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Dose Optimization in Computer Tomography Pediatric Cranial Scans

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Abstract

Background and Objective: Nowadays, Computer Tomography is one of the best radiological imaging technics which can give right diagnostic information, among the detection of multiphasic adenomas, the detection of cardiac, cerebral and vascular abnormalities. Although these good qualities, this technic is too radiant for the patient. In this paper, we based on the irradiation doses delivered from the current protocols to find a practical method of their optimization during the pediatric cranial scan. **Materials and Methods:** This work relies on a collection of data from patients in the hospitals, so that analyze them, give the conclusions and, propose an optimal practical method to decrease the irradiation doses. To collect data, we performed a prospective study of seventeen months (from December 2017 to May 2019) carried out simultaneously in three hospitals of the city: The Centre Medical la Cathédrale (H_1), the Yaoundé Central Hospital (H_2) and the Yaoundé Gyneaco-Obstetric and pediatric hospital (H_3). This study included a total of 192 cases of cerebral trauma, of which 11 cases excluded for incomplete information. The dosimetry quality control (CTDIvol) using the PMMA phantoms of 16 cm and 32 cm fulfilled. The scanographic parameters of the patient acquisition protocol were recorded and analyzed. Some of those parameters were modified and entered the CT with the help of a biomedical engineer to reduce the delivered dose. The relationship between CTDIvol and kV is statistically significant ($p < 0.05$) to identify significant differences in obtained results before and after the optimization of protocols. **Results:** Among patients, 172 are boys, and the remaining 9 are girls all were in the 0 to 15 age group. CTDIvol values varied from 34.2 mGy to 107.8 mGy and PDLs from 107.8 mGy.cm to 2214.5 mGy.cm in H1. In H2, CTDIvol varied from 5.8 mGy to 44 mGy and PDLs from 91.4 mGy.cm to 665.5 mGy.cm. CTDIvol varied between 9.34 mGy to 92.81 mGy and PDLs from 162.38 mGy.cm to 2713.67 mGy.cm in H3. All values are taken at 75th percentile, with or without contrast injection. **Conclusion:** The implementation of the optimization of protocols requires the display of the CT parameters to use and to respect during the traumatic brain tests. With displaying and respecting protocol, the CTDIvol decreased by almost 50 per cent.

Keywords

Computed Tomography, Dose Optimization, Pediatric Cranial Scans, Protocol

1. Introduction

The development of treatment technics in healthcare improved during those last years. Thus, new devices and equipment allow today to the diagnosis, monitoring and treatment of complex diseases. Computed tomography (CT) is one of the medical imaging equipment whose performance improves every year. The first CT was invented in 1970 [1]. Today, the number of pediatric CT has considerably increased [2], mainly due to the improvement and availability of scanners in the hospitals and the medical imaging laboratories. CT is a high-performance medical imaging technic. However, it is also highly irradiating compared to conventional radiography. Its practice is not without consequent in the life of patients because the risk of induced death by radio cancer for a Sievert has estimated at 14 per cent a birth versus 1 per cent at age 75, although the debate about ionizing radiation effects is still divergent [3] [4]. The risk assessment of induced radio cancer for CT scans performed before the age of 10 is between 0.001‰ (per thousand) and 10‰ (per thousand) depending on the type of examination and the age of the patient [1]. Secondary effects occur in the short terms following high doses of radiation. Those effects can be "deterministic", in the low dose range (<1 Gy), or "stochastic" that appear late depending on the dose received [5]. Technological progress in CT has considerably improved the performance of equipment. However, they have not helped to reduce the delivered dose, and they could even increase it by allowing faster acquisitions on large volumes of exploration. The delivered doses remain poorly appreciated because of a lack of indexes dosimetry references for relevant measures available on our equipment, and, also the absence of a team set up for the improvement of display and the compliance of protocols.

