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Reduce Absorbed Doses and Protection of Radiosensitive Organs of Children Exposed to Ionizing Radiation on Adult Scanners

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Abstract

Purpose: The purpose of this work is to reduce absorbed doses by children and show how the manipulator's lead apron can be used to protect highly radiosensitive organs during pediatric CT scan on older generation scanners.

Method: From 2015 to 2018, scan length of 312 children were assessed prospectively. Head and bodies CT scan of children aged 0 to 15 years in three hospitals (H1, H2 and H3) were recorded.

Results: A test is performed in a country that studies this type of scanner. In 2015, the child's radiosensitive organs were not protected during acquisitions and the scan lengths were longer than comparative literatures. After recommendations proposed in 2015 and the participation of many technicians from this country in the first radiology quality control seminar in September 2017 by an author of this article, in 2018, lead apron is used to shield radiosensitive organs of children during examinations. Lead apron is placed on the appropriate bodies parts. No relevant artifacts were found, and the image quality was not affected. For skull examinations, scan lengths and Dose Length Product decreased by 4.9%, 6.32% and 3.46% and by 25.14%, 36.29% and 19.85% for children<1 year, 1-4 years and 5-9 years respectively.

Conclusion: The reduction of scan length according to the clinical indication and the use of the lead apron to shield the radiosensitive organs when it is well positioned on the patient reduce absorbed doses by children exposed to ionizing radiation on adult scanners.

Keywords: Computed tomography; Lead apron; Image quality; Radiosensitive organs; Ionizing radiation

Introduction

The use of medical imaging has grown considerably over the years because of the lives it saves. Among medical imaging techniques, computed tomography (CT) appears today as one of the most effective image quality and medical diagnosis imaging modality. It produces detailed images of internal organs. Its technological evolution up to present has increased its performances in terms of image quality and diagnosis in many pathologies (traumas, and tumor surveillance), thus reducing the mortality rate. This evolution has been accompanied by a growing concern to protect the patient against ionizing radiation associated with the use of X-rays tubes. Therefore, the use of X-rays tubes must be controlled. Pediatric patients are particularly threatened by the effects (deterministic and stochastic) of overexposure to radiation due to several factors including among others the strong radio sensitivity of their tissues and organs. The long life expectancy of pediatric patients is likely to increase their radiating doses [1,2]. For these reasons, attention on dose reduction techniques is growing and several scientific studies on the topic have been published [3-5]. Gantry tilting, organ-based tube current modulation, bismuth shielding and iterative reconstruction [6,7] are among the most widely used procedures to reduce the eye lens dose. All authors agree that gantry tilting and tube current modulation (or reduction) techniques [8,9] have to be preferred to high attenuation-filter (bismuth shielding) ones allowing for dose reduction while maintaining image quality. However, these techniques are not implemented in all available commercial scanners, especially in less recent ones. The manufacturer of the eye shield guarantees a reduction in the dose of eye lenses up to 50% (average reduction of 40%) [10]. Avoiding any contact between the protection system and the patient's eyes can reduce the biological risk and increase the patient's observation. The general objective of this study was to assess the use of lead apron generally worn by scan technicians to protect child's radiosensitive organs in developing countries that do not have bismuth shields. We also did a comparative study of the scan length studied in 2015 and 2018 in order to observe the improvement of pediatric CT scan practice in hospitals in the country. Strategies are proposed to use lead apron in developing countries still using older generation scanners.

Materials and Methods

Patients

All CT scans of the skull and abdomen obtained over a 3-year period were assessed for inclusion in this prospective analysis, which was approved by the institutional review board. Inclusion criteria were as follows:<1 year, 1-4 years, 5-9 years and 10-14 years, suspected traumas for skull examinations, and the tumor surveillance for abdominal cases. From 2015 to 2018, 312 patients participated in this study, for 460 acquisitions. In this study, the Volume CT Dose Index (CTDIV), Dose Length Product (DLP), and scan length recorded on the 16 cm phantom for all examinations of the head and 32 cm for the abdomen. Verbal consent was obtained from all patients or legal representatives.

