Radiation dose optimization in routine computed tomography: a study of feasibility in a University Hospital*

Otimização da dose em exames de rotina em tomografia computadorizada: estudo de viabilidade em um hospital universitário

Juciléia Dalmazo[1], Jorge Elias Júnior[2], Marco Aurélio Corte Brocchi[3], Paulo Roberto Costa[4], Paulo Mazzoncini de Azevedo-Marques[5]

Abstract **OBJECTIVE: To study the feasibility of reducing radiation dose in protocols for acquisition of helical computed tomography images in a University Hospital. MATERIALS AND METHODS: A survey of radiation doses in computed tomography protocols was performed with phantoms and ionization chamber. Changes in kVp and mAs were proposed, determining the average noise. Protocols with noise values ≤ 1% were submitted to qualitative assessment of contrast and spatial resolution by three observers. RESULTS: Tests of variations were performed with 22 protocols for pediatric skulls, 26 for adult skulls, 28 for abdomen, and 18 for chest. The reduction in dose achieved ranged between 7.4% and13% for pediatric skull, 3.8% and 25% for adult skull, 9.6% and 34.3% for abdomen, 6.4% and 12% for chest. It was also noted that the use of windowing and zoom tools supported the acceptance of images by the observers. CONCLUSION: Radiation dose levels can be reduced by up to 34.4% in comparison with routine protocols, keeping the noise at acceptable levels. The use of digital manipulation tools allowed the acceptance of images with higher noise levels, thus resulting in radiation dose reduction.**
Keywords: Computed tomography; Radiation dose reduction; ALARA; Signal-to-noise ratio; CTDI; Optimization.

Resumo **OBJETIVO: Estudar a viabilidade de redução da dose de radiação em protocolos de aquisição de imagens de tomografia helicoidal em um hospital universitário. MATERIAIS E MÉTODOS: Foi realizado levantamento de dose de radiação de protocolos de tomografia com objetos simuladores e câmara de ionização. Foram propostas variações de kVp e mAs, determinando-se a média de ruído. Protocolos com valores de ruído menores ou iguais a 1% foram submetidos à avaliação qualitativa de contraste e resolução espacial por três observadores. RESULTADOS: Foram realizados 22 testes de variações para o protocolo de crânio pediátrico, 26 para crânio adulto, 28 para abdome e 18 para tórax. A redução da dose conseguida variou entre 7,4–13% para protocolo de crânio pediátrico, 3,8–25% para crânio adulto, 9,6–34,3% para abdome e 6,4–12% para tórax. Notou-se também que a utilização de ferramentas de janelamento e *zoom* favoreceu o aceite das imagens pelos observadores. CONCLUSÃO: É possível reduzir os níveis de dose de radiação em até 34,4%, comparativamente aos protocolos utilizados na rotina, mantendo-se o ruído em níveis aceitáveis. O uso de ferramentas de manipulação digital das imagens possibilitou a aceitação de imagens com níveis maiores de ruído, favorecendo o processo de redução de dose de radiação.**
Unitermos: Tomografia computadorizada; Redução da dose de radiação; ALARA; Relação sinal-ruído; CTDI; Otimização.

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INTRODUCTION

The annual number of computed tomography studies (CT) has constantly increased since its introduction in the clinical practice(1,2). Various factors contribute to this growth, including technological hardware improvements, leading to faster data acquisition with significant reduction in the images acquisition time, as well as the increase in the number of clinical indications for CT, associated to a greater availability of CT installed units and a relative tendency to costs reduction(3,4).

The increasing utilization of diagnostic imaging methods employing ionizing ra-

* Study developed at Centro de Ciências das Imagens e Física Médica (CCIFM) – Hospital das Clínicas da Faculdade de Medicina de Ribeirão Preto da Universidade de São Paulo (HCFMRP-USP), Ribeirão Preto, SP, Brazil.

1. Physicist, Fellow PhD degree, Faculdade de Medicina de Ribeirão Preto da Universidade de São Paulo (FMRP-USP), Ribeirão Preto, SP, Brazil.

2. MD, PhD, Professor and Coordinator at Centro de Ciências das Imagens e Física Médica (CCIFM) – Faculdade de Medicina de Ribeirão Preto da Universidade de São Paulo (FMRP-USP), Ribeirão Preto, SP, Brazil.