The optimization of irradiation doses during CT exam is a big challenge today. Many types of research conducted to reduce those doses and keep the quality of captured images for the right diagnosis. In this paper, we focus mainly on irradiation doses during the pediatric cranial CT. The objective of this work is to determine delivered irradiation doses from the current protocols to find a practical method of their optimization during the pediatric cranial CT. The paper organized as follows: Section 2 reviews published methods in the field. In Section 3, materials and methods are exploited to collect data throughout our work. Section 4 presents our results concerning the optimization of protocols during the CT exam. Those results are analyzed and discussed also—a conclusion provided in Section 5.

2. State of the Art

In 2014, Thomas Nelson said that a good team for improvement of display and the compliance of protocols must be composed by a radiologist, a medical physicist, and a technologist [6]. The radiologist is the clinical expert that justifies the prescription of CT scan in children and defines the imaging task. A medical physicist is a clinical expert who can suggest the CT parameters and technics so that the radiation doses of the child patients are As Low As Reasonably Achievable (ALARA). The technologist is the clinical expert in implementation, workflow and provides insight into the practical limitations and modifications of the proposed protocol [7]. The big challenge today is the achievement of diagnostic images while optimizing the child patient doses. That reduces the harmful effects of x-rays in those children. The radiation protection in pediatric is an old concern and dose reduction on CT has been a goal of paediatricians for many years [8] [9]. Our country (Cameroon) ranked at the bottom of the scale (171st out of 188 countries) of a report of the countries offering better health conditions, recently published by the global mobility burden evaluated by WHO [10]. It shows that the quality of care remains to be improved, and that does not exclude the medical imaging sector, specifically pediatric CT. CT is used in some hospitals even so the devices often suffer to obsolescence, lack of qualified technicians, poor maintenance, mishandling, lack of restraint, caches and instability of electricity. This has consequences for patients who are supposed to treat.

Several authors have examined the work of CT generally in the world and particularly in Cameroon. In [11], Biwele Sida *et al.* worked on the contribution of CT in the diagnosis of pancreatic pathology in Cameroon. Their work focused on adults, and they have not performed the optimization of irradiation doses [11]. In 2014, Guegang *et al.* proposed an evaluation of irradiation doses of adult patients with CT ultrasound [12]. They did not work on optimization, display and esteem protocols. Moifo *et al.* performed work on the determination of clinical values or electroencephalography of variables that could predict brain scan abnormalities in childhood epilepsy [13]. Ongolo Zogo *et al.* proposed an evaluation of dose in pediatric CT [14]. They put a point of emphasis on the display of protocols. However, the study was not focused on protocol optimization. In [15], Lambert *et al.* showed that the reduction and optimization dose in CT might be influenced not only the CT protocol but also many other factors alone the entire CT workflow. These are pre-scan tips and post-scan factors. In the pres-can tips, there are scanography parameters, scout of view (CT localizer), the excellent positioning of patients in the gantry too. In the post-scan, there are reconstruction approach and iterative reconstruction algorithms [6] [15] [16] [17] [18] [19]. According to Kofler *et al.* in 2014, the emphasis placed on a team approach that team constitutes of one radiologist, one physicist and one technologist [7]. That core team worked together carefully evaluates proposed improvements [7] [15] [17] [19].

Based on the authors and to the best of our knowledge, none researches performed a study, especially on irradiation doses during the pediatric cranial CT, to reduce the irradiation doses from the current protocols. This drawback is the main objective of this paper. Indeed, we determine the delivered irradiation doses from the current protocols to find a practical method of their optimization during the pediatric cranial CT.

3. Methods and Materials

A prospective study performed over 17 months (December 2017-May 2019). Dosimetry quality control (CTDIvol) is performed using the PMMA phantoms of 16 cm and 32 cm. The scanographic parameters of patient's protocols acquisition are raised and analyzed. Some of these parameters are modified and introduced in the scanner with the help of biomedical engineer in order to reduce delivered doses. The data raised during pediatric exams. The H_1, H_2 and H_3 hospitals are equipped respectively with TOSHIBA Aquilion 128 bars scanners installed in January 2015, HITACHI 16 bars installed in December 2016 and Neusoft Neuviz 16 bars installed in December 2015. These three scanners are equipped with child protocols and offer the possibility to change the voltage and the load. These medical imaging services account around 85 per cent of pediatric imaging activity in the Yaoundé city, which has a population of 2.3 million in 2018 [20]. All these structures are also training centres for radiologists and medical imaging technicians.

