



Original Article

Optimization of pediatric computed tomography protocols: dose reduction without loss of image quality

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Abstract: This study aimed to optimize pediatric computed tomography (CT) protocols for abdomen and chest examinations, focusing on reducing radiation dose without compromising diagnostic image quality. Information was collected from factory protocols, current-modulated protocols, and those used in the routine of a university hospital, covering different age groups and acquisition parameters. The analyses included the evaluation of image quality metrics such as Signal-to-Noise Ratio (SNR), Contrast-to-Noise Ratio (CNR), Modulation Transfer Function (MTF50% and MTF10%), as well as dose indices (CTDIvol and DLP). Measurements were carried out using an ATOM 007/007IE anthropomorphic phantom, instead of a wire phantom, in accordance with international recommendations that recognize the applicability of different methods for determining MTF. Optimized protocols were proposed and tested. The data demonstrated that the suggested protocols allow significant dose reductions compared to the original protocols while maintaining adequate image quality levels. The comparison between factory, clinical routine, and optimized protocols highlighted the importance of adapting technical parameters to the pediatric profile and the available equipment, reinforcing the need for radioprotection practices aligned with the principles of justification and optimization. The results contribute to the development of safer and more effective guidelines in the context of pediatric CT, promoting highly accurate diagnoses with the lowest dose reasonably achievable, in accordance with the ALARA principle.

Keywords: optimization, pediatric computed tomography, image quality.



Otimização de protocolos pediátricos em tomografia computadorizada: redução de dose sem perda de qualidade de imagem

Resumo: Este estudo teve como objetivo otimizar protocolos de tomografia computadorizada (TC) pediátrica para exames de abdome e tórax, visando a redução de dose de radiação sem comprometer a qualidade diagnóstica das imagens. Foram coletadas informações dos protocolos de fábrica, dos protocolos com modulação de corrente e dos utilizados na rotina de um hospital universitário, abrangendo diferentes faixas etárias e parâmetros de aquisição. As análises incluíram a avaliação de métricas de qualidade de imagem, como Relação Sinal-Ruído (RSR do inglês SNR), Relação Contraste-Ruído (RCR do inglês CNR), Função de Transferência de Modulação (MTF50% e MTF10%), além de índices de dose (CTDIvol e DLP). As medições foram realizadas em phantom antropomórfico modelo ATOM 007/007TE, em substituição ao wire phantom, conforme recomendações internacionais que reconhecem a aplicabilidade de diferentes métodos para determinação da MTF. Os protocolos otimizados foram propostos e testados. Os dados demonstraram que os protocolos sugeridos possibilitam reduções significativas de dose em relação aos protocolos originais, mantendo níveis adequados de qualidade de imagem. A comparação entre os protocolos de fábrica, de rotina clínica e os otimizados evidenciou a importância da adaptação de parâmetros técnicos ao perfil pediátrico e ao equipamento disponível, reforçando a necessidade de práticas de radioproteção alinhadas aos princípios da justificação e otimização. Os resultados obtidos contribuem para o desenvolvimento de diretrizes mais seguras e eficazes no contexto da TC pediátrica, promovendo diagnósticos de alta precisão com a menor dose razoavelmente possível, conforme o princípio ALARA.

Palavras-chave: otimização, tomografia computadorizada pediátrica, qualidade de imagem.

1. INTRODUCTION

Computed tomography (CT) is widely used for diagnosis in medicine, employing ionizing radiation to produce medical images based on the attenuation coefficients of different anatomical structures. The resulting images are displayed in grayscale, where tissue densities are quantified in Hounsfield Units (HU) [1]. In CT image reconstruction, mathematical models convert attenuation data into digital images, where each pixel represents a bidimensional area and each voxel a three-dimensional volume [2].

Although CT has greatly advanced diagnostic imaging by providing high-resolution anatomical visualization, it is also the imaging modality that delivers the highest radiation dose to patients. Therefore, implementing effective quality assurance programs is essential to ensure reliable diagnoses with the lowest possible dose [3]. Radiological protection principles guide this process: the optimization principle, known as ALARA (As Low As Reasonably Achievable), emphasizes performing examinations with minimal radiation exposure without compromising diagnostic quality, while the justification principle establishes that no medical exposure should occur unless the expected benefits outweigh potential radiation risks [4,5].

