted with respect to frequency evaluation. Examinations were categorised into seven types from a total of 6394 examinations (centre A, $n=3519$ and centre B, $n=2875$). Head and chest examinations were identified as the most frequently performed in the paediatric centres.

Portuguese proposed adult CT DRLs

The adult protocols were reviewed with respect to imaging parameters, including tube voltage, the tube current–time product, rotation time and field of view (FOV), used per anatomic region (Table 3). Mean CT dose values for adults ($CTDI_{vol}$ and DLP) were analysed in order to establish the DRLs at the 75th percentile as summarised in Table 4. The proposed Portuguese CT DRLs for the most commonly performed CT examinations are 75 mGy/1010 mGy cm for head, 14 mGy/470 mGy cm for chest and 18 mGy/800 mGy cm for abdomen. Comparison with published data from other European countries is summarised in Table 5.

Large variations in $CTDI_{vol}$ were noted between clinical sites with values for CT head ranging from 42 to 150 mGy, chest from 3 to 80 mGy and abdomen examinations from 3 to 50 mGy. Variations were also noted for spinal CT examinations with values of 7 to 190 mGy for cervical spine, 7 to 120 mGy for dorsal and 10 to 140 mGy for lumbar spine examinations.

Table 3. Summary of national CT exposure parameters by anatomic region for adult examinations in 2010.

Body region	Tube voltage (kV)	Tube current–time product (mA s)	Rotation time (s)	FOV (cm)
Head	125.11 (6.24)	282.95 (94.77)	1.78 (0.69)	22.62 (2.26)
Neck	121.82 (7.24)	186.45 (77.68)	0.80 (0.20)	22.18 (3.96)
Chest	121.14 (7.84)	179.98 (120.96)	0.69 (0.16)	36.88 (5.45)
Abdomen	122.50 (6.15)	226.88 (118.74)	0.70 (0.15)	37.76 (6.15)
Pelvis	123.86 (6.18)	208.37 (109.14)	0.76 (0.17)	38.60 (4.57)
Cervical	125.23 (7.31)	242.82 (92.30)	0.86 (0.24)	18.50 (9.08)
Dorsal	127.05 (8.23)	261.20 (95.25)	0.95 (0.23)	21.59 (9.17)
Lumbar	126.59 (9.14)	280.11 (89.37)	0.95 (0.26)	21.92 (10.35)
Joints	120.75 (13.85)	162.40 (79.34)	1.05 (0.89)	19.38 (6.53)

Values are mean (\pm SD).

Table 4. Proposed Portuguese CT DRLs for adult MSCT examinations described as CTDI_{vol} and DLP values, per body region.

Dose descriptor CTDI _{vol} (mGy) and DLP (mGy cm)		
Body region	Mean (\pm SD)	75th percentile
Head	69.95 (14.66)	75
	802.21 (387.76)	1010
Neck	19.75 (17.96)	20
	384.72 (225.83)	465
Chest	12.39 (12.02)	14
	389.96 (228.30)	470
Abdomen	13.96 (8.03)	18
	562.72 (315.85)	800
Pelvis	17.23 (17.05)	18
	542.93 (314.32)	645
Cervical	36.33 (36.22)	39
	483.35 (279.34)	600
Dorsal	29.17 (22.13)	33
	654.89 (407.75)	780
Lumbar	34.62 (26.55)	38
	650.61 (371.58)	845
Joints	19.23 (16.08)	25
	320.03 (321.44)	405

To facilitate comparison between the various equipment vendors, data from the most commonly used scanner, the 16-row multidetector scanner, were selected (Figure 2). General ElectricTM scanners returned the highest CTDI_{vol} values in 7 of the 8 anatomical CT examinations with SiemensTM noted as having the lowest CTDI_{vol} values for 5 of the 8 anatomical CT examinations.

Paediatric CT protocols

All the three CT scanners involved in paediatric data collection were all MSCT models. Two CT scanners

were manufactured by SiemensTM (64- and 6-row multidetector) and one by PhilipsTM (16-row multidetector).

The three regional centres categorised children by age; however, age subsets were defined differently across centres (Table 6) and were not aligned to paediatric radiography recommendations⁽¹⁷⁾ or in a format that matched other European paediatric CT DRL published data^(18, 19, 21).

Paediatric DRLs and radiation dose findings

The sample of patient data with respect to radiation dose was composed of 330 children: 42 % female and 58 % male. CTDI_{vol} values for head and chest CT examinations are represented in Figures 3 and 4.

Review of the collected data facilitates local DRL establishment in the three paediatric centres of excellence, and from this information, national CT DRLs are proposed (Table 7).