3. Master, Physicist in Radiodiagnosis at Hospital das Clínicas da Faculdade de Medicina de Ribeirão Preto da Universidade de São Paulo (HCFMRP-USP), Ribeirão Preto, SP, Brazil.

4. PhD, Professor at Department of Nuclear Physics, Instituto de Física da Universidade de São Paulo (IFUSP), São Paulo, SP, Brazil.

5. PhD, Associate Professor at Centro de Ciências das Imagens e Física Médica (CCIFM), Department of Medical Practice, Faculdade de Medicina de Ribeirão Preto da Universidade de São Paulo (FMRP-USP), Ribeirão Preto, SP, Brazil.

Mailing address: Dr. Jorge Elias Júnior. Centro de Ciências das Imagens e Física Médica, HCFMRP-USP. Avenida Bandeirantes, 3900, Monte Alegre. Ribeirão Preto, SP, Brazil, 14048-090. E-mail: jejunior@fmrp.usp.br

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diation, particularly CT, is the main cause for the marked increase in the mean medical radiation dose per capita per year[2]. Currently, the annual per capita radiation dose considered as secondary to medical care, particularly for diagnosis purposes, has overcome the dose received from environmental factors (food, radon gas and others)[1]. As a result, there is an increasing concern of the medical community, equipment manufactures and even patients with the control of doses determined by the different diagnostic methods that rely on ionizing radiation[5,6]. Besides occupational radiation protection, the clinical practice adopts the ALARA (As Low As Reasonably Achievable) principle as a guideline for the rational use of these imaging methods[3,4,7,8].

Specifically considering the pediatric population, it is important to highlight that children present a considerably higher risk for development of radiation related neoplasia as compared with the adult population[1,9,10]. Such higher risk is explained by the presence of a greater cell population undergoing division in the different organs and tissues in development, and also for the greater life expectancy both in absolute and relative terms. As an example, a one-year-old child presents a 10 to 15 times higher risk than a 50-year-old adult for developing a malignant neoplasm, for the same radiation dose[1]. For these reasons, there is an increasing concern with the radiation dose utilized in pediatric radiological studies, and particularly in the case of CT scans. Several published studies report strategies and actions to reduce radiation dose[3,5,9,11–13].

There are several strategies in development or already in use in more modern equipment, such as, for example, tube current modulation according to the variation in the slice thickness for the evaluated anatomic region[6,14]. However, in Brazil there are many relatively old CT systems in use with no software or parameter manipulation capabilities, which ultimately influence the dose delivered at each exam.

Therefore, the present study is aimed to evaluate the feasibility of an optimization strategy to reduce radiation dose in single-slice helical CT protocols in a University Hospital.

MATERIALS AND METHODS

Strategy description

Initially, data on the absorbed radiation dose in routine protocols for both adult and pediatric skull, chest and abdomen CT studies were collected. With such data, an evaluation of the impact of variations in the voltage parameters (kVp) and current vs. time (mAs) was undertaken considering the radiation dose and image quality, the latter studied by the noise measurement and subjective analysis of images obtained with specific phantoms.

Equipment

The tests were performed with a Somatom Emotion single-slice helical computed tomography unit (Siemens Medical Solutions; Erlangen, Germany).

For the radiation dose measurements, cylindrical 15 cm long polymethylmetacrylate phantoms were utilized, one with 32 cm in diameter, representing the torso, and another with 16 cm in diameter, representing the head (Figure 1), according to the American Association of Physicists in Medicine (AAPM) specifications. Such phantoms presented absorption and scattering characteristics that are similar to those of the anatomic structures of the skull and of the torso with holes in the center and at predetermined locations, at 1 cm from the periphery at the 12, 3, 6 and 9 o'clock positions, allowing the insertion of ionization chambers.

The radiation dose measurements were obtained by means of a pencil type ionization chamber model 10X5-3CT (Radcal Corporation; Monrovia, CA, USA), coupled with a Radcal electrometer model 9015. Figure 1 shows the assembly for absorbed dose measurement for the standard body phantom.

