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Protection of the Eyes, Thyroid and Gonads in Pediatric Tomodensitometry: Use of the Leaded Apron

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Abstract: The eyes, gonads, breasts and thyroid are the most radiosensitive organs of the human body. The CT scan of the head and body may unnecessarily expose them to ionizing radiation even if the area of clinical interest is far from them. The aim of this study is to show how the manipulator's lead apron can be used to protect highly radiosensitive organs during children's CT scan. The study also proposes protection systems used in developed countries and compares the scan lengths of children in that country with certain international publications. In 2015, children's radiosensitive organs were not protected during acquisitions. After recommendations proposed in 2016 on the usefulness of the protection of these organs, in 2018, despite the great scan lengths of their scanners, the organs are protected with the leaded apron in the hospitals studied. This protective apron was placed on the appropriate bodies parts, no relevant artifacts were found, and the image quality was not affected. The use of a shield (lead or bismuth) for radiosensitive organs reduces the dose in tissues and directly protects the radiosensitive parts contained in great scan lengths. The use of the lead apron to cover these organs is possible when it is well positioned on the patient. Thyroid and breast protection should be used when the resulting artifact does not affect the quality of the image.

Keywords: Computed Tomography, Bismuth Shielding, Image Quality, Radiosensitive Organs, Ionizing Radiation

1. Introduction

Computed tomography (CT) plays an important role in the diagnosis of patients' pathologies, but its use can under certain conditions, cause more material damage. It is used in adult and pediatric patients. In pediatric, it must be better controlled because of the high radiosensitivity of pediatric tissues and their small size. They are smaller than adults. This is why the protection of organs at risk is beneficial to avoid as much as possible the deterministic or stochastic effects on certain radiosensitive organs. CT is now a diagnostic tool used to evaluate various pathologies in children (detection and monitoring of cancers, trauma). But it delivers doses of ionizing radiation ten to one hundred times higher than conventional radiology [1]. It is in pediatrics that it makes sense; the sensitivity of children to ionizing radiation is much higher than that of adults [2]. This radiosensitivity is due to the growth of their organisms, the large proportion of their young cells, their high life expectancy and their genetic potential related to their offspring. The International Commission on Radiological Protection (ICRP) has indeed estimated the risk of death from cancer and for a Sievert (for a single exposure) throughout the life of a patient at 14% at birth compared to 1% at 75% years [3]. Although the long-term effects of low doses of ionizing radiation remain highly controversial [4, 5], patient radiation protection is still, as a precaution, based on the linear non-threshold relationship model.

Recently, in light of the results of an epidemiological analysis [6], the ICRP has lowered the dose threshold for these effects and now recommends, for exposed workers, a dose equivalent limit of 20 mSv to lens in a year, averaged over a 5-year period, not to exceed 50 mSv in any single year. For these reasons, attention on dose reduction techniques is growing and several scientific studies on the topic have been published [7–9]. Gantry tilting, organ-based tube current modulation, bismuth shielding and iterative reconstruction [10, 11] 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 [12, 13] 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. For example for the eyes, the manufacturer of the shield guarantees eye lens dose reduction up to 50% (40% mean reduction): these results are on-line with reported data in literature [14]. Moreover, cases of artefact due to the contact between the shielding system and the patient have been noted [14]. Avoiding contact between the shielding system and patient's eyes can bring two important benefits: increase in patient's compliance and a reduction of biological risk. This study aims to use the lead apron generally worn by scanner manipulators to protect children's radiosensitive organs in developing countries that do not have bismuth or lead shields.

2. Materials and Method

2.1. Eligibility Criteria

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 member 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'. The CT acquisitions were performed on the children aged 0 to 15 who have had skull and abdominal CT scan in hospitals H_1, H_2 and H_3 (see table 1). The prospective study method was approved in the three hospitals. Of the three machines in the hospital, scan lengths of 131 patients over a 6-month period (February to July 2015) were noted. The age groups are: <1 year, 1-4 years, 5-9 years and 10-14 years. In this study, the $CTDI_V$ and DLP are recorded on the 16 cm phantom for all examinations of the head and 32 cm for the abdomen. This study was approved by the research ethics board of the three hospitals studied in this country.