The rigorous application of these principles becomes even more critical in pediatric patients, who exhibit greater radiosensitivity due to higher cellular proliferation rates and longer life expectancy, increasing the probability of late-onset radiation-induced effects [5]. Exposure to ionizing radiation in children poses a relevant risk factor for neoplasia development, as radiation-induced DNA damage can trigger carcinogenesis. Studies have shown that CT scans performed in childhood are associated with an elevated lifetime risk of radiation-induced cancers [6,7].

To ensure safety and diagnostic performance, the use of pediatric phantoms plays a central role in quality assurance for CT imaging. These simulators replicate the anatomical characteristics and tissue attenuation of pediatric patients, allowing accurate equipment calibration and optimization of imaging protocols. This enables dose reduction without compromising image quality, minimizing biological risks for children [8,9].

Given the importance of balancing diagnostic image quality and radiation dose, the evaluation and optimization of CT protocols are essential to prevent excessive exposures and ensure compliance with radiological protection standards. Analyzing clinical routine protocols helps identify those that exceed recommended dose levels and highlights opportunities for improvement. In this context, this study contributes to quality assurance in diagnostic imaging by developing optimized CT protocols for pediatric abdomen and chest examinations, tailored to specific age ranges and anatomical regions.

The main objective of this study was to optimize pediatric chest and abdomen CT protocols, ensuring significant dose reduction without loss of diagnostic image quality. Specifically, the study aimed to: (1) present the optimization process for pediatric CT protocols through analysis of acquisition parameters, image quality, and dose indices; (2) compare local dose index reports with national and international reference levels; and (3) propose the implementation of optimized protocols into the routine workflow of a large university hospital in Curitiba, Brazil.

2. MATERIALS AND METHODS

The study was conducted using a Philips® MX 16-slice CT scanner equipped with a continuous rotation acquisition system. For image acquisition, the ATOM dosimetry phantom Model 007 was used to simulate the thoracic region and the ATOM Model 007TE was used to simulate the abdominal region (Figure 1), both manufactured by CIRS®. These phantoms reproduce the anatomical characteristics of pediatric patients approximately five

years old. Data was collected from both factory-defined and clinically implemented protocols for pediatric chest and abdomen examinations. The parameters evaluated included: scan type, series, length, slice thickness (mm), increment (mm), tube voltage (kV), tube current (mAs per slice), number of images, acquisition time (s), CTDIvol, DLP, pitch, gantry rotation time (s), field of view (mm), reconstruction matrix, and type of filter.

Figure 1: ATOM 007 phantom used for thoracic simulation and ATOM 007TE phantom used for abdominal simulation



Source: Authors' archive, 2025.

For abdominal phantom acquisitions, exposures were performed using the original clinical protocol defined during equipment installation, with automatic current modulation (DOM technology), applied to three age groups: up to 2 years, 3 to 6 years, and 7 to 12 years. Image reconstruction was performed using the Philips SA, SB, and SC reconstruction filters, which differ in spatial frequency characteristics: SA, a smoother filter optimized for soft-tissue imaging such as the abdomen; SB, an intermediate filter balancing detail and noise; and SC, a sharper filter typically used for lung window evaluation, enhancing high-frequency structures. For factory protocols (manufacturer presets), the same reconstruction filter variations were applied to weight ranges of <10 kg, 10–30 kg, 30–50 kg, and 50–70 kg.

For the thoracic phantom, exposures were also performed using the original clinical protocol (post-installation), but without current modulation, for the same age groups (2 years, 3 to 6 years, and 7 to 12 years), and similarly using filters SA, SB, and SC. For the factory-defined protocols, the filters were tested for the same weight ranges as above (<10 kg, 10 to 30 kg, 30 to 50 kg, and 50 to 70 kg).

Tables 1 and 2 present routine (original clinical) protocols and manufactured (manufacturer presets) before optimization.