It is important to note that significant differences in head CTDI_{vol} values were identified, for the newborns and 5-y-old children across all centres. The highest variation in head CTDI_{vol} values was noted for newborns, with a 15.5-mGy SD. It is clear from the data (Figure 3) that in two of the three centres, CT protocols did not vary according to patient age.

For chest CT examinations, there was no significant difference between CTDI_{vol} values of 5- and 10-y-old children. The highest variation on chest CTDI_{vol} values between the centres was detected for 15-y-old patients (Figure 4). Again, there was no significant difference in CTDI_{vol} values for children 5, 10 and 15 y old.

Review of paediatric protocols

Analysis of the protocols for paediatric examinations was performed to ascertain the potential for optimisation and explanation of the variance in DRL findings. The protocols identified are summarised in Table 6,

Table 5. Comparison of proposed Portuguese adult CT DRLs with published international studies, for the most commonly performed examinations, described as CTDI_{vol} and DLP values.

Dose descriptor CTDI _{vol} (mGy) and DLP (mGy cm)						
Body region	This study	EUR (1999) 16262 ⁽²⁶⁾	UK (2003) MSCT ⁽²⁹⁾	MSCT (2004) ⁽³⁰⁾	ACR (2008) ⁽³¹⁾	DoseDatamed2 (2012) ⁽³²⁾
Head	75	—	80	60	75	65
	1010	1050	931	—	—	1000
Chest	14	—	13	10	—	10
	470	650	557	—	—	500
Abdomen	18	—	14	15	25	25
	800	780	559	—	—	400
Lumbar	38	—	—	15	—	35
	840	—	—	—	—	500

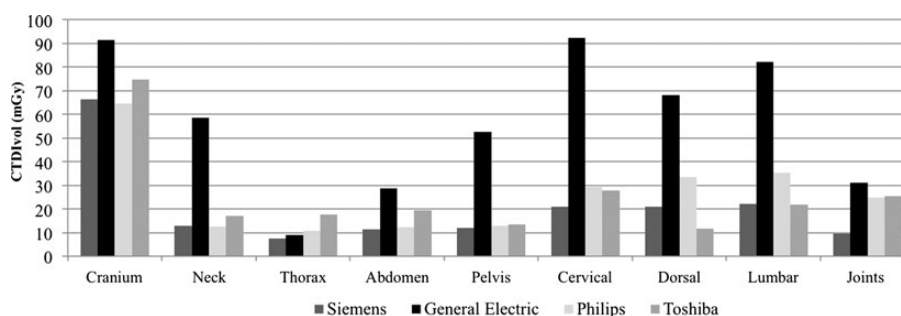


Figure 2. Adult mean CTDI_{vol}, for 16-slice MSCT scanners, for the four most common manufacturer suppliers.

Table 6. Head and chest CT protocols currently employed at the three national paediatric centres.

Centre	Protocol name	Tube voltage (kV)	Rotation time (s)	Tube current–time product (mA s)	Slice thickness (mm)	FOV (cm)	Mode	Pitch	Series	Dose modulation
Head										
A	0 to 3 y olds	120	1	230	4.8	18.7	Axial	—	1	no
	Children	120	1	310/290	2.4/4.8	20.4	—	—	2	no
B	Newborn	80	1.5	200	5.0	18.0	—	—	1	yes
	1 y olds	110	2.5	130	2.0	19.7	—	—	1	yes
	2 to 10 y olds	130	2.5	140	4.0	18.0	—	—	1	no
C	0 to 18 months	120	0.75	300	3.0	20.0	—	—	1	no
	18 month to 6 y olds	120	0.75	350/300	3.0/6.0	20.0	—	—	2	no
	>7 y olds	120	0.75	375/300	3.0/6.0	20.0	—	—	2	no
Chest										
A	0 to 3 y olds	80	0.5	50	5.0	25.4	Helical	0.8	1	no
	Children	100	0.5	50	5.0	25.4	—	0.8	1	no
B	Newborn	110	0.8	40	5.0	18.0	—	1.5	1	yes
	1 y olds	110	0.8	40	5.0	18.0	—	1.5	1	yes
	2 to 10 y olds	110	0.8	80	5.0	18.0	—	1.5	1	yes
C	Children	120	0.5	50	3.0	18.0	—	0.688	1	no

