Radiation Doses in Pediatric Computed Tomography Procedures: *Challenges Facing New Technologies*

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Abstract. Despite the fact that in recent years an increasing number of radiologists and radiological technologists have been applying radiation dose optimization techniques in paediatric Computed Tomography (CT) examinations, dual and multi -slice CT (MSCT) scanners present a new challenge in Radiation Protection (RP). While on one hand these scanners are provided with Automatic Exposure Control (AEC) devices, dose reduction modes and dose estimation software, on the other hand Quality Control (QC) tests and CT Kerma Index (*C*) measurements and patient dose estimation present specific difficulties and require changes or adaptations of traditional QC protocols. This implies a major challenge in most developing countries where Quality Assurance Programmes (QAP) have not been implemented yet and there is a shortage in the number of medical physicists This paper analyses clinical and technical protocols as well as patient doses in 204 CT body procedures performed in 154 children. The investigation was carried out in a paediatric reference hospital of Uruguay, where are performed an average of 450 paediatric CT examinations per month in a sole CT dual scanner. Besides, C_{VOL} reported from the scanner display was registered in order to be related with the same dosimetric quantity derived from technical parameters and C values published on tables. Results showed that not all the radiologists applied the same protocol in similar clinical situations delivering unnecessary patient dose with no significant differences in image quality. Moreover, it was found that dose reduction modes represent a drawback in order to estimate patient dose when mA changes according to tissue attenuation, in most cases in each rotation. The study concluded on the importance of QAP that must include education on RP of radiologists and technologists, as well as in the need of medical physicists to perform QC tests and patient dose estimations and measurements.

Key words: Paediatric, Patient dose, Multiple Slice Computed Tomography

1. Introduction

The International Conference of Radiological Protection of Patients in Diagnostic and Interventional Radiology, Nuclear Medicine and Radiotherapy held in Malaga, Spain, in March 2001, estimated that doses in diagnostic imaging could be reduced without image quality being affected, taking special attention on paediatric patients due to the high radiosensitivity of children tissues [1].Malaga Conference recommendations included optimization in CT examinations because they are recognized as high dose procedures, causing the largest amount (i.e., 35 – 40 %) of the collective effective dose of x rays owing to diagnostic procedures [2]. In developed countries, this percentage can reach the 50 % or more - in one American radiology department CT contributed about the 67% of its collective patient dose. In addition, the frequency of CT examinations has been increasing rapidly from 2% of all radiological examinations in some countries a decade ago to 10-15 % now [3].

Fulfilling national laws or following regional directives or international recommendations [3, 4, 5], in recent years, and in some countries, an increasing number of radiologists and technologists have been applying radiation dose optimization techniques in paediatric CT. Besides, various international and regional organisms - i.e. International Atomic Energy Agency, World Health Organization, Pan American Health Organization, European Commission -, some national regulatory authorities as well as hospitals in an independent way, have been investigating patient doses in CT and establishing Guidance (Reference) Levels (GL) for most frequent CT procedures, at least for adult patients [5, 6, 7], in accordance with international recommendations [8, 9, 10].

However, dual and MSCT scanners present a new challenge in RP, particularly of paediatric patients. On one hand, this equipment is provided with AEC devices, dose reduction modes and dose estimation software that constitute helpful tools for optimization only if they are well known -and used. On the other hand, dual and MSTC scanners delivered, potentially, higher doses than single-detector row CT scanners due to new specific parameters that may increase patient dose. Due to this, new dosimetric quantities have been introduced, and consequently QC tests. *C* measurements and patient dose estimation present specific difficulties, requiring changes or adaptations from the so-called traditional protocols.

The aforementioned elements imply a major challenge in most developing countries where QAP are not still mandatory and the number of medical physicists is not enough. Despite not having enough information available about patient doses in CT examinations in these countries, this does not mean that in some of them individual and collective CT doses are lower than those reported from developed countries.

In Uruguay -3.2 million inhabitants- the implementation of QAP in diagnostic imaging is not mandatory. In 2001, there were 20 CT scanners all over the country [11], but at the present time this number has been incremented in 50 %. Most of them are in Montevideo, the capital, concentrated in an area of 530 Km², where 1.3 million people live. Although CT paediatric examinations are performed in most of them, there is a sole paediatric reference hospital in which around 440 CT paediatric procedures are carried out per month in a dual scanner.