Table 1: Routine (original clinical) protocols

Age	Abdominals With modulation		Abdominals Without modulation		Thoracic Without modulation	
	kV	mAs	kV	mAs	kV	mAs
Parameters						
0–2 yrs	90	292	90	100	90	90
3–6 yrs	90	94	90	140	90	67
7–12 yrs	120	57	120	79	120	42

Source: Authors' archive, 2025.

Table 2: Manufacture (presets) protocols

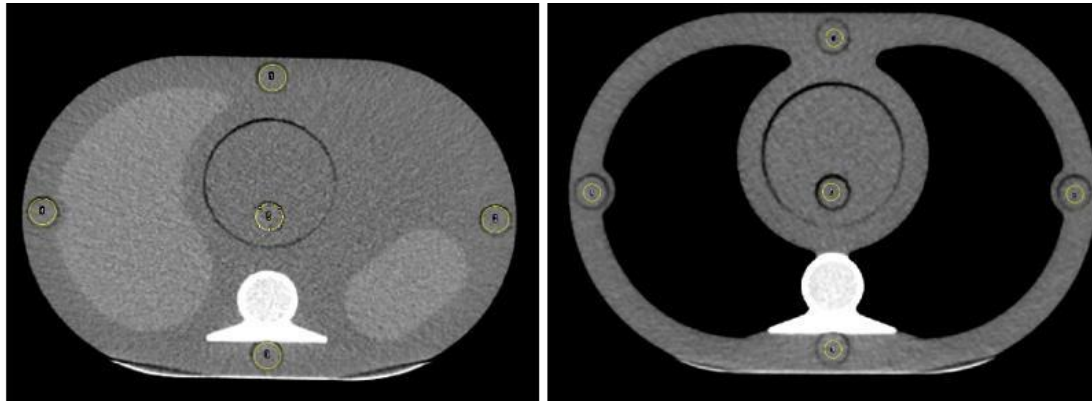
	Abdominal		Thoracic	
	kVp	mAs	kVp	mAs
<10 kg	120	79	120	50
10 to 30 kg	120	110	120	80
30 to 50 kg	120	140	120	100
50 to 70 kg	120	180	120	140

Source: Authors' archive, 2025.

Subsequently, the relative signal ratio (SNR) and relative contrast ratio (CNR) were analyzed, along with the CTDI and DLP indices, and modulation transfer functions (MTF 50% and MTF 10%). The selection of the optimal protocol was based on the objective evaluation of these quantitative results.

Noise measurements in the images were performed using ImageJ® software, widely used for quantitative analysis in medical imaging. Image noise corresponds to undesired or random variations in pixel values that affect image uniformity and quality. Noise was quantified through the standard deviation (SD) of pixel intensity within regions of interest (ROIs); higher SD values indicate greater variability and consequently higher noise levels. In this study, SD was measured in five ROIs (positions 1 to 5), as shown in Figure 2.

Figure 2: Regions of interest (ROIs) used for the assessment of RCR and RSR in the abdominal and thoracic simulators



Source: Authors' archive, 2025.

For MTF calculation, a rectangular ROI was positioned over the vertebral region and image background to obtain cycles/pixel and Modulation Factor (MF) data. It is important to note that, in this study, the conventional wire phantom typically used for MTF measurements was not available at the institution. As an alternative, the ATOM 007 and 007TE dose phantoms are employed to acquire the required images and conduct the analyses.

This approach follows international recommendations such as the AAPM TG-233 report, which recognizes the validity of different methods and phantoms for MTF determination, including slanted-edge techniques and anatomical structure-based measurements in anthropomorphic phantoms. The report emphasizes that, when applied consistently and comparatively within the same equipment, these methods are suitable for performance evaluation and protocol optimization. Therefore, the use of ATOM 007 and 007TE dose phantoms was considered appropriate for this study, whose main objective was to compare pediatric CT protocols on the same imaging system, using equivalent anatomical regions, thus ensuring the relative reliability of the obtained results.