ADULT AND PAEDIATRIC PORTUGUESE CT DRLs

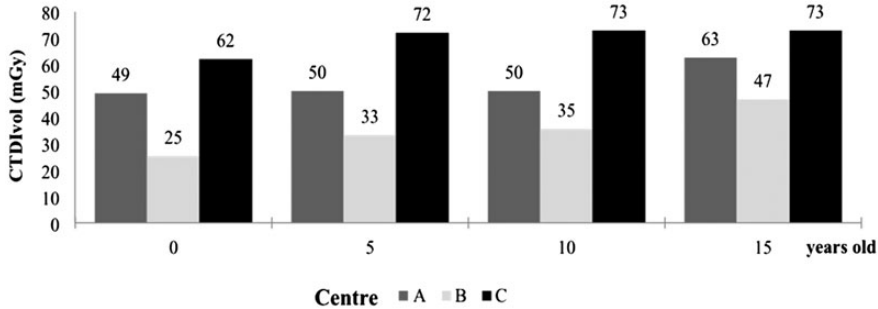


Figure 3. Head examination CTDI_{vol} values (percentile 75) per paediatric age categorisation across the three national Portuguese paediatric centres.

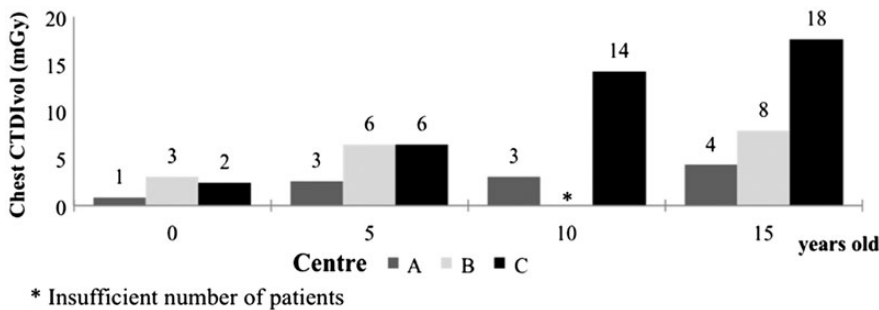


Figure 4. Chest examination CTDI_{vol} values (percentile 75) per paediatric age categorisation across the three national Portuguese paediatric centres.

Table 7. The proposed age-categorised national paediatric CT DRLs, described as CTDI_{vol} and DLP values, for head and chest CT examinations.

Dose descriptor	Age	CTDI _{vol} (mGy) and DLP (mGy cm)	
		Mean (± SD)	75th Percentile
Head	0	39.42 (15.55)	48.31
	5	511.75 (228.26)	630.00
		44.60 (14.34)	49.95
		673.57 (239.78)	767.00
	10	52.32 (14.25)	69.95
		785.43 (269.86)	1096.37
15	59.20 (12.53)	72.28	
	929.81 (233.99)	1119.70	
Chest	0	1.58 (0.87)	2.42
	5	26.31 (18.72)	42.75
		3.89 (2.17)	5.60
		98.33 (65.50)	138.50
	10	5.26 (4.03)	5.65
		175.77 (198.78)	186.00
15	6.27 (4.30)	7.19	
	212.18 (185.99)	194.50	

and it should be noted that all the paediatric centres employed axial mode for head examinations and helical mode for chest CT procedures. Dose modulation was only employed in centre B.

Centres A and C reported a 120 kV tube voltage (Table 6) for head CT examinations across all age groups whereas centre B modifies tube voltage for newborns (80 kV), increasing to 120 kV for 1-y-old children, and 130 kV for children >1 y old. Recommendations⁽³⁰⁾ indicate that the tube voltage should vary from low (<110 kV) to medium (110 to 130 kV) according to patient size; however, patient categorisation is not indicated.

Centre B also employs tube current modulation in addition to varying tube voltage and reported the lowest tube current–time product values, which were tailored to age categorisation. The exposure parameters selected in centre B resulted in the lowest obtained CTDI_{vol} values for the CT brain examination across the three paediatric centres as it also only undertakes a single series with slice thicknesses of 2–5 mm (Figure 3). In centres A and C, the choice of slice thickness varies from 2.4 to 3 mm for the infratentorial region and from 4.8 to 6 mm for the supratentorial region.

Centre A had the lowest $CTDI_{vol}$ values for CT examinations of the chest, for all age categorisation (Figure 4), potentially owing to low tube voltages adopted (Table 6), whereas centre B maintains a single tube voltage and reported tube current–time product modification within age categories. The selection of slice thickness remained constant in centres A and B (5 mm) whereas centre C reported use of 3-mm slice thicknesses combined with increased tube voltage levels, resulting in the highest $CTDI_{vol}$ values.