Purpose. The main goal of the present paper is to evaluate radiation doses received by children in CT procedures performed in a third level paediatric hospital of Uruguay, as well as to relate them with those reported from the scanner display. Secondary goals are to analyze technical and clinical protocols in order to find out possibilities of modifying or correcting those aspects of the practice conducive to children dose reduction with no lost of image quality (Optimization RP Principle).

2. Material and Methods

The investigation was undertaken in a third level paediatric center of Uruguay, where an average of 800 CT procedures -450 of them correspond to paediatric patients- are performed per month in a sole CT dual scanner, Siemens Emotion Duo, installed in November 2005. The scanner has never been subjected either to QC tests or dosimetric evaluations due to the lack of appropriate instrumentation, likewise in all the CT scanners of the country.

The staff is composed of 5 permanent radiologists and 10 permanent radiological technologists as well as a similar number of turn-over radiologists and 3 turn-over radiological technologists to cover holidays.

Chest -both in helical and axial modes-, chest & abdomen, chest, abdomen & pelvis and abdomen & pelvis examinations were chosen for the evaluations because they are usually performed in most radiology departments that carry out paediatric CT procedures.

Children were subdivided in four age groups considering variations of body sizes: 1 year old, 5 years old, 10 years old, and between 11 and 14 years old.

Following published recommendations [7, 12], dosimetric quantities chosen to evaluate children doses were C_{VOL} and $P_{KL,CT}$. The foremost was defined by the International Electrotechnical Commission as a volume average dose which takes into account the helical pitch or the axial scan spacing for a patient examination:

$$C_{VOL} = C_W \frac{NT}{l} = \frac{C_W}{p} \qquad (1)$$

Where: N is the number of simultaneously acquired tomographic slices, T is the nominal slice thickness, l is the distance moved by the patient couch per helical rotation -or between scans for a series of axial scans-, and p is the pitch factor. For MSCT, NT should be the total nominal width of the x ray beam.

Equation (1) shows that C_{VOL} is derived from C_W which is calculated from $C_{PMMA,100}$. The latter is measured using a specially designed pencil ionization chamber with an active length of 100 mm for the tube-current exposure, $P_{I,t}$, of 100 mAs. Measurements are performed in the centre ($C_{PMMA,100,c}$) as well as in four positions of the periphery ($C_{PMMA,100,p}$) of head (H) and body (B) standard CT dosimetry phantoms (16 and 32 diameter, respectively). From these data is defined the weighted C, $C_{W,H/B}$ (expressed in Gy/ 100 mAs), as follows:

$$C_{W,H/B} = \frac{1}{3}\left(C_{PMMA,100,c} + 2C_{PMMA,100,p}\right) \quad (2)$$

In order to obtain C_{VOL}, first, $C_{W,H/B}$ must be normalized to unit $P_{I,t}$:

$$nC_{W,H/B} = \frac{C_{W,H/B}}{100} \quad (3)$$

Where the subscript n is used to denote when the value of C or C_W has been normalized to unit Pit:

$$nC_W = \frac{C_W}{P_{I,t}} \quad (4)$$

Finally, to apply (1) C_W must be obtained by multiplying $C_{W,H/B}$ with the $P_{I,t}$ per each scan rotation. Dual and MSCT with x ray tube current modulation techniques vary the tube current for each rotation, to compensate changes in the pitch in order to maintain a constant noise and patient dose [13]. A parameter named “effective mAs” or “mAs per slice” is sometimes quoted in these scanners, designed to reflect the effect on the average absorbed dose in the scanned volume when the pitch changes. Consequently, for dose calculations it is important to distinguish between one quantity and the other:

$$\text{"}Effective\text{"}\, mAs = \frac{P_{I,t}}{p} \quad (5)$$

The other dosimetric quantity chosen was the CT air kerma–length product, $P_{KL,\,CT,}$ for the whole CT examination. This quantity is an indicator of the integrated radiation dose of an entire CT examination:

$$P_{KL,CT} = \sum_j nC_{VOLj} \times l_j \times P_{I,tj} \quad (6)$$

Where j represents each serial or helical scan sequence forming part of the examination, lj is the distance moved by the patient couch between or during consecutive scanner rotations and $P_{I,tj}$ is the total tube loading for scan sequence j. The units are Gy.m. In practice, $P_{KL,CT}$ for the complete examination is obtained by adding together the contributions from each individual scan sequence of length L (displayed in the scanner monitor):

$$P_{KL,CT} = nC_{VOL} \times l \times P_{I,t} = C_{VOL} \times L \quad (7)$$

Although this quantity reflects most closely the radiation dose for a specific CT examination than C_{VOL}, its numeric value is affected by variations in patient anatomy (e.g., the value of $P_{KL,\,CT}$ is higher for taller patients only because of their greater height). Therefore, some authors consider that C_{VOL} is more useful in designing CT imaging protocols and comparing radiation doses among different protocols. However, most protocols include both dosimetric quantities.