The images for the quality study with the proposed parameter variations were obtained by utilizing the specific AAPM standard phantom, model 76-410 which was freely borrowed by Instituto de Eletrotécnica e Energia da Universidade de São Paulo (IEE-USP) (Figure 2).

Studied variables

The kVp and mAs values were duly noted for each protocol, as well as their suggested variations for protocols that were developed for radiation dose reduction.

The initial evaluation of radiation dose in routine protocols as well as the CT equipment calibration were performed by means of the correlation between the CTDIvol obtained with the ionization chamber positioned within the phantoms, considering the acquisition of a section at

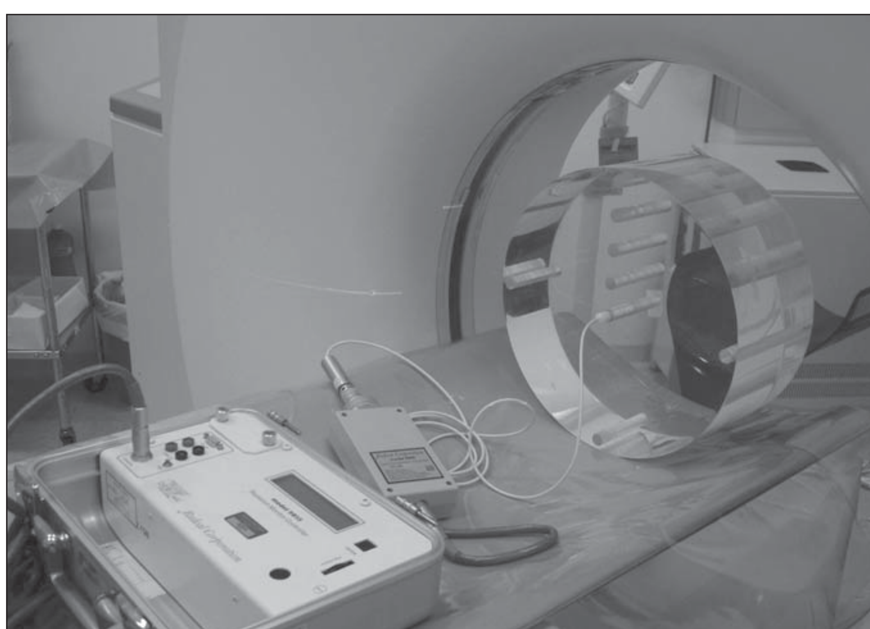

Figure 1. Electrometer, ionization chamber and body phantom exposed to the tomographic beam for CTDI calculation.

Figure 2. Quality phantom for analysis of noise, contrast and spatial resolution of the image.

Table 1 Results for kVp and mAs, as well as respective CTDIvol values. Ex: Routine protocol for adult skull.

Current (mAs)	CTDIvol (mGy) (voltage 130* kVp)	CTDIvol (mGy) (voltage 110 kVp)	CTDIvol (mGy) (voltage 80kVp)
342	54.58	37.55	16.42
174	27.77	19.11	8.35
122	19.63	13.51	5.90
120*	19.15*	13.18	—
115	18.43	12.68	—
100	16.04	11.03	—
90	14.36	9.88	—
80	12.93	8.89	—
70	11.25	7.74	—
60	9.58	6.59	—
54	8.62	5.93	—
45	7.18	—	—

* Values for mAs utilized and respective CTDIvol for the routine protocol for adult skull.

the central position of the chamber, and the CTDIvol provided by the equipment. The CTDIvol is obtained from the ratio between the weighted computed tomography dose index (CTDIw)[15,16] and the pitch, which is defined as the distance travelled by the table and one rotation of the X-ray source, divided by the total collimated beam width. The CTDIvol is referenced on the equipment by the DICOM tag (0018,9345). Considering that the index of correlation between the values obtained in the measurements performed with the ionization chamber and those provided by the equipment was practically 100% ($r = 0.99$; $p < 0.0001$), the equipment CTDIvol measurements were selected for results presentation of and discussion.

Strategy for the proposal of changes in routine CT studies protocols

Based on the initial standard protocols, the variations of the kVp and mAs parameters applied to the tube were proposed, with the remaining parameters (slice thickness, pitch, pixel size and total exposure) being kept constant for each protocol, as shown on Table 1 for the protocol of skull CT. The CTDIvol was measured again for each proposed parameter change (Table 1).