CT protocols

This study started in 2015 and a one-month internship was conducted in October 2018 to check if the recommendations are still put into practice and the doses are optimize. The CT acquisitions were performed on children aged 0 to 15 who have had skull and abdominal CT scan in hospitals H1, H2 and H3 **(Table 1).**

Table 1: Characteristics of scanner devices in the three hospitals

Hospital	Model	Date of manufacture	Date of installation	CT technique
H2	GE Bright Speed8	Nov-10	2012	4-barrettes
H3	GE Light Speed16	Mars 2003	2009	16-barrettes
H1	HITACHI ECLOS Speed16	Mars 2009	2009	16-barrettes

For each CT scan, in 2015, the helical mode and the same 120 kV for all age groups were used. The tube current-time products used ranged from 57.75 to 283.33 mAs, slice thickness (T) from 1.25 to 2.5 mm. All scanners used the adult protocol for pediatric exams. Radiosensitive organs were not protected. The scan lengths were not harmonized. Each technician delimited as he wanted in the different hospitals. In 2018, for all age groups, the high tube voltage ranged from 100 kV to 120 kV, tube current-time product from 100 to 250 mAs, and slice thickness from 2 to 2.5 mm. Lead apron are divided according to the dimensions of the radiosensitive organs to be protected and are used to protect those radiosensitive organs. Scan length are reduced and harmonized.

Figure 1: Lead apron use in our centers.

The scanner's lead apron **(Figure 1)** should be placed on the appropriate organ, taking into account the clinical indication of the examination to avoid for the target clinical area. After the scout scan, the shielding apron may be technically deposited on the radiosensitive organs contained either in the head, neck or body of the patient. For reasons of stability and resistance, two rounds of plaster are sufficient or a tape 'Velcro'.

Make a restraint with available equipment before using the leaded apron

Restraints used in the hospitals studied are unsuitable for agitated and unconscious pediatric patients. They cannot prevent frightened and restless patients from moving on the examination table. The use of the leaded apron requires a complete immobilization of the patient. This protective apron is heavy and must not be moved during the examination to avoid possible artifacts. For hospitals that do not have pediatric scanners, we can find solutions for pediatric examinations done on adult machines, that is to say machines having only a functional adult protocol. When the hospital is not able to buy props for pediatric patients, we can manufacture them with equipment that is easy to acquire. This is the reason why with this material we can improve the restraints used in hospitals. For this, we need a Plexiglas sheet that we have to cut with a suitable blade according to the dimensions of the motorized table of the scanner, the size of the children and in the shape of a person to facilitate the attachment with belts or seat belts **Figure 2**. For complete immobilization of the child, we will need a long band or 7 small bands or 7 belts. This contention must be removable. Let us not forget that this measure of restraint must be done with the parents' agreement to avoid their possible reproach. This restraint will prevent entry of the parent into the examination room and prevent exposure to ionizing radiation. Choosing a restraint or sedation related to the age of the pediatric patient and his or her behaviour is not an easy task.

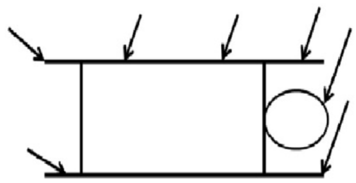

Figure 2: Example of shape that the plexiglass sheet must have: the arrows correspond to the positions of the belts necessary for the immobilization of the pediatric patient. Given the lack of good restraint in the hospitals studied, we must buy plexiglass with a good thickness and cut as in this image by adding belts.

Statistical analysis

Statistical analysis was performed using Microsoft Excel software. Data were expressed as mean, minimum, maximum and third quartile. This formula was used to calculate the scan lengths:

PDL=CTDIv × L

Results

Children were exposed to ionizing radiation on adult machines. The hospitals in 2015 did not have adequate tools to protect the radiosensitive organs of children (gonads, thyroids and eyes) from ionizing radiation (IR). Lead apron and bismuth shield were not used to protect radiosensitive organs. Hospitals generally used the same protocol parameters for children and adults. None of these hospitals had pediatric software in their device to optimize the doses absorbed by children. Scout view took almost the whole body of children **Figure 3**. The use of radiological protocols and procedures that are not adapted to the pediatric examination produces great scan lengths, which results in the exposure of unnecessary parts to ionizing radiation.

Figure 3: Scout scan of an examination of the head and abdomen of a child taken in hospital number 2 (H2).

This image shows the patient's length of scan in relation to his height, area to be explored.