As aforementioned, no instrumentation is available for dosimetric purposes. Consequently, $C_{W,H/B}$ was derived from $C_{PMMA,100,c}$ and $C_{PMMA,100,p}$ values corresponding to kVp values applied in the clinical practice for Siemens Emotion Duo scanner obtain from ImPACT worksheet Version 0.99x 20/01/06 [14]. Taking into account children sizes and following recommendations for paediatric CT dose evaluation [7], chosen $C_{PMMA,100,c}$ and $C_{PMMA,100,p}$ were those measured in a head CT dosimetry phantom. Each $nC_{W,H}$ (no more $nC_{W,H/B}$) was normalized to unit $P_{I,t}$,, as well as corrected with the collimation factors presented in ImPact worksheet that vary according to the collimation used in each CT sequence. These factors result in relating the total nominal x-ray beam width along the z axis and the reference collimation (usually 10 mm), and is 1,00 for collimations of 10 and 5,0 mm, 1,01 per 8,0 and 3,0 mm, and 0,97 for a selected collimation of 2,0 mm. $C_{PMMA,100,c}$ and $C_{PMMA,100,p}$ values obtained in ImPact worksheet take into account the number of simultaneously acquired slices per rotation.

The collected data included patient age, genre and the contour of the examined region measured by a sole radiological technician and for each child in a representative axial image of the exam using a scanner tool (named "free distance"). This parameter was chosen because in the CT sector it is not usual to register patient weight and height, as well as that the contour is closely related to children sizes. Besides, technical parameters for each sequence were registered: kV and $P_{I,t}$ settings ("effective mAs"); pitch; exposure time; collimation; scan length of each sequence; and scanner operation mode (axial or helical). Moreover, C_{VOL} reported from the scanner display was registered in order to be related with the same dosimetric quantity estimated as aforementioned. Finally, it was also registered whether the sequences was performed in manual mode or with AEC. This device in Siemens Emotion Duo (CareDose4D) obtains the attenuation information to adapt the tube current for patient size from the planning scan projection radiograph (SPR, ScoutView, Topogram, etc.) and uses 'online' data from the preceding 180° of rotation to modulate the tube current; this parameter for standard patients is specified by the user.

3. Results and discussion

204 procedures performed in 154 children were analyzed. The number of each type of examination and sequences performed, as well as operation modes of the CT scanner and children data are shown in Table 1. Similar mean values of the contours of the examined regions (with low standard deviations) were obtained for each age group in all types of studies, despite these results not being shown due to the lack of space.

Table 1. Number of children examined and number of sequences performed in each CT study, as well as children data (mean age and genre).

Examination	Operation Mode	Children (Number)	Sequences (Number)	Children data: Age (years) (mean± sd)	Genre (%) Girls	Genre (%) Boys
Chest	Axial	21	21	6,9 ± 4,4	61,9	38,1
	Helical	41	46	8,4 ± 4,3	51,2	41,8
Abdomen & pelvis	Helical	39	80	6,4 ± 4,8	35,9	64,1
Chest & abdomen	Helical	14	15	8,1 ± 4,8	50,0	50,0
Chest, abdomen & pelvis	Helical	39	42	9,0 ± 4,3	38,5	61,5

The highest average number of sequences performed per examination was found in abdomen & pelvis (80 / 39). However, 11 children were subject up to 3 sequences and 12 children up to 2 sequences in a sole examination. For the other types of examinations similar number of sequences and exams per children were found

Tables 2 to 5 show mean and third quartile values of C_W, C_{VOL}, $P_{KL,CT}$, kVp and $P_{I,t}$ for each type of examination and for all age groups, as well as the specification whether the exams were performed by using the AEC device. Besides, Fig. 1 to 4, show third quartile values (GL) of $P_{KL,\,CT}$ for each type of examination and age group. For those type of exams performed with an without AEC, in all of them and for all age groups, significant low mean and third quartiles values of $P_{I,t}$ were obtained for studies performed with AEC. Besides, significant low mean and third quartiles values of C_W, C_{VOL} and $P_{KL,CT}$, were found for all types of studies and for all age groups performed with the AEC device, with only one exception. This corresponds to abdomen & pelvis (Table 3) performed with AEC in children between 11 and 14, and is probably due to low pitch values (*0, 5*) selected by radiological technologists. It should be also noted that mean and third quartile values of $P_{KL,CT}$ are low when the AEC device is used although this dosimetric quantity depends not only on C_{VOL} but also on the number of sequences acquired for each child as well as the total length of the scanned region.