Evaluation of image quality

The images quality was quantitatively evaluated by the measurement of quantic noise, and qualitatively by the subjective evaluation of images obtained in the AAPM standard phantom, independently and blindly performed by three radiologists with more than 10 years of experience.

The quantic noise is the result of the variation in the number of X-ray photons absorbed by the detector in a determined time interval and, considering the geometric characteristics of the image (pixel size, matrix size, slice thickness) as fixed, presents an inversely proportional relation with the dose received by the patient. The methodology adopted for the evaluation of images quality was based on the Agência Nacional de Vigilância Sanitária (ANVISA – Brazilian agency of sanitary vigilance) guidelines “Medical radiodiagnosis: safety and equipment performance” that establishes the practical aspects for the standards established by Ordinance 453 of the Brazilian Ministry of Health[17], considering the quantic noise as the standard deviation of the values for the gray scale for a central square 5 × 5 mm region on a uniform image (Figure 3) divided by the nominal pixel value of that region. Although the ANVISA protocol indicates the need to evaluate the noise at five different points, as it refers to medical equipment quality control procedures, in the present study the option was made to simplify such procedure, by performing the measurement in the central region of the phantom for quality evaluation so as to observe the noise variation considering a situation of greater attenuation and beam hardening. The noise

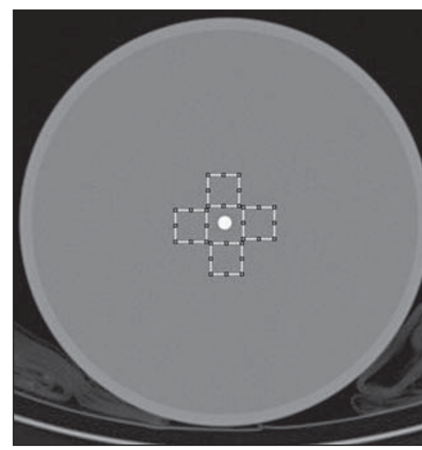

Figure 3. CT section of phantom for quality study, with four selected central areas selected in the ImageJ software for image noise calculation.

on the digital image was evaluated by means of the public domain ImageJ software[18], considering as acceptable those values ≤ 1%[9].

The qualitative analysis was performed for the tested protocols that presented the lowest dose rates and with noise levels within the established limit. The evaluation comprised spatial resolution and high resolution contrast tests performed by the radiologists utilizing the ImageJ software without and with the use of windowing and zoom resources. The visualized objects indicated by the radiologists on the images were compared with the test objects map included in the phantom (Figure 4).

The images were evaluated separately and in duets by means of a questionnaire with nine questions for each set of images,

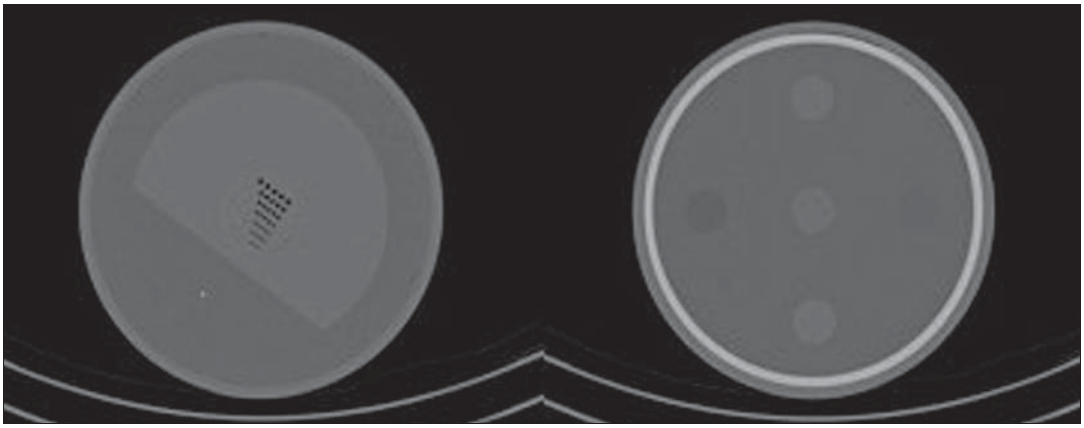

Figure 4. CT sections of phantom for quality study and analysis of image spatial resolution and contrast.

aimed at the study of images contrast and resolution threshold, considering even what set of objects were visible for the diagnosis of an image. The observer classified whether the image had diagnostic quality or not, considering the visibility of existing objects. Additionally, a classification of the image quality was requested, considering the values 1 (very good), 2 (good), 3 (median), 4 (bad) and 5 (very bad).