The study population consisted of all children aged 0 to 15 years. The data collection form, inspired by an IRSN model for dosimetry evaluations in CT, included the following items: hospital, CT scan type, patient's first and last names, sex, weight, clinical information, FOV, patient parameters examination (the high voltage, the mass load (mAs), current modulation (mA), thickness in mm, pitch and doses delivered (CTDI in mGy, and PDL in mGy.cm) as seen in **Table 1**. **Table 1**, **Table 2** and **Table 3** provide us with an example of kind of data collected from H1, H2 and H3. We notice that each of these hospitals used different manufacturers.

The data have been collected simultaneously in H_1, H_2 and H_3. At the same time, we have used the data from registry records and CT central memory. The examination reports provided the clinical information and the area to be scanned. Exams conducted all the time with the presence of technician and sometimes with a radiologist when there are disturbing cases. Subsequently, protocol optimization is proposed and displayed in the H_1. The irradiation doses after protocol optimization are recorded and analyzed. The technicians do not always respect the new protocol optimization during examinations. This optimized protocol introduced into a scanner with the help of a biomedical engineer who comes to Cameroon for maintenance work.

R software is used to representing the box plots that allowed us to see the observed dose in most patients. ANOVA in Minitab for calculating frequencies of qualitative variables means standard and median deviations of quantitative variables. The values of effective doses are compared to those of IRSN.

Table 1. Pediatric CT scan data collected from H_1.

Name of Hospital: H1								**Manufacturer**: Toshiba Aquilon 128 barrettes				
Parameters / N°Patient	Age (Years)	Gender	Rotation Time	Acquisition Type	kV	mAs	Total Scan Time	Thickness	FOV	Pitch	CTDIvol	PDL
1	11	F	0.75	Helical	100	150	19.36	0.5	201.56	0.656	34.2	687.10
2	4	F	0.5	Helical	100	150	14.61	0.5	193.1	0.656	34.2	704.2
3 with PDC	5	F	0.75	Helical	120	150	34.79	0.5	193	0.656	103	2149
4 with PDC	15	F	0.75	Helical	120	187	18.47	0.5	195	1.656	97	2210
5 with PDC	1	F	0.75	Helical	120	187	17.34	0.5	184.69	1.656	92.34	2023
6	1	M	0.5	Helical	100	75	15.09	0.5	166.88	0.656	17.10	369.2
7	1	M	0.5	Helical	100	75	13.42	0.5	172	0.656	17.10	309.4
8	2	F	0.5	Helical	100	75	12.71	0.5	190.31	0.656	17.10	283.7
9	9	M	0.5	Helical	100	75	13.4	0.5	162.82	0.656	17.10	309.4
10 with PDC	9	M	0.5	Helical	100	150	35.54	0.5	190.31	0.656	68.40	1476.8

Table 2. Pediatric CT scan data collected from H_2.

Name of Hospital: H_2						**Manufacturer**: HITACHI: 16 bars.				
N°	Age (Years)	Gender	Rotations Time (s)	Acquisition Type	Tension (kV)	mAs	FOV	Pitch	CTDI v (mGy)	DLP (mGy.cm)
1	10	M	0.75	Helical	100	169.3	197	0.65	12.8	251
2	8	F	0.5	Helical	100	81	210	0.65	6.2	114.4
3	3	M	0.5	Helical	120	81	193	0.65	9.7	230.2
4	1	M	0.5	Helical	100	82.5	208	0.65	6.3	116.1
5	3	M	0.75	Helical	100	174.5	195	0.65	13.2	242.7
6	8	M	0.5	Helical	100	10.3	220	0.65	6.6	173.4
7	3	M	0.75	Helical	120	153.6	189	0.65	18.2	382.8
8	10	M	0.5	Helical	100	81	205	0.65	6.2	146.5
9	3	M	0.5	Helical	120	78	220	0.65	9.4	221.7
10	4	M	0.5	Helical	120	84	202	0.65	6.4	135.1

Table 3. Pediatric CT scan data collected from H_3.