The dose values (CTDI_{vol} and DLP) were initially estimated using the ImpactScan® spreadsheet (Table 3) and subsequently validated experimentally. Image quality was assessed using Signal-to-Noise Ratio (SNR), Contrast-to-Noise Ratio (CNR), noise (standard deviation in regions of interest), and Modulation Transfer Function (MTF). The values were

corrected to maintain methodological consistency, so that MTF10% was higher than MTF50%, as expected. In addition, the figure of merit ($FOM = CNR^2 / CTDI_{vol}$), a consolidated methodology in the literature, was applied to integrate dose and image quality. The extrapolation from the literature was based on diagnostic reference levels (DRLs) published by ICRP 135 and national studies, adjusted for age ranges and phantom weights.

Table 3: CTDI and DLP values obtained using ImpactScan® and CT scan Brilliance 16 (Philips) (similar model to MX-16)

Anatomic Region	Group	kV	mAs	CTDI (mGy)	DLP (mGy.cm)
Abdomen (with modulation, age group)	0–2 yrs	90	292	9.5	142
	3–6 yrs	90	94	3.3	49
	7–12 yrs	120	57	5.8	87
Abdomen (without modulation, age group)	0–2 yrs	90	140	3.1	46
	3–6 yrs	90	79	4.6	68
	7–12 yrs	120	79	8.1	121
Abdomen (weight group)	<10 kg	120	79	4.2	63
	10 to 30 kg	120	110	5.8	87
	30 to 50 kg	120	140	10.3	154
Thoracic (without modulation, age group)	0–2 yrs	90	90	2.9	44
	3–6 yrs	120	67	2.2	33
	7–12 yrs	120	40	3.7	55
Thoracic (weight group)	<10 kg	120	50	3.1	46
	10 to 30 kg	120	80	5.9	88
	30 to 50 kg	120	100	7.3	110
	50 to 70 kg	120	140	10.3	154

Source: Authors' archive, 2025.

3. RESULTS AND DISCUSSIONS

In this study, a comparative analysis was performed between the factory-defined protocols, the clinical routine protocols (with and without current modulation), and the newly optimized protocols developed specifically for pediatric abdominal and thoracic CT examinations. The evaluation encompassed the analysis of technical parameters, dose indices (CTDI_{vol} and DLP), and image quality metrics (MTF, SNR, and CNR). The initial assessment of the pediatric CT protocols used at the studied institution revealed significant

variations among the acquisition strategies, especially between those employing or omitting automatic tube current modulation and those based on the manufacturer's default settings. These discrepancies indicate the lack of standardized pediatric-specific protocols, a scenario that reflects the broader national context in Brazil, where adult-based protocols are frequently scaled down empirically without formal physical or clinical validation [10,11].

Tables 4 and 5 present a concise summary of the dose metrics (CTDIvol and DLP) obtained for abdominal and thoracic CT examinations across pediatric age groups, comparing baseline protocols (factory protocols, clinical routine protocols) with optimized versions and highlighting the corresponding dose reductions.

The analyses demonstrated average reductions of 40% to 50% in CTDIvol for abdominal CT scans. For thoracic scans, the reductions reached up to 22% in CTDIvol, while maintaining MTF, SNR, and CNR values within diagnostic limits (Table 6). The figure of merit (FOM) confirmed that optimization preserved image quality even under lower-dose conditions. The DLP values were derived from acquisitions using anthropomorphic phantoms, which have a fixed length, implying that reductions in CTDIvol resulted in proportional reductions in DLP. This methodology was explicitly described to avoid ambiguities and ensure transparency in the interpretation of results.

Table 4: Mean dose in pediatric abdominal protocols

Age group (yrs)	Before optimization					After optimization		
	Protocol	kV/mAs	CTDIvol (mGy)	DLP (mGy·cm)	Optimized kV/mAs	Optimized CTDIvol (mGy)	Optimized DLP (mGy·cm)	Reduction CTDIvol (%)
0–2	Routine (modulated)	90/292	5.4	138	90/140	2.7	40	~50%
3–6	Factory	90/140	7.9	189	90/120	3.8	58	~52%
7–12	Factory	120/79	12.9	295	120/70	5.0	75	~61%

Source: Authors' archive, 2025.