RESULTS

The CTDIvol and mean noise values obtained for the routine protocols of pediatric skull, adult skull, abdomen and chest CT are presented on Table 2. Mean noise of 1.6% was observed for the chest protocol.

By utilizing fixed 80, 100 and 130 kVp values, measurements of CTDIvol and mean noise were performed in 22 variations of the pediatric skull protocol (mAs ranging from 45 to 271), 26 variations of the adult skull protocol (mAs ranging from 45 to 342), 28 variations of the adult abdomen protocol (mAs ranging from 24 to 182) and 18 variations of the chest protocol (mAs ranging from 29 to 100). Based on these results, new protocols were suggested considering the combination of lowest CTDIvol obtained in association with the defined noise threshold, which were utilized for the evaluation of the quality of the image obtained in the standard AAPM phantom specific for quality evaluation. The data on the suggested protocols and respective CTDIvol and mean noise values, as well as the average dose reduction comparatively with the routine protocols, are presented on Table 2.

As regards the qualitative evaluation of the suggested protocols, the specialists agreed that by using the zoom and windowing tools at the display monitor, the suggested protocols for pediatric skull, adult skull, adult abdomen and adult chest did not present any differences comparatively with the routine protocols in what concerns spatial resolution and contrast, as shown on Tables 3 to 6. However, it is important to note that in the case of adult skull, there was a trend towards improvement in the rating of the contrast quality of the images acquired with the suggested protocol, when the windowing and zoom tools were utilized.

DISCUSSION

The obtained results allowed the observation of an excellent correlation between the CTDIvol values obtained by measurements performed with the ionization chamber and those provided by the equipment, which makes it so much easier to know the actual radiation dose utilized in CT studies in general. Such high correlation, which was actually expected, confirms the appropriateness of the equipment calibration.

Table 2 Comparison between routine and suggested protocols that achieved acceptable noise level and diagnostic quality considering kVp and mAs parameters, CTDIvol value, mean noise value and corresponding mean dose reduction for each protocol.

Protocol	Routine			Suggested			Mean dose reduction
	kVp / mAs	CTDIvol (mGy)	Mean noise	kVp / mAs	CTDIvol (mGy)	Mean noise	
Pediatric skull	130 / 80	12.9	0.9%	130 / 75	11.9	0.9%	7.4%
				130 / 70	11.2	1.0%	13.0%
Adult skull	130 / 120	19.1	0.7%	130 / 115	18.4	0.9%	3.8%
				130 / 100	16.0	0.9%	16.2%
				130 / 90	14.3	0.9%	25.0%
Adult abdomen	130 / 100	9.6	0.8%	130 / 90	8.7	0.8%	9.6%
				130 / 80	7.7	0.9%	20.0%
				130 / 65	6.3	1.0%	34.3%
Adult chest	110 / 80	7.7	1.6%	110 / 70	6.8	1.7%	12.0%
				130 / 50	7.2	1.5%	6.4%

Table 3 Qualitative evaluation of image contrast and spatial resolution of the routine protocol for pediatric skull and the corresponding suggested protocols with kVp and mAs variations, both with and without utilization of zoom and windowing resources.