Name of Hospital: H_3					**Manufacturer:** Neusoft neuviz 16 bars					
N°	Age (Years)	Gender	Rotation Time (s)	Acquisition Type	Tension (KV)	Charge par Coupe (mAs)	FOV	Pitch	CTDIv (mGy)	PDL (mGy.cm)
1	1	M	0.5	Helical	180	160	151	0.671	10.51	199.21
2	13	M	0.5	Helical	90	151	190	0.671	9.34	203.27
3	1	M	0.5	Helical	180	151	165	0.671	9.94	167.59
4	1	M	0.5	Helical	180	151	193	0.671	9.94	188.43
5 with PDC	6	H	0.75	Helical	120	151	218	0.671	48.2	1148.745
6	1	M	0.75	Helical	120	151	150	0.671	23.44	420.61
7 with PDC	15	M	0.75	helical	120	160	202	0.671	24.79	986.96
8	5	M	0.5	Helical	120	159	203	0.671	24.73	469.58
9 with PDC	12	M	.075	Helical	120	160	208	0.671	74.19	1552.69
10 with PDC	13	F	0.5	helical	120	160	207	0.671	24.8	593.52

4. Results

That study included 181 cases of head trauma among which 9 girls and 172 boys all included in the age group 0 to 15 years, either percentage of girls is 5 per cent and 95 per cent of boys, with 84 patients in H_1 hospital, either 42 before or 42 after optimization, 48 to H_2 and 49 to H_3. CTDIvol ranged from 34.2 mGy to 107.8 mGy and, the PDLs between 107.8 mGy.cm and 2214.5 mGy.cm in H1. In H2, CTDIvol is between 5.8 mGy and 44 mGy and, DLPs between 91.4 mGy.cm and 665.5 mGy.cm. CTDIvol is between 9.34 mGy and 92.81 mGy and DLP between 162.38 mGy.cm and 2713.67 mGy.cm in H_3. All these values have been obtained at 75th percentile, with or without contrast injection. At H1, before optimization, the median was 51.50 mGy and the average 56.89 mGy for CTDIvol. The median DLPs were 909.35 mGy.cm and average 1069.24 mGy.cm. After optimization in the same hospital, the median CTDIvol is 23.15 mGy, for an average of 31.51 mGy. The median DLP is 446.4 mGy.cm, and the average is 97.40 mGy.cm. The voltages have values between 90 kV and 120 kV and the intensity of 80 mA at 374 mA and the charge per cup varying between 41.5 mAs and 187 mAs in the three hospitals.

From these results, it follows that the highest irradiation doses are those of the H_1 hospital even after optimization. The lowest values are those of H_2 hospital with CTDIvol values between 5.8 mGy and 44 mGy and a median of 9.6 mGy. The DLPs between 91.4 mGy.cm and 695.5 mGy.cm with a median of 218.35 mGy.cm. We can see the box plot displayed in **Figure 1**, the variation of the CTDIvol in **Figure 2** and the variation of the DLP in each hospital. **Figure 3** and **Figure 4** present the variation of the DLP according to the age groups. The optimization of protocols in H_1 hospital allowed a dose reduction of approximately 50 per cent. These optimization parameters displayed in **Table 4**. Unfortunately, two months later in that hospital, the tube was changed by another biomedical engineer to our absence, and the previously introduced optimization parameters aren't done. Then the dose increases in some child patients when the technicians do not adjust the parameters. After optimization of H_1 hospital protocols, CTDIvol decreased by 50 per cent compared to baseline doses.