Table 2 compares the 3rd quartile of the scan length (Cm), CTDIV (mGy) and DLP (mGy.cm) in 2015 and 2018 of this study, with international studies for skull (Trauma) for one acquisition. The 2015 data is lower than the TOGO 2016 [11] and DRL France 2019 [12] values except for children aged 5-9 years where TOGO 2016 has a scan length greater than this study. In 2018, the data from this study is lower than the 2015 values. Scan lengths decreased by 4.9%, 6.32% and 3.46% for children<1 year, 1-4 years and 5-9 years respectively. DLP also decreased by 25.14%, 36.29% and 19.85% for children<1 year, 1-4 years and 5-9 years respectively. The scan lengths of 2018 are lower compared to those of TOGO 2016. Those values are close to those of the DRLs FRANCE 2019. For CTDIV and DLP, the collected data are superior to the comparison literatures.

Table 2: Comparison of the 3rd quartiles of the scan length (Cm), CTDIV (mGy) and DLP (mGy.cm) in 2015 and 2018 of this study, with international studies for the skull (Trauma) for one acquisition.

Dose values	Scan length (L)			DLP			CTDIV		
Examination/ Ages	Skull/<1	Skull/1-4	Skull/5-9	Skull/<1	Skull/<1	Skull/5-9	Skull/<1	Skull/1-4	Skull/5-9
This study (2018)	19.59	20.58	22.3	670.1	727.3	962	34.2	35.33	43.11
Togo 2016 (Mean) [2]	24.81	22.22	25.4	546	800	813	22	36	32

DRL France (2019) [7]	16	16.36	18.1	320	360	470	20	22	26

Table 3 compares the 3rd quartiles of the scan length (Cm), CTDIV (mGy) and DLP (mGy.cm) in 2015 and 2018 of this study, with international studies for the Abdomen (Tumor) for one acquisition. The data collected in 2015 are in majority superior to the data of the DRLs FRANCE of 2012 [13] and 2019. For the children of 1-4 years and 10-14 years, the lengths of scan are practically identical to those of the DRLs FRANCE 2012. Changes were made between DRLs FRANCE from 2012 to 2019. The scan lengths of DRLs FRANCE 2018 are higher than those of this study (2015) and DRLs FRANCE 2012, but its DLP and CTDIV are lower. The scan lengths increased but the doses decreased. This is why it is important to protect the radiosensitive organs contained in these long scan lengths.

Table 3: Comparison of the 3rd quartiles of the scan length (Cm), CTDIV (mGy) and DLP (mGy.cm) in 2015 and 2018 of this study, with international studies for the Abdomen (Tumor) for one acquisition.

Dose values	**Scan length (L)**			**DLP**			**CTDIV**		
Examination	Abdomen			Abdomen			Abdomen		
Ages	01-Apr	05-Sep	14-Oct	01-Apr	05-Sep	-14-Oct	01-Apr	05-Sep	14-Oct
This study (2015)	20.38	30.49	35.31	177.77	300.36	371.2	8.72	9.85	10.51
DRL France (2012) [7]	20	24	35	80	120	245	4	5	7
DRL France (2019) [7]	32.5	38	45	65	95	180	2	2.5	4

In Europe, for example, the use of shields is an objective measure of the protection of these organs in the area exposed to IR, as shown in **Figures 4 and 5** [14]. **Figure 4** shows an artifact seen on the eyeball, but no artifact seen in the brain. This artifact does not influence the interpretation of the scan. It would be beneficial for our hospitals to use these methods of protection to protect the pediatric patient from potential stochastic effects.

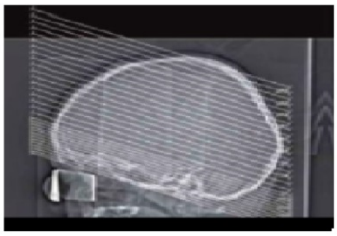

Figure 4: Slicing of a cranial parallel of CT at the base of the skull to protect the orbits. The scout scan also shows a band of eye protection [14].

Figure 5: Chest Scout scan with unnecessary exposure of additional body parts but using a shield when the scout is for example very large compared to the size of the child.