Table 2. Mean and third quartile values of C_W, C_{VOL} and $P_{KL,CT}$ for each age group in axial an helical chest CT exams, in manual and AEC operation modes.

Axial chest		**AEC** (c)	**C_W (mGy)**	**C_{VOL} (mGy)**	**$P_{KL,TC}$ (mGy.cm)**	**kVp**	**$P_{I,t}$ (mAs)**	**R C_{VOL}** (d)
	Mean ± sd (b)	NO	17,2±0	1,72±0	52±0	130±0	80±0	0,994
	Third quartile		17,2	1,72	52	130	80	
1 y o(a)	Mean ± sd	YES	5,3± 0,4	0,53±0,04	6 ± 1	110±0	37±3	1,091
	Third quartile		5,5	0,55	6,6	110	38	
5 y o	Mean ± sd	YES	6,4±1,1	0,64±0,11	13±7	110±0	44±8	1,084
	Third quartile		7,3	0,73	14	110	50	
10 y	Mean ± sd	YES	7,2±2,5	0,72±0,25	15±3	110±0	50±17	1,019
	Third quartile		8,0	0,80	17	100	55	
>11 y o	Mean ± sd	NO	17,2± 0	1,72±0	43 ±8	130±0	80±0	0,994
	Third quartile		17,2	1,72	46	130	80	
	Mean± sd	YES	7,6±1,6	0,76±0,16	16±6	110±0	52±11	1,085
	Third quartile		9,3	0,93	19	110	60	
Helical chest								
1 y o (a)	Mean ± sd(b)	NO	16,1±0	8,1±0	97±0	130±0	75±0	0,998
	Third quartile		16,1	8,1	97	130	75	
	Mean ± sd	YES	3,9±1,0	2,0±0,5	20±6	115±9	24±2	1,061
	Third quartile		4,1	2,1	21,4	115	25	
5 y o	Mean ± sd	NO	17,2±1,7	8,6±0,8	161±29	130±0	80±8	0,997
	Third quartile		17,7	8,9	177	130	83	
	Mean ± sd	YES	4,9± 0,9	2,5± 0,5	62±34	123±10	27±4	1,015
	Third quartile		5,4	2,7	53	130	28	
10 y o	Mean ± sd	NO	17,0±1,5	8,8±1,8	191±59	130±0	79±7	1,036
	Third quartile		17,2	8,6	202	130	80	
	Mean ± sd	YES	5,9±0,6	3,0±0,3	59±3	130±0	28±3	0,975
	Third quartile		6,1	3,1	61	130	29	
>11 y o	Mean ± sd	NO	16,1±2,2	8,1±1,4	203±55	130±0	75±10	1,005
	Third quartile		16,9	8,5	229	130	70	
	Mean ± sd	YES	9,2±4,8	4,6±2,4	62± 18	130±0	43±23	0,979
	Third quartile		11,0	5,5	74	130	51	

[(a)] years old ; [(b)] standard deviation; [(c)] Automatic Exposure Control [(d)] C_{VOL} cal/ scanner: relation between C_{VOL} calculated and C_{VOL} displayed in the scanner monitor

Results also show that differences in mean and third quartile values of C_W and C_{VOL} are higher in small children. For example, in helical chest sequences performed with AEC (Table 2), mean C_{VOL} is 43 % lower than when AEC is not used. For children aged 10, this percentage is 66 %; for children aged 5 increased up to 71 %, and for children aged 1 is 76 %. The explanation is that in manual operation mode the radiological technologists selected similar technical parameters for all age children, delivering unnecessary- and significant- higher doses to small patients.

Figure 1. Third quartile values of $P_{KL,CT}$ in the whole chest examination (axial and helical) performed in manual and Automatic Exposure Control operation modes for all age groups.