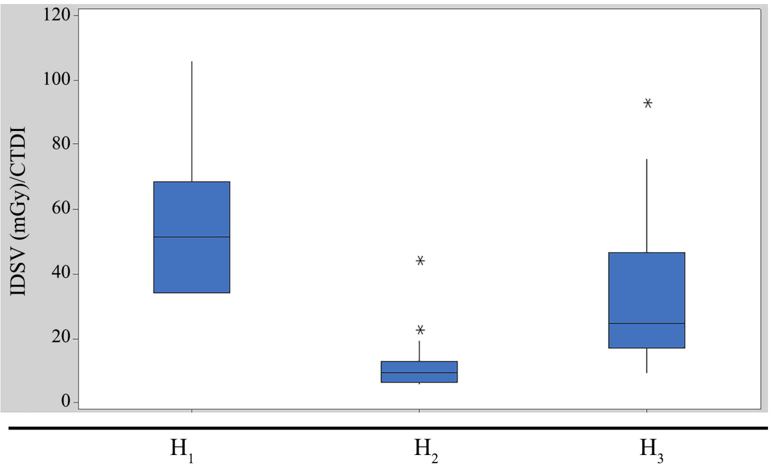

Figure 1. Variation of the CTDIvol in H_1, H_2 and H_3 before the optimization of the protocols.

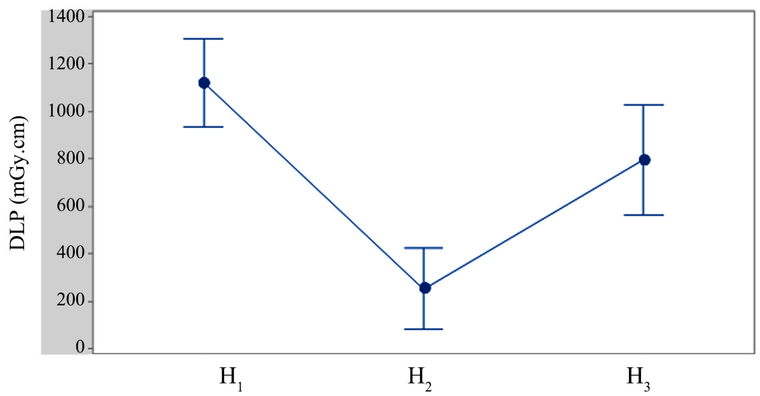

Figure 2. DLP variation in H_1, H_2 and H_3 hospitals and place before optimization.

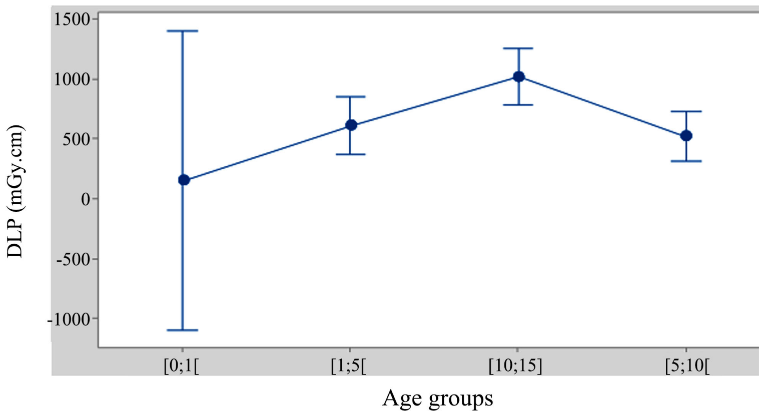

Figure 3. Variation of DLPs according to age groups.