Figure 1. *Lead apron use in our centers.*

Table 1. *Characteristics of scanner devices in the three hospitals.*

Hospital	Model	Serial	Date of Manufacture	Date of installation	CT technique
H_2	GE Bright Speed^{8}	26058HM4	Novembre 2010	2012	4-rotation helical
H_3	GE Light Speed^{16}	55957HM5	Mars 2003	2009	16- rotation helical
H_1	HITACHI ECLOS Speed^{16}	225761HM6	Mars 2009	2009	16- rotation helical

2.2. Statistical Analysis

Parameters such as Dose Length Product (DLP), computed tomography dose index of Volume ($CTDI_V$), scan length (L), tube current-time product (mAS), High tube voltage (kV), Age, Gender, Thickness (T), the mode and the pitch of each child for each type of scan were noted during the various exams and processed in the Microsoft Excel software. In 2015, hospitals used the helical mode and the same 120 kV for all age groups. The tube current-time product used ranged from 57.75 to 283.33 mAS, the thickness (T) from 1.25 to 2.5 mm according to the default values offered by the scanners.

The highly radiosensitive organs of children are not protected regardless of the type of examination. They are exposed to ionizing radiation on adult machines despite their difference in size from that of adults. The restraints used (Figure 2) cannot immobilize agitated patients. Absorbed doses ($CTDI_V$) were high for children. During the examination, $CTDI_V$ were not modified according to the age of the patient. Hospitals generally used the same dose of radiation, the same tube voltage (kV) and tube current-time product (mAS) for children and adults. Which made some children's films totally black and not visible, and not interpretable by radiologists. However, they were forced to make other acquisitions. Which increases the absorbed dose. None of these hospitals had pediatric software in their device to optimize the doses absorbed by children. Scout scan took almost the whole body of children (Figure 3) because the scanners are configured for adults. The scan lengths of the patients, as well as those of Huda and Vance, SFIPP / IRSN (French Society of Pediatric and Prenatal Imaging/Institute of Radioprotection and National Security) and Shrimpton PC, are presented in Table 2. This table shows that the scan lengths of this study are superior to the comparison literatures for all categories age (25.4 mGy.cm H_1 compared to 8 mGy.cm Schrimpton children <1 year for example).

Figure 2. *Band used as a restraint in our centers. This restraint does not totally immobilize children especially those who are afraid and are agitated.*

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. *Average scan lengths (in Cm) of hospitals compared to international results.*

Exam	Age	H_1 mean (Range)	H_2 mean (Range)	H_3 mean (Range)	Huda et Vance[23]	SFIPP/ IRSN 2008[20]	Shrimp- ton[24]
Skull	<1	25.4 (25.4-25.4)	19.06 (13.75-27.24)	11.5 (11.5-11.5)	11	-	8
	1 -4	33.6 (32.6-32.6)	18.14 (14.75-21.75)	-	11	14	11
	5 - 9	30.83 (30.8-30.83)	22.60 (16.5-31.75)	16.18 (16.18-16.18)	12	15	13
	10 - 14	-	22.17 (8.75-33)	-	12	18	13
Abdo-men	<1	48.3 (48.3-48.3)	-	-	9	-	13
	1 -4	-	26.83 (4.5-41)	31.33 (19.37-43.75)	10	20	19
	5 - 9	34.4 (34.4-34.4)	-	-	13	27	25
	10 - 14	-	30.55 (6.85-49.25)	-	16	35	31

SFIPP is the French Society of Pediatric and Prenatal Imagery
IRSN is Prenatal Imagery and Institute of Radioprotection and National Safety.

2.3. Make a Restraint with Available Equipment Before Using the Leaded Apron

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 plexiglass sheet that we have to cut with a suitable blade according to the dimensions of the motorized table of the TDM, the size of the children and in the shape of a person to facilitate the attachment with belts or seat belts (Figure 4). 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 behavior is not an easy task. Restraints used in the hospitals studied (Figure 2) are unsuitable for agitated and unconscious pediatric patients. They cannot prevent frightened and restless patients from moving on the examination table. An air mattress (vacuum pillow) may be necessary (see Figure 5).

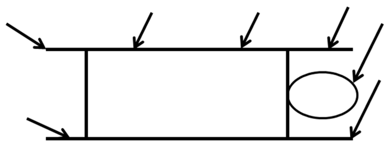

Figure 4. *Example of shape that the plexiglass sheet must have: the arrows correspond to the positions of the belts necessary for the immobilization of the pediatric patient. Given the lack of good restraint in the hospitals studied, we must buy plexiglass with a good thickness and cut as in this image by adding belts.*