Some developing countries cannot purchase the protection systems listed below. This is why we propose for these countries to technically use the lead apron worn by CT technologists. They can use it to shield the radiosensitive organs contained in the body. In the case of skull examinations, another lead apron is required which must be cut according to the size of the eyes. It is therefore imperative to have two lead aprons in the scan room. It is also true that one can manufacture it in a traditional way but it is not an easy task because this still requires a thorough study of the material to use. This measure is not sufficient to optimize pediatric computed tomography in these countries, but it is a starting point for optimization. Child protection systems are marketed online **Figure 6.** For the developing countries, means are needed to buy them and means for delivery. Given these difficulties, the safest way to optimize scan practice in these countries is to use the available means. The lead apron is a solution when it is well used and when it gives no artifact on the images. To avoid these artifacts, the protective apron must be well positioned and securely immobilized on the patient. To scan a part of the body (thorax, neck, abdomen or pelvis), it can be deposited as in **Figures 5 and 6.**

Figure 6: System for protecting the radiosensitive parts of the neck and body.

To protect the whole body it can be arranged as in **Figure 5.** To protect the eyes (it should not suffocate the patient), Alberto, Nocetti, Mistretta and al in their article [15] used the bismuth shield to protect the eyes of the anthropomorphic phantom. This shield has been placed on a height adjustable support **(see Figure 7).**

Figure 7: Developed height adjustable system for shielding set-up.

This is to improve the view of the patient. This support is possible for small protection systems but for the lead apron it is necessary a more solid system. The lead apron is heavier than the bismuth shield, which is why a system capable of supporting the weight of a part of the deck and on which it can be immobilized. Heaney and Norvill in their article [16] put the bismuth shield on the eyes **(Figure 8).**

Discussion

Assessment of this study with other studies

As children are irradiated on parameterized machines for adults, medical imaging technicians must have written pediatric protocols for each type of procedure, permanently available near their equipment for an optimized procedure for any pediatric examination. They have to reduce the kilovotage (kV), milliamps seconds (mAS) for example according to the patient age and the type of exam. These modifications must be made according to the values (kV, mAS, etc.) recommended by international literature and must be displayed in the scan control room to allow all service technicians to have a look before any pediatric examination on a scanner for an adult. We must also adapt our practices to the new tools. To reduce the repetition of examinations that significantly increase the dose absorbed by patients, we can immobilize pediatric patients. Immobilization can be performed by sedation or by bandaging the ends of the studied area (eg: the head) with perforated sticky sparadap (18 cm × 5 cm roll) by doing at least three rounds around the motorized table for children under 7 years old. It is the responsibility of medical imaging technicians to respect the principles of radiation protection to reduce the risk of radiation on these children.

The results observed in **Table 2** show an improvement in the practice of pediatric examinations on adult scanners in this developing country. This improvement is due to the recommendations proposed by the authors of this article in 2015 and the participation of these technologists in the first radiology quality control seminar in September 2017 by an author of this article. They were built on the concept of radiation protection and the quantities of doses delivered by their device, including CT scanner. This seminar was realized with a large contribution of the International Atomic Energy Agency (IAEA) through his expert in radiology (Dr. Marco BRAMBILLA), that we will like to thank. These recommendations and this seminar allowed us to have scan lengths (2018) lower than those of the TOGO 2016 and close to the DRLs France 2019. This shows that improvements are still possible. In 2015, CT Technologists who used older generation scanners did not have techniques to reduce the doses that children took. This explains the superiority of the data from this study in 2015. Togo has his result because it used the "tube current modulation" mode which allows dose reduction only, the exposure parameters in this mode are not always adjusted appropriately to the clinical issue or the size of the patient, especially for children [11]. Now, the hospitals studied in this country that still use the old generation scanners know how to reduce the absorbed doses for children. Those who have purchased new scanners also know how to do it despite the new techniques (iterative reconstruction) to reduce the doses implanted in the new CT scanners.

The doctor's role is very important and dose reduction begins first with the test prescriber. He/she must master the principles of radiation protection and the consequences that result from non-compliance with these principles. When prescribing a CT scan, he must justify it and ensure that this radiological examination will bring more benefits than inconvenience to the patient and not prescribe it because CT is a rapid examination in medical diagnosis. Let us not forget that the clinical decision taken by doctors for the choice of the type of examination is not an easy task. They often lack information for decision making of the CT scan because some patients often forget to bring their old records from the medical imaging department. That's why they have little access to a patient's imaging history to guide their decision about prescribing additional imaging exams. For pediatric patients with no history of radiation, the use of CT exams should be optimized. Optimization of doses in pediatric is necessary because overexposure may lead children to a particularly significant cancer risk in certain radiosensitive tissues such as the thyroid, gonads and breasts even after childhood for decades. Therefore, they must regularly maintain and update their equipment and software.