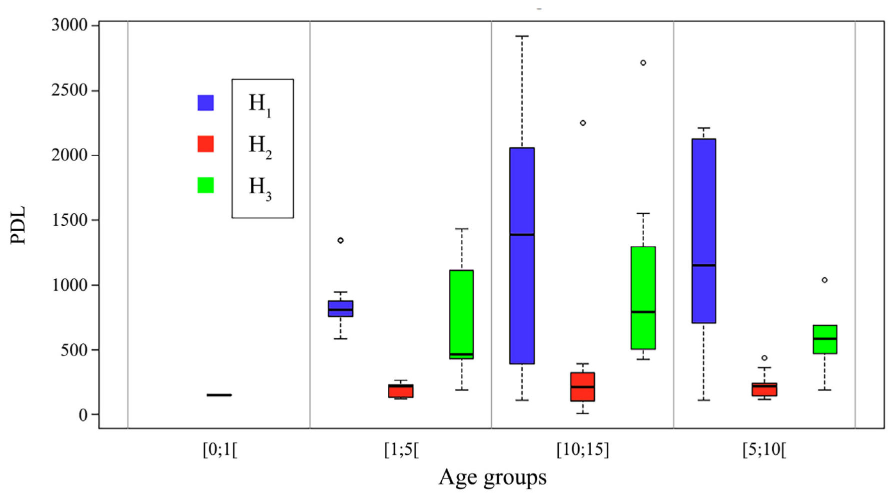

Figure 4. Variation of DLP by hospital and age group.

Table 4. Optimization of protocol used in H_1.

Age Groups	Tension in (kV)	Intensity in (mA)	Rotation Time in (s)
[0 - 1[	100	150	0.5
[1 - 5[	100	200	0.5
[5 - 10[	100	200	0.5
[10 - 15]	100	200	0.75

CTDIv1: Radiation dose in the H_1 hospital before protocol optimization. CTDIv2: Radiation dose in the H_1 hospital after protocol optimization. CTDIvh: Radiation dose in the hospital H_2. CTDIvg: Radiation dose in H_3 hospital.

The area graph shown in Figure 5 allows us to see the decrease of CTDIv1 before optimization and CTDIv2 after the protocol optimization. Figure 6 presents the linear graph of averages showing the variation of CTDIv1 and CTDIv2 as a function of age groups after the protocol optimization. During scanner examinations, technicians could lower voltage values from 100 kV to 90 kV after injection of contrast media to get better images. According to the DRL in Europe, the CT head is 58 mGy [21]. In our country, it is estimated at 51 mGy. The decrease of the voltage remains in the majority of cases compatible with the use of the dose reduction software's (contrarily to the charge) [22]. A decrease in the voltage of 20 per cent decreases the dose to almost 50 per cent. Optimization can also go through by an iterative reconstruction because when they are used, the voltages are low. Currently, in hospitals, these use only for the improvement of the images after the examination. The technicians reduce the noise and not the dose. Time constraints favour the helical mode to the axial mode, which radiates less. The length of the scan should be taken into account. Although CTDIvol values of H_1 hospital still high compared to other hospitals (H2, H3), CTDIvol values for all hospitals, including those after the optimization of protocol, can be seen on the area graph display in Figure 7.

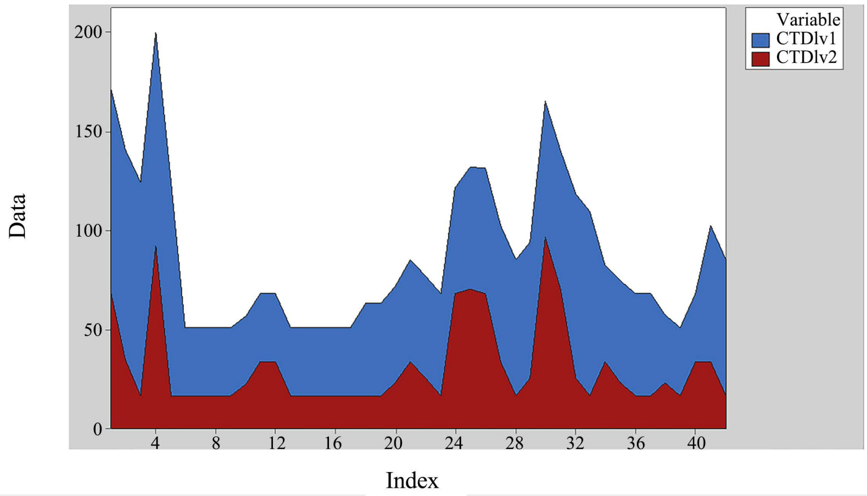

Figure 5. Area graph showing the decrease CTDIv1before to CTDIv2 after the protocol optimization.