Image	Zoom / windowing	Parameters kVp / mAs	Rating by observers				Diagnostic quality	
			Good	Very good	Median	Bad	Yes	No
Contrast	Without / Without	130 / 70	0	0	2	1	1	2
		130 / 75	0	0	2	1	1	2
		130 / 80*	0	1	2	0	3	0
	With / Without	130 / 70	0	0	3	0	2	1
		130 / 75	1	0	2	0	2	1
		130 / 80*	0	0	3	0	3	0
	Without / With	130 / 70	2	0	1	0	2	1
		130 / 75	1	1	1	0	3	0
		130 / 80*	3	0	0	0	3	0
	With / With	130 / 70	1	1	1	0	3	0
		130 / 75	1	1	1	0	3	0
		130 / 80*	1	1	1	0	3	0
Spatial resolution	Without / Without	130 / 70					2	1
		130 / 75					3	0
		130 / 80*					3	0
	With / Without	130 / 70					3	0
		130 / 75					3	0
		130 / 80*					3	0
	Without / With	130 / 70					1	2
		130 / 75					2	1
		130 / 80*					3	0
	With / With	130 / 70					3	0
		130 / 75					3	0
		130 / 80*					3	0

* Routine protocol.

Table 4 Qualitative evaluation of image contrast and spatial resolution of the routine protocol for adult skull and corresponding suggested protocols with kVp and mAs variations, with and without the utilization of zoom and windowing resources.

Image	Zoom / windowing	Parameters kVp / mAs	Rating by observers				Diagnostic quality	
			Good	Very good	Median	Bad	Yes	No
Contrast	Without / Without	130 / 115	1	0	2	0	2	1
		130 / 90	1	0	1	1	2	1
		130 / 120*	2	0	0	0	2	1
		130 / 100	0	0	3	0	2	1
	With / Without	130 / 115	0	0	3	0	2	1
		130 / 90	1	0	1	1	2	1
		130 / 120*	2	0	0	0	2	1
		130 / 100	0	0	3	0	2	1
	Without / With	130 / 115	1	0	2	0	3	0
		130 / 90	0	0	3	0	3	0
		130 / 120*	0	0	2	1	3	0
		130 / 100	1	0	2	0	3	0
	With / With	130 / 115	2	1	0	0	3	0
		130 / 90	0	1	2	0	3	0
		130 / 120*	1	0	1	1	3	0
		130 / 100	1	0	2	0	3	0
Spatial resolution	Without / Without	130 / 115					3	0
		130 / 100					3	0
		130 /120*					3	0
		130 / 100					2	1

(Table 4 continues)

Table 4.

Image	Zoom / windowing	Parameters kVp / mAs	Rating by observers				Diagnostic quality	
			Good	Very good	Median	Bad	Yes	No
Spatial resolution	With / Without	130 / 115					3	0
		130 / 90					3	0
		130 / 120*					3	0
		130 / 100					2	1
	Without / With	130 / 115					3	0
		130 / 90					3	0
		130 / 120*					3	0
		130 / 100					2	1
	With / With	130 / 115					3	0
		130 / 90					3	0
		130 / 120*					3	0
		130 / 100					2	1

* Routine protocol.

Table 5 Qualitative evaluation of image contrast and spatial resolution of the routine protocol for adult abdomen and corresponding suggested protocols with kVp and mAs variations, with and without the utilization of zoom and windowing resources.

Image	Zoom / windowing	Parameters kVp / mAs	Rating by observers				Diagnostic quality	
			Good	Very good	Median	Bad	Yes	No
Contrast	Without / Without	130 / 65	2	0	0	1	2	1
		130 /80	0	1	2	0	3	0
		130 / 90	1	1	0	1	2	1
		130 / 100*	1	1	1	0	3	0
	With / Without	130 / 65	0	0	3	0	3	0
		130 /80	0	0	3	0	3	0
		130 / 90	1	0	1	1	2	1
		130 / 100*	2	0	1	0	3	1
	Without / With	130 / 65	0	1	2	0	3	0
		130 /80	2	1	0	0	3	0
		130 / 90	1	1	1	0	3	0
		130 / 100*	2	1	0	0	3	0
	With / With	130 / 65	0	1	2	0	3	0
		130 /80	3	0	0	0	3	0
		130 / 90	0	1	2	0	3	0
		130 / 100*	2	0	1	0	3	0
Spatial resolution	Without / Without	130 / 65					3	0
		130 /80					3	0
		130 / 90					3	0
		130 / 100*					3	0
	With / Without	130 / 65					3	0
		130 /80					2	1
		130 / 90					3	0
		130 / 100*					3	0
	Without / With	130 / 65					3	0
		130 /80					3	0
		130 / 90					3	0
		130 / 100*					3	0
	With / With	130 / 65					3	0
		130 /80					3	0
		130 / 90					3	0
		130 / 100*					3	0

* Routine protocol.