Protection of radiosensitive organs

The use of the lead apron is known to protect the technologist during a scan but not to protect the radiosensitive parts of children during a CT scan. Some technologists theoretically know that it can be used to protect these organs, but none of these technologists applied it in 2015. Therefore, it will be useful for each hospital to use it. Our proposed method will be useful for CT technicians, because they are going to contribute to optimization of pediatric CT in their country. However, from the results of this study (survey done in 2018 for 1 month), radiosensitive organs of children are now protected. Other studies have shown a small reduction in the radiation dose to the eyes using both the supra-orbital baseline and bismuth eye shielding [17]. Yeoman et al. [18] have found a reduction of 87% in the radiation dose to the eyes by angling along the supra-orbital plane. Given the significant benefit in dose reduction to the eyes achievable, a clinical decision must be made based on whether the possibility of reduced artefact outweighs the risk. To our knowledge, this is the first study that solves the main problem of protecting the radiosensitive organs of children over great scan lengths produced by our hospitals. The results revealed how we could use lead apron to protect pediatric radiosensitive organs.

In our previous study, we proposed solutions to optimize the radiation dose of pediatric CT in developing countries that still use legacy scanners. In this study, the artifact was not a problem when we protected the neck and body when scanning the head. The problem was how to protect the eyes when examining the head with a lead apron without choking the child. We found that it was sufficient to technically pose the protective apron, immobilize it and prevent it from choking the patient with an object that could not produce artifact. Alberto, Nocetti, Mistretta, et al and Heaney and Norvill in their article proposed using the bismuth shield to protect the eyes from the anthropomorphic phantom placed respectively on a height-adjustable support **(see Figure 7)** [15] and on the eyes **(Figure 8)** [16].

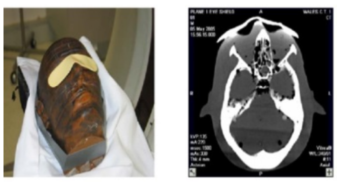

Figure 8: Bismuth eye shield on the "Rando" head phantom and an axial CT slice showing the resulting local artefact [19].

The technicians do not respect in a rigorous and conscientious way the principles of radioprotection and the radiological and non-radiological protocols recommended by the international commissions of radioprotection [19]. The lightness that exposes children to doses already very high in the case of a single acquisition can induce subsequent cancers if these children undergo another scan during their lives.

Those great lengths cause exposure to ionizing radiation from certain parts of the body of children that should not be. It would be interesting to adjust this radiological parameter in order to reduce the areas of interest for irradiation to the essential. The limitation of the scan length has a positive effect because it reduces the DLP. To achieve this objective, the requesting physicians must clearly specify the suspected organ in his request for examination. It is possible that the pathology of the patient is not in the area requested by the prescriber of the exam but beside. For this reason, technicians increase the scan length of the requested area during the exam. They do it because they want to help patients by preventing them from redoing (paying) another exam. However, the radiosensitive organs contained in these great scan lengths must be protected. For now, we propose to use the lead apron or protective systems such as the bismuth shield for the lens, the shields for the thyroid, breasts and gonads. The limited number of scanners and financial resources are forcing technicians to increase these scan lengths to prevent patients from paying for an exam again. This method is more or less beneficial for patients and has become a routine in hospitals. The prescriber of the examination must first examine and diagnose the pathology in order to prescribe the area to be scanned. The technicians performing the examination must limit the scan lengths to the area requested by the prescriber and respect the reference lengths used in other countries. When the area exposed to IR contains organs at risk, it is necessary to take protective measures. Although these difficulties, our results showed that the lead apron is an up to date solution to protect radiosensitive organs of children in those countries.

This study had limitations due to a number of scanners which had breakdown.

Conclusion

Shielding the radiosensitive organs with a lead apron over long scan lengths are effective strategies to reduce the doses absorbed by children exposed to IR in developing countries that still use old generation scanners. Knowledge of the dangers of ionizing radiation on child's health is a factor influencing the reduction of scan lengths during an examination. The reduction of the scan lengths according to the clinical interest is beneficial.

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