(a) Axial (b) Helical

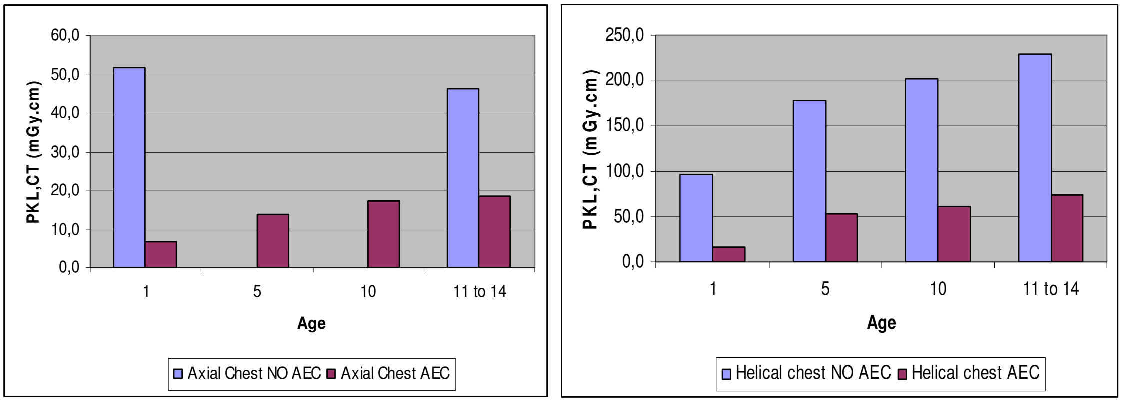


Table 3. Mean and third quartile values of C_W, C_{VOL} and $P_{KL,CT}$ for each age group in Abdomen & pelvis CT exams, in manual and Automatic Exposure Control operation modes.

Abdomen & pelvis		**AEC** (c)	**C_W (mGy)**	**C_{VOL} (mGy)**	**$P_{KL,TC}$ (mGy.cm)**	**kVp**	**$P_{I,t}$ (mAs)**	**R C_{VOL}** (d)
1 y o(a)	Mean ± sd (b)	NO	15,5± 2,1	7,8±1,1	340±337	126±8	78±10	1,013
	Third quartile		17,2	8,6	490	130	80	
	Mean ± sd	YES	5,3±1,6	2,6±0,8	88±46	123±10	27±5	1,007
	Third quartile		6,7	3,4	139	130	32	
5 y o	Mea n± sd	NO	15,6±1,3	9,2±2,8	376±289	123±10	84±7	1,227
	Third quartile		17,2	9,7	614,9	130	90	
	Mea n± sd	YES	8,6±7,1	5,1±5,2	164±211	114±9	49±28	1,467
	Third quartile		5,5	2,8	118,3	110	38	
10 y o	Mean ± sd	NO	16,5±1,9	8,3±1,0	404 ±278	126±8	83±5	1,011
	Third quartile		17,2	8,6	576	130	83	
	Mean ± sd	YES	6,5±1,5	3,9±1,5	91±44	120±12	36±0	1,198
	Third quartile		7,1	4,5	110	125	36	
>11 y o	Mean ± sd	NO	15,1±3,6	8,4±2,7	414±237	122±10	82±14	1,111
	Third quartile		17,2	8,6	499,5	130	90	
	Mean ± sd	YES	17,4±7,1	26,7±22,8	720±604	120±10	93±20	2,522
	Third quartile		23,6	47,2	982	130	110	

(a) years old ; (b) standard deviation; (c) Automatic Exposure Control; (c) C_{VOL} cal/ scanner: relation between C_{VOL} calculated and C_{VOL} displayed in the scanner monitor

Standard deviations for $P_{KL,CT}$ are high due to this dosimetric quantity depends on the total length of the scan region as well as on the number of sequences performed by patient, and the latter is in close relation with each specific clinical purpose. Due to the high standard deviations found, median values of $P_{KL,CT}$ were calculated but there are not shown here. Standard deviations for C_{VOL} are high only for a few of isolated cases. For example, in children aged 5 subject to abdomen & pelvis examinations with the AEC device (Table 3), C_{VOL} is (5, 1 ± 5, 2) mGy. This standard deviation is due to in the half of the sample, pitch values of *1, 5* were selected by the radiological technologists. The other example is in children between 11 and 14 years old subject to abdomen & pelvis examinations with the AEC device (Table 3) that was aforementioned discussed. Finally, in children aged 5 in Chest & abdomen examinations performed without AEC (Table 4), C_{VOL} is (13, 9± 8, 6) mGy. In this case, the sample was very small (only 3 children) and in one of them the selected pitch value was *0, 9.*

