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Dosimetry of Pediatric Patients in Skull Computed Tomography Exams

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1. Introduction

In the last five years, there has been a significant increase in the number of CT scans, bringing with it a concern for patient safety, especially when it comes to pediatric patients who should not be exposed to ionizing radiation unnecessarily or with doses higher than necessary, to ensure an acceptable diagnostic image. Currently CT scans in pediatric patients correspond to 11% of the total requested CT examinations, which is due to the technology advancement, its wide availability and rapid acquisition of images that enable greater benefits compared to other radiodiagnostic modalities. On the other hand, the high radiation doses absorbed by patients combined with the greater sensitivity of children's organs and tissues, especially in head exams, which corresponds to 75% of all procedures performed in these patients, demonstrate the need to optimize CT exams [1, 2, 3].

The study of patient dosimetry is essential to identify the potential for the application of optimized procedures and radiological protection in diagnostic radiology. The Monte Carlo (MC) method has become an important tool to estimate absorbed doses in organs and tissues in diagnostic imaging procedures [4].

To optimize doses in CT, the Dosimetry and Nuclear Instrumentation Group of the Department of Nuclear Energy at Federal University of Pernambuco (GDOIN-DEN/UFPE) is a pioneer in the development of dosimetric tools based on real-time online MC calculations. Recently, this group developed the CALDose_XCT which aims to calculate the absorbed dose in organs due to CT scans.

This study evaluated head multislice CT exams performed in pediatric patients at a hospital in Recife, Brazil, measuring the CT air kerma indexes and the absorbed doses in the patients' organs, varying the positioning of the mesh phantoms used in the CALDose_XCT software.

2. Methodology

The equipment used in this study was the Philips Brilliance, which is a 64-channel multislice CT scanner. The gantry has angulation capacity ranging from -30º to +30º. Its tube voltage ranges from 80 to 140 kVp and it uses GOS solid state detectors presenting 43,008 detector elements with 0.625 mm each and several options of total beam collimation, e.g.: 64 x 0.625 mm; 32 x 1.25 mm; and 16 x 2.5 mm.

108 head CT scans were evaluated in pediatric patients grouped into the following age groups: 0 to 1 years; 1 to 5 years; 5 to 10 years; and 10 to 15 years. The following irradiation parameters and patient data were registered: age and gender; tube current and potential; collimation; pitch; rotation time; scan length; and gantry tilt angle. Routine protocols established by the manufacturer for performing the tests were also registered and are presented on Table 1. These are categorized as "adult" or routine, "pediatric" and "baby".

Table 1: Acquisition protocols for pediatric exams at the evaluated Philips Brilliance 64 CT scanner.

Protocols	**Adult**	**Pediatric**	**Baby**
Tube potential (kV)	120	120	120
Tube load (mAs)	300	250	200
Tube current (mA)	179	270	216
Rotation time (s)	0.5	0.4	0.4
Beam collimation (mm)	40	40	40
Helical pitch	0.290	0.450	0.450
Gantry tilt	0º	0º	0º
Acquisition mode	Helical	Helical	Helical

To measure the CT air kerma index ($C_{a,100}$) a pencil ionization chamber (manufactured by PTW, model 30009, serial number 0516) was used, coupled to a PTW Unidos E electrometer, pre-calibrated for CT x-ray beam quality at the Laboratory of Metrology of Ionizing Radiations (LMRI-DEN/UFPE). To measure the CT weighted air kerma index (C_W) a 16 cm diameter standard dosimetric PMMA phantom (manufactured by PTW Freiburg) was positioned in the center of the gantry, along the rotation axis.

To estimate the absorbed doses by the organs and tissues, the registered and estimated parameters were inserted into the CALDose_XCT free online dosimetric service. The CALDose_XCT was validated comparing the simulated values and the values of $C_{a,100}$ and C_{VOL} measured in a standard dosimetric PMMA phantom with 16 cm diameter. The scan length for head exams used in CALDose_XCT extends from the top of the head to the first cervical vertebra. Therefore, to compare the absorbed doses in the organs with and without head tilt, simulations with an angle of 18º were performed in newborn and 1-year-old phantoms, as it can be seen in Figure 1. The CALDose_XCT does not allow the application of head tilt, so the simulations were performed directly in the MC EGSnrc code to evaluate whether the head tilt method is a good alternative for reducing the absorbed dose to the brain, eye lens, oral mucosa and salivary glands.