Table 6 Qualitative evaluation of image contrast and spatial resolution of the routine protocol for adult chest and corresponding suggested protocols with kVp and mAs variations, with and without the utilization of zoom and windowing resources.

Image	Zoom / windowing	Parameters kVp / mAs	Rating by observers				Diagnostic quality	
			Good	Very good	Median	Bad	Yes	No
Contrast	Without / Without	130 / 50	0	0	3	0	1	2
		110 / 80*	2	1	0	0	3	0
		110 / 70	1	2	0	0	3	0
	With / Without	130 / 50	0	0	1	2	1	2
		110 / 80*	2	1	0	0	3	0
		110 / 70	1	2	0	0	3	0
	Without / With	130 / 50	1	0	2	0	2	1
		110 / 80*	1	2	0	0	2	0
		110 / 70	0	3	0	0	3	0
	With / With	130 / 50	0	0	3	0	2	1
		110 / 80*	1	2	0	0	3	0
		110 / 70		3	0	0	3	0
Spatial resolution	Without / Without	130 / 50					3	0
		110 / 80*					3	0
		110 / 70					3	0
	With / Without	130 / 50					3	0
		110 / 80*					3	0
		110 / 70					3	0
	Without / With	130 / 50					3	0
		110 / 80*					3	0
		110 / 70					3	0
	With / With	130 / 50					2	1
		110 / 80*					3	0
		110 / 70					3	0

* Routine protocol.

The mean noise values for the routine protocols were within the established threshold of 1%, except for the chest protocol, in which the mean noise value was 1.6%. Such value is explained by the fact that the chest CT utilizes narrow collimation in order to obtain thin slices, thus determining a smaller quantity of photons incident on the detectors. For this reason, there was no proposal for dose reduction in the chest protocols, as the noise level was already above the established limit.

By observing the quantitative and qualitative evaluation of the images, it becomes clear that all CT protocols could utilize reduced kVp and mAs parameters while maintaining diagnostic quality, and determining a lower radiation dose in each study, a fact that is in agreement with other studies in the literature[19–23], particularly with respect to mAs reduction. Such a reduction is particularly significant for CT studies in children, which has been a constant preoccupation over the last decade[10,13,24,25].

With the methodology utilized, the authors observed a reduction in radiation dose between 3.8% and 34.3%. It is possible to achieve further radiation dose reduction with techniques that take anthropometric individual data into consideration, as reported by Kalra et al.[22], or by working with less conservative noise levels, for example in the order of 5%. It should be reminded that any level of radiation dose reduction must be pursued as determined by the ALARA principle[3,4,7,8].

Also, it must be highlighted that in practically all subjective evaluations performed by the radiologists, better scores were observed with the utilization of the zoom and windowing resources. Such results corroborate findings reported in the literature discussing the relation between reduction of radiation dose in CT studies, image quality and reliability of the subjective evaluation[26]. Considering that in digital imaging method the processes of images acquisition and display are separated, it is possible to independently optimize each process. Thus, within determined limits, it is possible to compensate for a loss in contrast due to a decrease in the signal/noise ratio by utilizing easily manipulated tools. The optimization of contrast resolution, with the consequential potential for dose reduction, is the main advantage of digital technology as far as the patients radiological protection is concerned.

The main limitation of the present study lies on the fact that the variations of other CT parameters such as pitch, slice thickness and rotation time were not approached. It is a known fact that when the pitch is increased the patient is exposed to a higher radiation dose. However such limitation is an expression of reality in several Brazilian CT centers, where limited resources do not allow an appropriate technological update of relatively old apparatuses as compared with units equipped with new resources for dose efficiency management, calibration of pediatric images quality, measurements of pediatric doses and protocols specifically designed for pediatrics[12].

CONCLUSION

Based on the results of the present study, the optimization of CT radiation doses in a university hospital was feasible with the proposed methodology utilizing phantoms and a pencil-type ionization chamber, achieving a radiation dose reduction of up to 34.3% for selected study protocols.

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