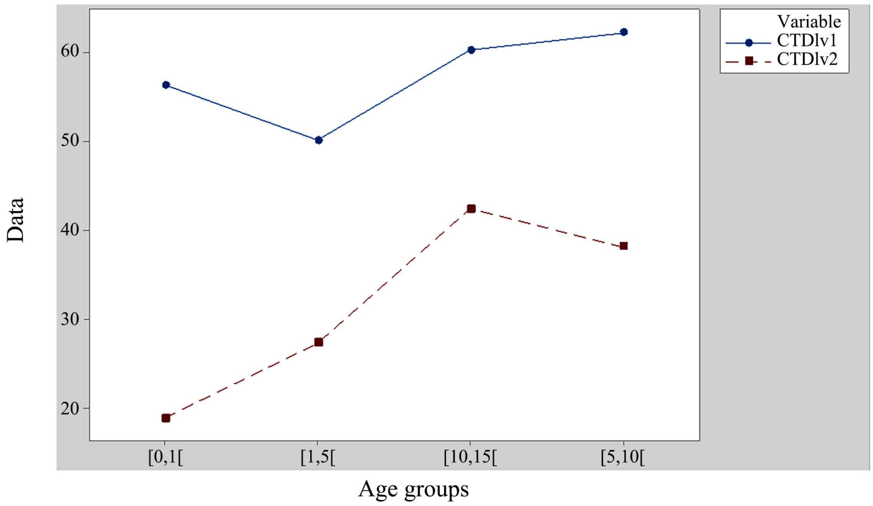

Figure 6. Linear graph of averages showing the variation of CTDIv1 and CTDIv2 as a function of age groups after the protocol optimization.

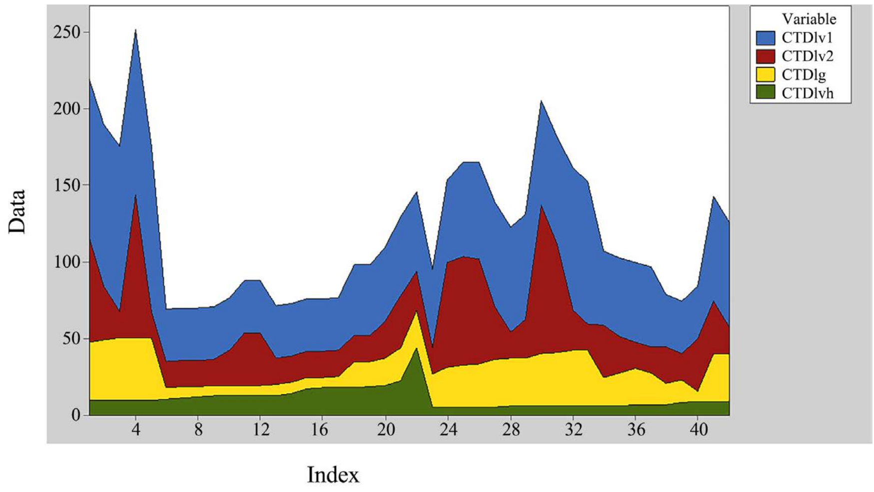

Figure 7. Area graph in hospitals after optimization.