Table 5: Mean dose in pediatric thoracic protocols

Before optimization						After optimization		
Age group (yrs)	Reference protocol	KV/mAs	CTDIvol (mGy)	DLP (mGy·cm)	Optimized kV/mAs	Optimized CTDIvol (mGy)	Optimized DLP (mGy·cm)	Reduction CTDIvol (%)
0–2	Routine	90/90	2.5	59	90/69	2.3	34	~ 8%
3–6	Routine	90/67	3.2	92	90/94	2.5	44	~22%
7–12	Factory	120/42	3.6	84	120/56	2.9	44	~20%

Source: Authors' archive, 2025.

Table 6: Image quality metrics

Age group (yrs)	Anatomic area	MTF50%		MTF10%		SNR		CNR		FOM	
		(lp/cm)		(lp/cm)						(CNR ² /CTDIvol)	
		Before	After	Before	After	Before	After	Before	After	Before	After
0-2	Abdominal	3.1	3.0	6.3	6.2	20.06	18	13.98	12	36.2	26.7
3-6		3.6	3.5	6.6	6.5	26.25	20	22.31	14	63	25.6
7-12		4.1	4.0	7.0	6.9	32.29	22	21.19	15	34.8	24.5
0-2	Thoracic	3.3	3.2	6.1	6.0	29.92	19	24.1	13	232.3	27.4
3-6		3.9	3.8	6.5	6.4	20.4	21	19.71	14	121.4	26.2
7-12		4.0	3.9	6.9	6.8	28.12	23	21.1	15	123.7	25.1

Source: Authors' archive, 2025.

For abdominal examinations, preliminary software simulations using the ImpactScan® spreadsheet produced initial estimated CTDIvol values ranging from 3.33 to 9.5 mGy and DLP values from 49 to 142 mGy·cm (Table 3). However, during the actual experimental validation on the CT scanner, the baseline routine protocol for the youngest cohort (0–2 years) presented a CTDIvol of 5.4 mGy and a DLP of 138 mGy·cm (Table 4). The non-modulated protocol showed similar performance but tended toward lower doses in patients with smaller effective diameters. In contrast, the factory-defined protocols exhibited substantially higher dose levels, with CTDIvol values between 7.9 and 12.9 mGy and a

maximum DLP of 295 mGy·cm (Table 4), reflecting their generic design intended to maximize image quality at the expense of increased exposure.

Technical parameter analysis demonstrated that tube current (mAs) and tube voltage (kV) were the most influential factors on dose indices. In routine protocols, tube voltage remained fixed between 90 and 120 kV, while current varied widely (57 to 292 mAs), indicating an empirical attempt to match patient size without a systematic model relating effective diameter or weight to the required dose [12]. Similar findings have been reported in other studies, which emphasize that uncontrolled variation in mAs can lead to unnecessarily high exposures in younger age groups and inconsistencies in image quality across examinations [12,13].

Automatic current modulation reduced dose levels in some cases but proved less efficient for pediatric applications. Since modulation algorithms are primarily calibrated for adult morphologies, they tend to overestimate current in children's abdominal regions, resulting in higher-than-necessary CTDI_{vol} values. This effect was also observed in other Brazilian studies, where automatic modulation increased the average dose by up to 30% compared to manually adjusted pediatric protocols [13,14].

Image quality evaluation across the configurations detailed in Table 6 showed that spatial resolution remained within diagnostic standards under all tested conditions, including baseline and lower-dose setups. Overall, the MTF_{50%} values for abdominal and thoracic structures ranged from 3.0 to 4.1 lp/cm, while the corresponding MTF_{10%} values ranged from 6.0 to 7.0 lp/cm (Table 6). These results remain safely above the minimum diagnostic thresholds required for pediatric torso imaging, adhering to the mathematical consistency where MTF_{10%} presents higher spatial frequency values than MTF_{50%} to adequately describe the system's contrast transfer function [5,15]. However, SNR and CNR variations indicated a clear trade-off between contrast and noise. While baseline modulated protocols achieved higher contrast ratios at the expense of higher doses, the unmodulated and

optimized configurations demonstrated that further parameter adjustments successfully balanced diagnostic clarity with essential radiation protection.