DISCUSSION

Equipment demographic

The survey response rate of 21 % whilst low is similar to that of the national survey of 2003 in the UK⁽¹⁸⁾. The Portuguese Healthcare System is mixed (public and private), and it is important to report that >50 % of the public institutions with CT equipment responded to the national survey, in comparison with just 10 % of private facilities. A number of factors could explain the difference in response between public and private installations, including protection of commercial interests, recent changes to imaging prescribing regulations and decreasing numbers of private installations affected by the county's current economic instability⁽³³⁾.

No statistically significant differences ($p > 0.05$) were identified when *independent samples t-test* was applied between private and public institutions CT dose values; however, increased data from private centres are needed.

Adult CT protocols

In the analysis of the obtained adult protocols (Table 3), the mean tube voltage of 125 kV was identified as common for all body regions, a comparable value with the UK survey model value (120 kV)⁽¹⁸⁾. Recent research studies currently recommend the use of lower tube voltages (from 120 to 80 kV) to aid dose optimisation especially for smaller size patients and during angiographic studies^(34, 35), indicating that the Portuguese settings require further optimisation.

Of interest was the substantial range of tube current–time product values reported for the chest (180 ± 121 mA s), abdomen (227 ± 119 mA s) and pelvis (208 ± 109 mA s) examinations, findings equally reflected in the mean and standard deviation of the $CTDI$ and DLP values (Table 4), highlighting the significant variations in scan parameter use identified as a result of the national survey and points to potential areas of optimisation. CT head examinations were also found to be performed in axial mode with two different series (supratentorial and cranial base) (80 %), with different slice thickness, which could explain the higher than expected CT dose values for

this anatomic region and is contrary to European guidelines for MSCT examinations⁽³⁰⁾.

In addition, noticeably high readings were identified for dorsal and lumbar spine examinations compared with the recommended EU levels; an explanation for this is most likely that the guidelines are for target volumes in the spine focussed upon areas of suspected pathology whereas in specific centres, the entire spinal region had been included in the examination procedure. Limiting the range of CT scanning just to the relevant region of interest is one of the simplest ways to limit the radiation exposure of patients and should be encouraged⁽³⁶⁾. It should be emphasised that although helical technology possesses the potential to easily extend scan ranges, routine use can lead to unjustifiable patient doses⁽³⁷⁾.

Paediatric CT protocol

Limited literature is available for comparison with paediatric CT imaging protocols across European countries. Paediatric CT DRL data are available from Ireland⁽¹⁹⁾, UK⁽¹⁸⁾, Germany⁽²⁰⁾ and Switzerland⁽²¹⁾, and these are defined for the most commonly performed examinations, to include head, chest and abdomen procedures. According to the frequency of CT examinations, in Portugal, upper abdominal CT examinations are uncommon in children. Irish and UK DRLs for paediatric CT are divided into three groups: <1 y, 5 y and 10 y old^(18, 19). Switzerland categorises children into four age groups: <1 y, 1–5 y, 5–10 y and 10–15 y old⁽²¹⁾. German authors identified five categories of age, namely newborns, up to 1 y, 2–5 y, 6–10 y and 11–15 y old⁽²⁰⁾. MSCT guidelines⁽³⁰⁾ are defined for specific pathology but only for newborns and 4- to 6-y-old patients. Thus, there appears to be a lack of standardisation with respect to age categorisation of paediatric patients for CT protocols across European countries. In order to facilitate dose level comparisons, all centres should adhere to common European policy.

The MSCT guidelines⁽³⁰⁾ recommend that tube current–time product should be adjusted to patient size and indicates low exposure for infants; however, no values are given. In this study, the tube current–time product varies from 225 to 350 mA s and 25 to 64 mA s for head and chest CT examinations, respectively. This variation was reflected in dose levels reported for different ages, potentially owing to the lack of standardisation of protocols between centres, with the added factor of varied age categorisation between centres adding a further confounder.

Recent research studies indicate that automated tube current modulation in paediatric examinations is based on patient size, i.e. the CT examinations being with a tube current adequate to the standard paediatric patient (5 y and 20 Kg). Therefore, young children will be exposed to less mA s reference value and older

children will exceed the reference value^(5, 38, 39). Other studies indicate that modulation has more impact on adult dose reduction than that on children⁽⁴⁰⁾ with one study reporting that automatic tube current modulation whilst decreasing adult dose negatively increased paediatric dose in specific circumstances⁽⁴¹⁾. In Portugal, only centre B employs automated tube current modulation for paediatric patients and this is reflected in the lower mean dose findings.