4. Discussion

For the dosimetry indicators, one need two parameters such as $CTDI_{vol}$ that is an indicator of tissue dose that accounts for the average dose distribution ($CTDI_w$) in the exposed volume during 360˚ (pitch) tube rotation and DLP which gives information on the emitted dose in function of length explored during the acquisition [23].

$$CTDI_{vol} = \frac{CTDI_w}{pitch} \tag{1}$$

$$DLP = CTDI_{vol} \times \text{length explored} \tag{2}$$

The $CTDI_{vol}$ is controlled during the installation of the scanner and each tube change, the gap between the $CTDI_{vol}$ display and measure should not exceed ±20%. The radiological risk is taken into account by the effective dose (E) in mSv, which can be estimated from the DLP using conversion factors (eDLP) [24].

$$E = DLP \times eDLP \tag{3}$$

According to the generalized linear model, we can notice that the age has a significant influence on the DLP, and, compared to less than one year, the others age groups have a higher dose, unfortunately. However, compared with the H_1 hospital, the other hospitals record significantly lower doses. **Figure 1**, **Figure 2** and **Figure 3** show the variations of the CTDIvols and DLPs in H_1, H_2 and H_3 hospitals before protocol optimization. In the moustache box (**Figure 1**), we see that CTDIvol values are higher than two other hospitals. In H_2, high doses do not achieve low doses of H_1 and H_2 hospitals. In **Figure 1** and **Figure 2**, the pooled standard deviation was used to calculate the intervals. We can also notice that the dose varies positively according to the load per cut and also according to the high voltage (the latter cannot usually be interpreted because of non-significance of the associated coefficient. We find that the DLP increases with the ageing patient regardless of the hospital centre (**Figure 4**). That can be seen through mediating values of doses that are higher for the age group [10 - 15] years. However, there are also higher overall dose values at H_1 than anywhere else. Given the high dose values in the H_1 hospital, the optimization of the protocol is necessary. The hereinabove parameters have been chosen in **Table 4** to perform optimization. After that CTDIvol lower about 50 per cent. Measurements on 16 cm and 32 cm PMMA phantoms in each hospital are compared to Nelson's phantom measurements in 2014. The measurements were done for the calibration of the computer tomography. **Figure 4** shows the change in DLPs by age groups and in each hospital. The variances assumed to be equal for the analysis. Factor information: the analysis of variance allows to say that at the threshold of 5 per cent, the DLP varies significantly by age groups, concerning trauma cases.

In **Figure 5**, the DLP is highest for age groups [5 - 10[and [10 - 15] for H_1 than H_2 and H_3 hence the need to optimize protocols in H_1 hospital, in addition to seeing the low doses of H_3 hospital. **Figure 5** shows how, after the protocol optimization one has low doses of irradiation (CTDIv2) in red colour before optimization, one has blue colour (CTDIv1). This area graph shows that protocol optimization is essential. **Figure 6** shows how, before the optimization of the protocol, we have a blue linear graph which has high values CTDIv1. **Figure 7** presents the CTDIvol of all hospitals. Although the diagnostic reference level is not regulatory limits [25], they are optimization tools that allow evaluation of its practices [26] [27].

5. Conclusion

The implementation of the optimization of protocols requires the display of the cranial parameters to be used and adhered to during brain examinations. That has resulted in a reduction of CTDIvol of 50 per cent. A follow-up survey shows that 20 per cent of exams do not comply with the new protocol. That requires weekly awareness sessions for directors of brain injury CT scans for the implementation of optimization (use the scanner settings displayed). Emphasis should be placed on the justification and practice of pediatric cancer, mainly as MRI compensates for the failure of the scanner. Nowadays, the different intelligence architecture for dose optimization and image analysis are proposed based on big data and machine learning [28]. In our future work, we plan to use CT image captured with a low dose and built a Machine Learning model based on a convolutional neural network to perform intelligence interpretation. We will propose an optimal big data architecture with convolutional neural network for dose optimization in CT pediatric cranial scan

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Ethical Approval

All displayed data in this paper were collected with the consent of patients during their exams.

Informed Consent

Written informed consent was obtained from the patient for publication of this review paper.

Conflicts of Interest

We wish to confirm that there are no known conflicts of interest associated with this publication.

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