Table 4. Mean and third quartile values of C_W, C_{VOL} and $P_{KL,CT}$ for each age group in Chest & abdomen CT exams, in manual and Automatic Exposure Control operation modes

Chest & abdomen		AEC (c)	C_W (mGy)	C_{VOL} (mGy)	$P_{KL,TC}$ (mGy.cm)	kVp	$P_{I,t}$ (mAs)	R C_{VOL} (c)
1 y d (a)	Mean ± sd(b)	NO	17,2 ±0	8,6 ±0	172±0	130±0	80±0	0,995
	Third quartile		17,2	8,6	172	130	80	
	Mean ± sd	YES	3,8± 0	1,9±0	47±0	110±0	26±0	1,047
	Third quartile		3,8	1,9	47	110	26	
5 y o	Mean ± sd	NO	18,3±2,5	13,9±8,6	329±216	130±0	85±12	1,431
	Third quartile		19,4	16,8	425	130	90	
	Mean± sd	YES	5,0± 0,9	2,5±0,5	71±19	120±12	28±1	1,023
	Third quartile		5,4	2,7	79	120	29	
10 y o	Mean ± sd	NO	17,2±0	8,6±0	146±10	130±0	80±0	0,995
	Third quartile		17,2	8,6	150,5	130	80	
	Mean ±sd	YES	6,7±0	3,3±0	107±12	130±0	31±0	0,983
	Third quartile		6,7	3,3	112	130	31	
>11 y o	Mean ±sd	NO	17,2±0	8,6±0	318±27	130±0	80±0	0,995
	Third quartile		17,2	8,6	344	130	80	

[(a)] years old ; [(b)] standard deviation; [(c)] Automatic Exposure Control [(c)] C_{VOL} cal/ scanner: relation between C_{VOL} calculated and C_{VOL} displayed in the scanner monitor.

Figure 2. Third quartile values of $P_{KL,CT}$ in the whole abdomen & pelvis examination, performed in manual and Automatic Exposure Control operation modes for all age groups.

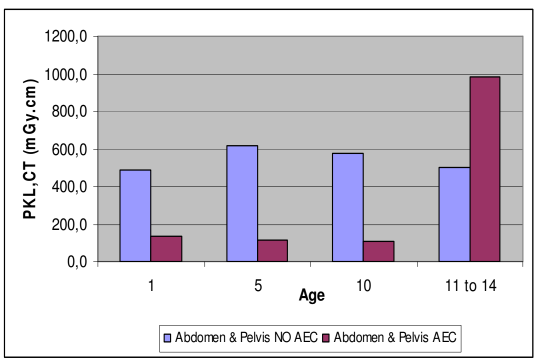
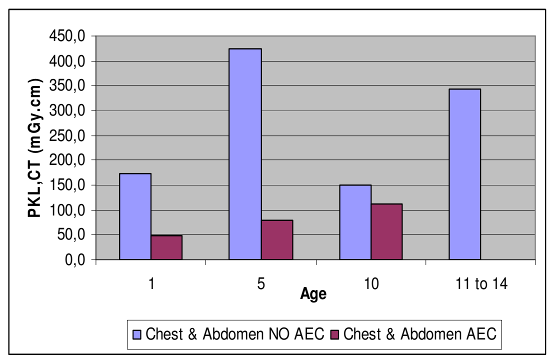


Figure 3. Third quartile values of $P_{KL,CT}$ in the whole chest & abdomen examination, performed in manual and Automatic Exposure Control operation modes for all age groups.