When compared to the diagnostic reference levels (DRLs) suggested by ICRP 135 [16] and by Heidorne Guerra *et al.* [17], the institution's baseline abdominal protocols exceeded international reference values for some age groups. For instance, ICRP 135 recommends CTDIvol averages of 2 mGy for patients under five years and 3 to 4 mGy for those aged seven to ten years. In comparison, the local routine modulated protocol reached a CTDIvol of 5.4 mGy for the youngest cohort (0–2 years), while the factory baseline preset reached 7.9 mGy for the 3–6 years group and 12.9 mGy for the 7–12 years group (Table 4). This reinforces the need to establish local DRLs tailored to institutional conditions and available CT technology.

Corroborating this finding, Souza [18] conducted a study at Hospital Pequeno Príncipe in Curitiba, revealing that doses in pediatric abdominal and cranial CT protocols were up to 60% higher than European DRLs. Following protocol revision, the hospital implemented the “Protocolo Pequeno Príncipe,” achieving a 35% average dose reduction without loss of diagnostic quality. This aligns with the results of the present work, which provide a consistent regional overview and a strong foundation for further optimization [18,19].

Based on the quantitative analysis of dose and image quality parameters, new optimized protocols were developed for pediatric abdominal CT, adjusted for three age groups: up to 2 years, 3 to 6 years, and 7 to 12 years. The proposed protocols achieved CTDIvol reductions of approximately 40% to 50% compared to the existing clinical routine, with stable MTF50% (3.0 to 4.0 lp/cm) and MTF10% (6.2 to 6.9 lp/cm) values, indicating preserved spatial resolution (Table 6).

For children under 2 years, optimized abdominal protocols achieved a CTDIvol value of 2.7 mGy and a DLP of 40 mGy·cm, representing a ~50% reduction compared to the modulated routine protocol (CTDIvol 5.4 mGy; DLP 138 mGy·cm) (Table 4). For the 3 to

6 years group, the optimized CTDIvol was 3.8 mGy and DLP was 58 mGy·cm, corresponding to a ~52% reduction relative to the baseline factory protocol (CTDIvol 7.9 mGy; DLP 189 mGy·cm) (Table 4). For the 7 to 12 years group, the optimized CTDIvol reached 5.0 mGy and DLP was 75 mGy·cm, reflecting reductions of up to 61% compared with the factory settings (CTDIvol 12.9 mGy; DLP 295 mGy·cm) (Table 4).

These results demonstrate that fine-tuning of current (mAs) and voltage (kV), combined with appropriate filter selection (particularly SA), allows for substantial dose savings without measurable degradation in spatial or contrast resolution, maintaining consistency with established diagnostic reference levels [18,19].

Similarly, optimized thoracic CT protocols were designed for the same age groups, considering anatomical and density differences between the thoracic and abdominal regions. These protocols aimed to enhance pulmonary and mediastinal contrast while minimizing dose exposure. The optimized thoracic protocols achieved CTDIvol reductions of 20 to 50% compared to the original protocols.

For patients up to 2 years old, the optimized thoracic protocol yielded a CTDIvol of 2.3 mGy and DLP of 34 mGy·cm, representing an 8% CTDIvol and 42% DLP reduction compared with the routine protocol (CTDIvol 2.5 mGy; DLP 59 mGy·cm) (Table 5). For 3 to 6 years, CTDIvol and DLP were reduced to 2.5 mGy and 44 mGy·cm, respectively, representing a 22% dose index reduction while maintaining MTF50% and MTF10% values equivalent to those of the routine scans (Table 6). For 7 to 12 years, CTDIvol decreased to 2.9 mGy and DLP to 44 mGy·cm, approximately 20% lower than factory parameters (CTDIvol 3.6 mGy; DLP 84 mGy·cm) (Table 5). The preserved MTF50% (3.9 lp/cm) and MTF10% (6.8 lp/cm) values for this age group (Table 6) indicate that image sharpness and contrast remained diagnostic, confirming that reduced kV (from 120 to 90 in younger cohorts) and optimized mAs were decisive for dose reduction.