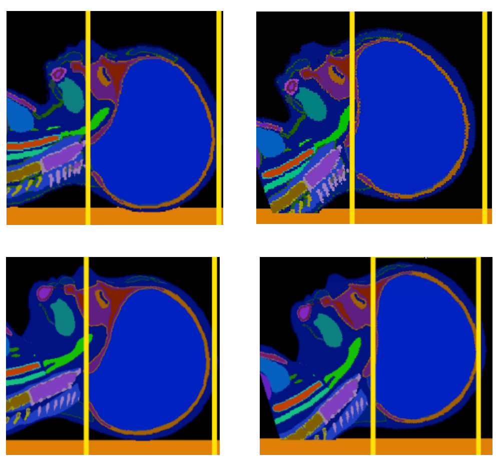


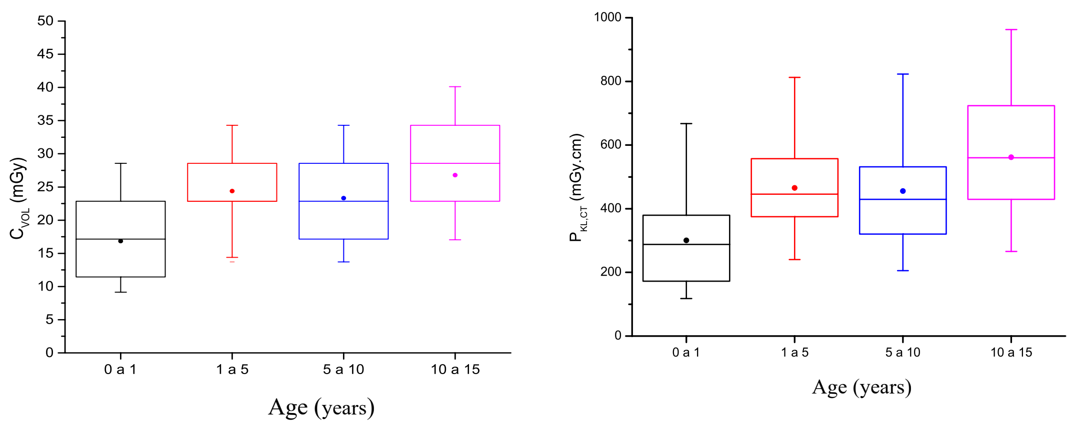
Figure 1: Newborn (top) and 1yearold (bottom) phantoms in standard position (left) and angled at 18° (right).

3. Results and Discussion

The distribution of estimated C_{VOL} values for each age group of the studied exams is shown in Figure 2. The variations were similar for almost all age groups, except for patients with 1 to 5 years old, who showed less variation. These variations are similar to what was observed when evaluating the x-ray tube load (mAs/slice). The radiation intensity and, consequently, the C_{VOL}, is directly proportional to the tube load, highlighting the need for more criteria in the selection of irradiation parameters by the scanner operator.

The air kerma-length product for complete CT scans ($P_{KL,CT}$) was also estimated for all collected exams where it was observed that variations greater than those observed for the C_{VOL} were caused by differences in the selected scan lengths for each exam. The use of acquisition parameters without optimization can increase the values of C_{VOL} and $P_{KL,CT}$.

Figure 2: Distribution of C_{VOL} and $P_{KL,CT}$ values for each age group.



To simulate this condition, as shown in Figure 1, the computational phantoms used in CALDose_XCT were tilted at 18º, with the baseline (location of the scan start) positioned on the supra orbitomeatal line, which is located above the region of the orbits. The results of this comparison are shown in Table 2.

Table 2: Comparison between simulations with 0º and 18º head tilt in newborn and 1-year-old phantoms for head CT scans.

Phantom	**Organs**	**Absorbed Dose (mGy)**		**Dose Reduction (%)**
		0º	**18º**	
Newborn	Brain	11.2±0.11%	10.9±0.08%	2.7%
	Eye lens	8.9±0.85%	3.7±0.94%	58.4%
	Oral mucosa	3.6±1.86%	1.1±2.29%	69.4%
	Salivary glands	4.5±1.22%	1.6±1.44%	64.4%
1 year	Brain	9.4±0.05%	10.5±0.05%	-11.7%
	Eye lens	10.5±0.54%	3.2±0.90%	69.5%
	Oral mucosa	1.7±1.16%	0.9±1.79%	47.1%
	Salivary glands	2.6±0.59%	0.9±0.96%	65.4%

The comparison shows that there was a reduction of the absorbed dose in most of the studied organs, especially in the eyes and salivary glands. For the newborn phantom the dose reduction in eyes and salivary glands were 58.4% and 64.5% respectively, and for the 1-year-old phantom, they were 69.5% and 65.4% respectively. This indicates that the hyperflexion of the patient's head can be a good method to reduce absorbed doses in radiosensitive organs, without prejudice to the visualization of relevant anatomical structures.

4. Conclusions

The dosimetric values estimated in this study are close, or surpassing them in some cases, to the reference levels for diagnosis established by the European Guidelines on Diagnostic Reference Levels for Pediatric Imaging of 2018 [5], showing that most of the evaluated pediatric scans could have been better optimized. The manufacturer's pre-established protocols were modified, apparently, without any defined physical criteria, which can result in either a reduction in image quality or an increase in the absorbed doses to the patients' organs. The use of high scan lengths in most of the exams demonstrates that there is lack of concern in selecting only the area of diagnostic interest. This practice can result in increased absorbed doses to organs that would be outside the radiation beam, such as the salivary glands and the thyroid.

The head tilt simulation of pediatric patients for head CT scans resulted in a reduction of the absorbed doses to the eye lenses, oral mucosa and salivary glands, proving to be an effective method for optimizing radiological protection in these procedures.

Given the above, the importance of training for professionals is highlighted, as well as the implementation of a Quality Assurance Program in the service, with the objective of optimizing procedures and reducing the detriment for pediatric patients undergoing CT scans.

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