Values of C_{VOL} calculated for each scanner following the methodology previously explained were compared against any values reported form the scanner display for all sequences of all types of examinations. The present paper only shows (right columns of Tables 2 to 5) means ratios calculated from each type of examination and age group, despite a complete statistical analysis was carried out. Mean values obtained in the present investigation agree with other published [7] due as they are close to the unit (mean value of mean ratio= *1, 13*), as well as in the wide differences for a few particular cases (maximum ratio: *2,55*). Disagreement is explained by the difference in the way that C_W are calculated (and hence C_{VOL} and $P_{KL,CT}$) following recommendations that, irrespective of children age and exam, should be obtained from 16 cm diameter standard CT dosimetry phantom. However, manufacturers not always follow this convention, and if CW is measured in a 32 phantom, its value is half the one obtained from a 16 cm diameter phantom. The present investigation also studied the mean ratios of C_{VOL} using the 32 cm diameter phantom for all sequences performed in all children, but results are similar to those obtained with a 16 cm diameter phantom. Consequently, another source of uncertainty in C_{VOL} may be the used of "effective mAs" rather than the average $P_{I,t}$ in each sequence. In practice, the latter is nearly impossible to obtain in helical exams performed with dual and MSCT because its value changes in each image, and when the examination finishes not all the real images obtained are available because most of them have been processed (reconstructed).Finally, disagreement is $P_{KL,CT}$ may be due to differences in the total length of each of the several sequences that conform an examination.

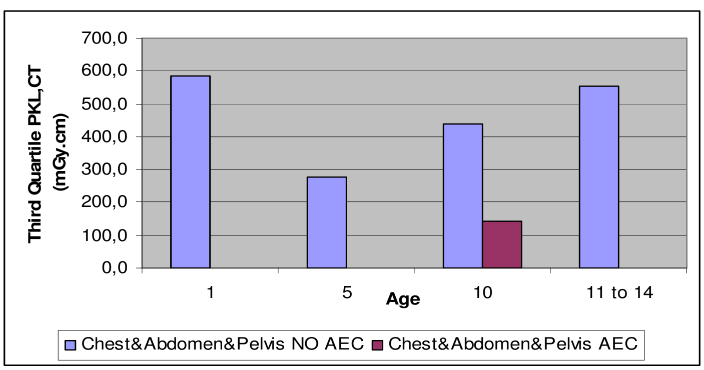
This investigation found that most of the exams are performed without the AEC device because radiologists consider that the noise in the images does not allow them the adequate diagnosis. The sole exception is axial (high resolution) chest examinations. Besides, technical parameters are selected by each radiological technician without following any kind of protocol. In relation with clinical protocols, radiologists decide in each particular clinical case the way to study it.

Table 5. Mean and third quartile values of C_W, C_{VOL} and $P_{KL,CT}$ for each age group in Chest & abdomen & pelvis CT exams, in manual and Automatic Exposure Control operation modes.

Chest & abdomen & pelvis		**AEC** (c)	**C_W (mGy)**	**C_{VOL} (mGy)**	**$P_{KL,TC}$ (mGy.cm)**	**kVp**	**$P_{I,t}$ (mAs)**	**R C_{VOL}** (c)
1 y o	Mean ± sd (b)	NO	13,1±0	11,3±4,4	459±247	110±0	90±0	1,866
	Third quartile		13,1	14,5	587	110	90	
5 y o	Mean ± sd	NO	16,0± 1,3	8,0± 0,7	255± 51	127±7	79±5	1,009
	Third quartile		16,7	8,3	278,7	130	80	
10 y o	Mean ± sd	NO	16,8± 1,8	9,3±2,3	430 ±11	129±5	80±7	1,129
	Third quartile		17,2	8,6	439,4	130	80	
10 y o	Mean ± sd	YES	6,7±0,2	3,3±0,1	141± 5	123±10	36±8	1,013
	Third quartile		6,8	3,4	142,7	130	39	
>11 y o	Mean ± sd	NO	17,0±2,4	9,6±2,6	521±168	127±7	83±8	1,149
	Third quartile		17,2	8,6	555	130	88	

[a] years old ; [b] standard deviation; [c] Automatic Exposure Control [d] C_{VOL} cal/ scanner: relation between C_{VOL} calculated and C_{VOL} displayed in the scanner monitor

Figure 4. Third quartile values of $P_{KL,CT}$ in the whole abdomen & pelvis examination, performed in manual and Automatic Exposure Control operation modes for all age groups**.**



Although patient dose and image quality should be evaluated together, the latter was not analyzed in the present paper. However, some examples of images obtained with the scanner where this investigation was carried out are given to demonstrate that it is possible to reduce patient dose with no significant loss of image quality for diagnosis purposes. Fig. 5 shows images corresponding to patients with significant differences in patient sizes (one is a newly-born and the other a 13 years old child), but receiving similar doses (C_{VOL} in both cases is 6, 0 mGy) because the AEC device was not used**.** Fig. 6 shows how the AEC device adapts the tube current to the attenuation of each particular anatomical region or patient size. Consequently, C_{VOL} values were 2, 6 and 5, 1 for newly-born was and for a 13 years old child, respectively.