Overall, these findings reinforce the critical role of protocol customization by age group and body size. The consistent SNR and CNR values across all optimized protocols demonstrate effective control of the signal-to-noise ratio (SNR), avoiding noise amplification even with lower tube currents. Similar results were reported by Gonzalez et al. [20] and Alcantara et al. [21], who emphasized that individualized pediatric CT protocols are essential for radiological protection due to children's higher radiosensitivity and longer life expectancy.

These outcomes validate the clinical feasibility of the optimization methodology and support the implementation of age-adjusted local DRLs in pediatric imaging centers, such as Hospital Pequeno Príncipe and other high-volume university hospitals in Curitiba [18,19,21].

4. CONCLUSIONS

The present study aimed to evaluate and optimize pediatric CT protocols, focusing on dose reduction without compromising diagnostic image quality, in compliance with the fundamental principles of radiation protection and international guidelines on justification and optimization, particularly the ALARA principle. The research was conducted within the Graduate Program in Biomedical Engineering at UTFPR, integrating knowledge from medical physics, engineering, and clinical imaging practice.

The initial analysis of factory and routine protocols revealed that, although adequate for adult imaging, the parameters applied to pediatric examinations often resulted in doses higher than necessary to achieve acceptable image quality. The comparison between protocols with and without current modulation demonstrated significant variations in CTDIvol and DLP, confirming that well-founded manual and individualized adjustments can lead to substantial dose reductions. These findings are consistent with previous studies conducted in reference centers, such as Hospital Pequeno Príncipe in Curitiba/Brazil, which also reported relevant improvements in pediatric CT efficiency following technical parameter revisions.

This study demonstrated that the optimization of pediatric CT protocols is technically feasible and safe. The adoption of mean values, the use of the figure of merit (FOM) as an efficiency indicator, and the reorganization of results into tables increased clarity and scientific reproducibility. Although the reduction in radiation dose inherently led to an expected decrease in signal-to-noise (SNR) and contrast-to-noise (CNR) ratios, the spatial resolution (MTF) was successfully preserved. Consequently, the optimized protocols achieved dose levels consistent with international and national DRLs while maintaining diagnostic image quality. The proposed systematization can be implemented in university and pediatric hospitals, contributing to more effective radiological protection practices aligned with the ALARA principle.

These findings demonstrate the feasibility of developing age-specific, personalized pediatric protocols that account for the anatomical and clinical particularities of each group. Moreover, they highlight the importance of establishing Diagnostic Reference Levels (DRLs), as recommended by the ICRP, as essential tools for continuous dose monitoring and standardization of safe imaging practices.

As a limitation, it should be noted that the evaluations were performed using physical anthropomorphic phantoms under simulated conditions, which, although ensuring reproducibility, non-linear attenuation control, and experimental control, do not fully represent the anatomical and clinical variability found in real patients. Therefore, future studies should validate the proposed configurations under clinical conditions, involving radiologists in subjective image quality assessments across different pathologies and motion scenarios.

In summary, this study demonstrates that the optimization of pediatric CT protocols is technically feasible, safe, and capable of substantially reducing radiation dose without compromising diagnostic quality. The systematic adoption of the methodologies proposed here can directly contribute to improving pediatric radiological practice, enhancing patient safety, and advancing radiation protection policies in Brazilian hospital settings.

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CONTRIBUTORSHIP

Conceptualization: NRM, DRBC, RVJ, MLMCA

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest regarding the research, authorship, or publication of this article. All stages of the study were conducted independently, without any financial support, commercial influence, or institutional bias from equipment manufacturers or third parties.

DATA AVAILABILITY STATEMENT

The authors declare that the data supporting the results of this study and the derived data supporting the conclusions of this study are available upon reasonable request to the corresponding author.