DRLs comparison

The adult CT DRLs obtained were compared with those of other international studies (Table 5)^(26, 29–32). The Portuguese CTDI_{vol} values for chest and lumbar CT examinations are highest of the published data sourced. For abdomen CT examinations, CTDI_{vol} values issued by the American College of Radiology (ACR)⁽³¹⁾ and by DoseDatamed2⁽³²⁾ are 36 % higher; however, the values of MSCT UK⁽¹⁸⁾ and MSCT guidelines⁽³⁰⁾ are ~20 % lower. The CT dose values reported for head CT examinations are lower than those of MSCT UK, equal to ACR and higher than the MSCT guidelines and DoseDatamed2.

In comparison with European Guidelines⁽²⁶⁾, the Portuguese DLP values for head and chest examinations are lower and a comparable DRL value for the abdomen examinations noted. However, the European values are defined for single-slice CT scanners, of which there were only two included in this study. A possible explanation for the differences on abdomen CT examinations may be related to different scan lengths utilised as Portuguese routine protocols scan from the diaphragm to the aortic bifurcation; however, RP 154⁽²⁷⁾ defines the abdomen CT as 'abdominal organs study' and includes both 'full abdomen' and 'upper abdomen' CT examinations. Therefore, interpretation of dose data from abdominal examinations needs to relate clearly to the anatomical region included.

A comparison of proposed paediatric CT DRLs, for head and chest examinations, with European countries is outlined in Table 8. The proposed Portuguese CTDI_{vol} and DLP values for head CT are higher than the UK⁽¹⁸⁾ and Germany⁽²⁰⁾ CT dose values.

Two of the Portuguese centres perform two series for head CT examinations; direct comparison of slice thickness can be made with only centre B. The UK⁽¹⁸⁾ survey reported only one series, with 4-mm slice thickness for all age groups in helical mode, instead of different slice thickness per age categorisation. The obtained DLP values for 10- and 15-y-old head CT examinations are higher than those for the adults. This suggests that children are being over-exposed with inappropriate protocols.

The CTDI_{vol} values of chest examinations obtained were found to be similar to the German DRLs for newborns and 5-y-old children. It should also be noted that despite the pitch value (1.4) used in centres A and C, the resultant dose findings are still lower than those in the UK survey⁽¹⁸⁾.

Overall, the CTDI_{vol} findings are lowest in the 10-y-old category, which may be due to low tube current–time product value used across the centres (40–80 mA s), and subsequently DLP dose levels were found to be the lowest.

Despite some encouraging findings, there is still substantial evidence of protocol differences and a lack of continuity in the manner with which paediatric patients are age-categorised and examined in the dedicated Portuguese paediatric centres. Furthermore, one must also consider that whilst Portugal has three national paediatric centres and three further sites with specialised paediatric services, incorporating 24 h care, a large proportion of paediatric CT examinations are performed in adult centres, potentially without tailored paediatric protocols⁽¹⁵⁾. These findings support the need for further investigation with respect to optimisation of CT protocols for paediatric examinations.

CONCLUSIONS

Portuguese DRLs for CT examinations have been identified for both adult and paediatric patients. Results indicate that the most common adult Portuguese CT examinations are head, chest and abdomen, with DRLs of 75, 14 and 18 mGy CTDI_{vol}, respectively. These values are ~30 % higher than European recommendations. Differences in

Table 8. Comparison of Portuguese paediatric head and chest CT DRLs with published international values, described as CTDI_{vol} and DLP values.

Dose descriptor	CTDI _{vol} (mGy) and DLP (mGy cm)													
	This study				UK, 2003 ⁽¹⁸⁾			Ireland, 2004 ⁽¹⁹⁾			Germany, 2006 ⁽²⁰⁾			
	<1	5	10	15	<1	5	10	<1	5	10	<1	[1,2[[2–5]	[6–10]
Head	48	50	70	72	28	43	51	—	—	—	27	33	40	50
	630	770	1100	1120	270	465	619	300	600	750	—	390	520	710
Chest	2.4	5.6	5.7	7.1	12	13	17	—	—	—	2	3.5	5.5	8.5
	45	140	185	195	204	228	368	200	400	600	55	110	210	55

protocols to image-specific anatomical regions are non-standardised, and an ~20 % variation dose was found across centres nationally. DRLs have also been established for six other CT examinations. The majority of proposed adult DRLs for CT examinations are higher than those of other European CT DRLs.

For paediatric head and chest CT examinations, DRLs proposed are 48 and 2 mGy for newborns, 50 and 6 mGy for 5 y olds, 70 and 6 mGy for 10 y olds and 72 and 7 mGy for 15-y-old children, respectively. The proposed DRLs for paediatric head CT examination are higher than those of European values whereas the proposed chest CT examination DRLs are similar across all age categories.

The findings of this work justify further research in the optimisation of CT protocols with the overall aim of reducing DRLs and individual patient dose levels.

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