Figure 5. Helical abdomen examinations performed with no use of AEC. Image (a) corresponds to a newly-born and was performed with 130 kVp and 60 mAs, C_{VOL} = mGy. Image (b) corresponds to a 13 years child performed with 110 kVp and 90 mAs; C_{VOL} = 6, 0 mGy.

(a) (b)

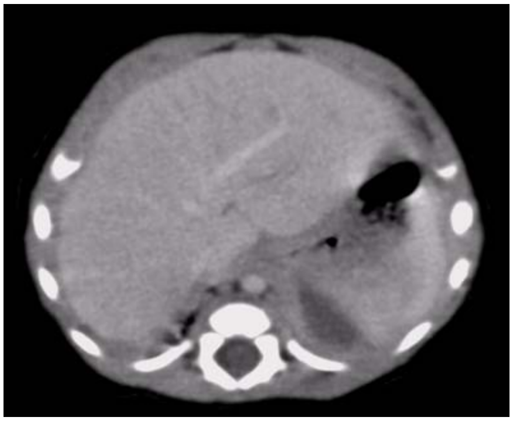
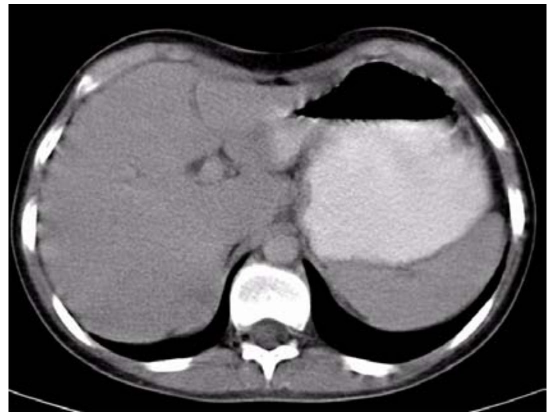
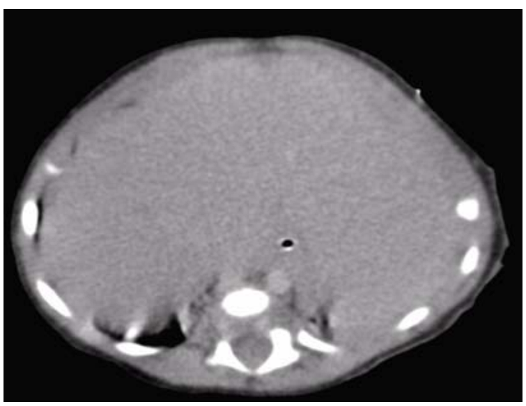
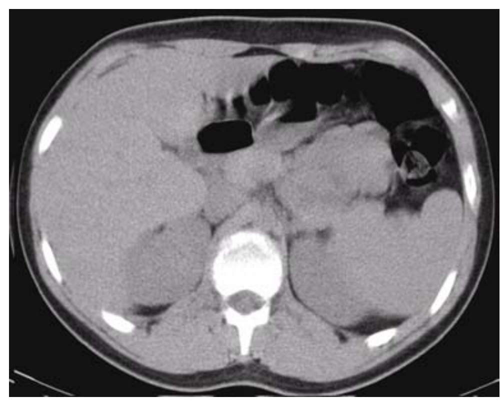



Figure 6. Helical abdomen examinations performed with AEC. Image (a) corresponds to a newly-born (130 kVp, 24 mAs; C_{VOL} =2,6 mGy) and (b) corresponds to a 13 years child (110 kVp, 76 mAs; C_{VOL}= 5,1 mGy).

(a) (b)

4. Conclusions

Despite the fact that mean and third quartile values of C_V and $P_{KL,CT}$ for chest examinations obtained in the present investigation are lower than other published (Europe and United Kingdom [8]), significant higher values of C_V and $P_{KL,CT}$ for all type examination and for all age group where found when AEC is not used. Considering that unnecessary higher doses are being received by children, optimization techniques should be applied as soon possible, beginning with education in RP in CT of radiological technologists. Education should be extensive to radiologists in order to explore the possibility of establishing clinical protocols as it is recommended by international organisms and national and regional societies of radiologists. With no doubt, it should be also necessary to implement a QAP which includes QC tests of the scanner as well as patient dosimetry.

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