REFERENCES

- [1] SANTOS, A.; NACIF, L. A. **Tomografia computadorizada**: fundamentos, técnica e aplicações. São Paulo: Atheneu, 2007.
- [2] HOFER, K. **Physics of Computed Tomography**: Principles and Technical Aspects. Heidelberg: Springer, 2005.
- [3] MOURÃO, A. P. **Dosimetria em Tomografia Computadorizada**: fundamentos físicos e aplicações clínicas. Belo Horizonte: UFMG, 2015.
- [4] FINATTO, M. et al. Quality assurance in pediatric computed tomography: dose optimization and image quality control. **Radiologia Brasileira**, v. 48, n. 4, p. 225–232, 2015.
- [5] INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS (ICRU). **Report 87**: Radiation Protection Principles. Bethesda, MD: ICRU, 2012.
- [6] AWAD, M. A. et al. Optimization of radiation dose in pediatric CT imaging: current challenges and future directions. **Pediatric Radiology**, v. 50, n. 8, p. 1126–1136, 2020.
- [7] BRENNER, D. J. et al. Estimated risks of radiation-induced fatal cancer from pediatric CT. **American Journal of Roentgenology**, v. 176, n. 2, p. 289–296, 2001.
- [8] PEARCE, M. S. et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. **The Lancet**, v. 380, n. 9840, p. 499–505, 2012.
- [9] OKUNO, E. **Proteção radiológica e dosimetria**: fundamentos. 2. ed. São Paulo: Oficina de Textos, 2018.

- [10] LIU, X. et al. Pediatric anthropomorphic phantoms for computed tomography dosimetry: design, calibration and validation. **Medical Physics**, v. 42, n. 4, p. 1856–1865, 2015.
- [11] AMERICAN ASSOCIATION OF PHYSICISTS IN MEDICINE (AAPM). **AAPM Report No. 204**: Size-Specific Dose Estimates (SSDE) in Pediatric and Adult Body CT Examinations. College Park, MD: American Association of Physicists in Medicine, 2020.
- [12] BONFLEUR, E. M. **Optimization of pediatric CT protocols**: balancing image quality and radiation dose. 2022. Dissertação (Mestrado em Engenharia Biomédica) – Universidade Tecnológica Federal do Paraná, Curitiba, 2022.
- [13] AMERICAN ASSOCIATION OF PHYSICISTS IN MEDICINE (AAPM). **AAPM Report No. 233**: Strategies for Image Quality and Dose Optimization in Pediatric CT. College Park, MD: AAPM, 2019.
- [14] AMERICAN ASSOCIATION OF PHYSICISTS IN MEDICINE (AAPM). **AAPM Report No. 204**: Size-Specific Dose Estimates (SSDE) in Pediatric and Adult Body CT Examinations. College Park, MD: AAPM, 2017.
- [15] KALENDER, W. A. **Computed Tomography**: Fundamentals, System Technology, Image Quality, Applications. 3rd ed. Erlangen: Publicis Publishing, 2014.
- [16] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION (ICRP). **Publication 135**: Diagnostic Reference Levels in Medical Imaging. Oxford: Pergamon Press, 2017.
- [17] HEIDORNE GUERRA, R. A. et al. Evaluation of radiation doses in pediatric computed tomography and proposal of optimization protocols. **Brazilian Journal of Medical Physics**, v. 13, n. 2, p. 85–93, 2019.
- [18] SOUZA, V. F. Avaliação e otimização de protocolos de tomografia computadorizada pediátrica no Hospital Pequeno Príncipe. Curitiba: Hospital Pequeno Príncipe, 2023.
- [19] HOSPITAL PEQUENO PRÍNCIPE (HPP). **Relatório Anual de Produção em Diagnóstico por Imagem**: Setor de Tomografia Computadorizada 2024. Curitiba: HPP, 2024.
- [20] GONZALEZ, P. et al. Implementation of pediatric CT optimization protocols: impact on image quality and patient dose. **Radiation Protection Dosimetry**, v. 169, n. 1-4, p. 232–240, 2016.

- [21] ALCANTARA, M. S. et al. Pediatric CT imaging optimization and radiation protection: review and institutional practices. **Journal of Applied Clinical Medical Physics**, v. 23, n. 10, p. 1–14, 2022.
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