3. Results

The protection of radiosensitive organs during examinations in the hospitals studied is not made in 2015. The hospitals in this study do not have adequate tools to protect the very sensitive organs of children (gonads, thyroids and eyes) from ionizing radiation (IR). 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 Figure 5 [15], 7 [16] and Figure 8. For certain sensitive organs (eyes, gonads, breasts and thyroid), the use of reusable bismuth shields is possible. For example, consider the adult patient in Figure 5 and Figure 6 who has 3-layer bismuth latex eye protection in place for eye protection [16, 17]. His scanner shows an artifact seen on the eyeball, but no artifact seen in the brain. This artifact does not influence the interpretation of the scanner. It would be beneficial for our hospitals to use these methods of protection to protect the pediatric patient from potential stochastic effects. 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 5. *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 [15].*

Figure 6. *Radioprotection of a child's scanner [16]: Reusable shields for bismuth attenuation and film of a brain and chest scan. This shield protects the patient's eyes and does not affect the interpretation of the patient's film.*

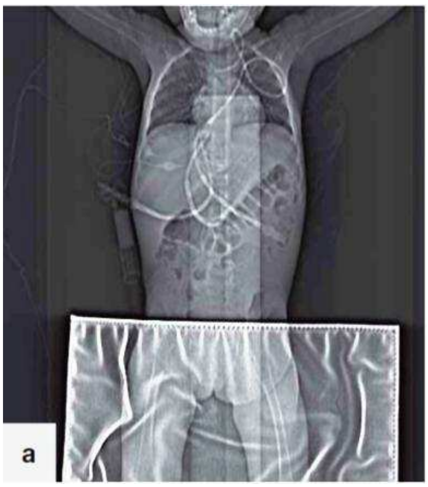

Figure 7. *Chest Scout scan with unnecessary exposure of additional body parts but using a shield when the scout is for example very large compared to the size of the child.*

Some developing countries cannot purchase the protection systems listed below. This is why we propose for these countries to technically use the leaded apron worn by CT manipulators. They can use it when they are not wearing it during an exam. The methods of use have been described in the material and method part. 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. For the developing countries, means are needed to buy them and means for delivery. Given these difficulties, the safest way to optimize scanner 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 of the patient. 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 6, 7, 8. Child protection systems are marketed online (Figure 8). To protect the whole body it can be arranged as in figure 7. To protect the eyes, it should not suffocate the patient. Alberto, Nocetti, Mistretta and al. in their article [18] used the bismuth shield to protect the eyes of the anthropomorphic phantom. This shield has been placed on a height adjustable support (see Figure 9). This 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 bistmuth 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 [19] put the bismuth shield on the eyes (Figure 10). The results of the scan lengths of this study was much higher (triple) than those obtained with similar studies (abdomen H_1 48.3 cm against 13 cm P.C. Shrimpton for children under one year). H_3 values are close to the values of these studies for age categories <1 and 5 to 9 years. The pediatric values obtained in our skull and abdomen study also exceeded the values established by Huda and Vance in adult patients; except for examination of the skull of children under one-year-old at H_3. In the studies of these two researchers, the scan lengths of the adults are 13 and 20 cm for the examinations of the head (trauma) and abdomen (tumor), respectively [20]. In addition, for age groups greater than one year, the Shrimpton studies are similar to those obtained in adult Huda and Vance patients, whereas those of SFIPP and IRSN (2008) move away on examination of the skull (Figure 12). For the abdomen, for children aged 1 to 4, the data from Shrimpton, SFIPP and IRSN (2008) are coherent with adult data for Huda and Vance (Figure 12), but for children over 5 years, they are much higher (difference of 2 cm to 15 cm) than those of Huda and Vance. This result is not without danger for the future of the organs of our children who receive ionizing radiation unnecessarily during examinations. The lengths of scoot scan (editable) allow delimiting the scan lengths of exams. The above result shows that pediatric scan lengths in our hospitals can be further reduced. Children's exams are done on adult machines. Adult scoot view lengths are also great for their bodies (Figure 12).

__Figure 8.__ System for protecting the radiosensitive parts of the neck and body (Source internet: http://www.xraystore.fr/4257-attenurad-protection-thyroide-boite-de-10.html and https://www.google.com/search?q=tablier+plomb%C3%A9+radioprotection&source=lnms&tbm=isch&sa=X&ved=0ahUKEwiX45Sz4prjAhUO8BQKHSABArQQ_AUIECgB&biw=1094&bih=462&dpr=1.25).

__Figure 9.__ Developed height adjustable system for shielding set-up [18].

__Figure 10.__ Bismuth eye shield on the "Rando" head phantom and an axial CT slice showing the resulting local artefact. [19].

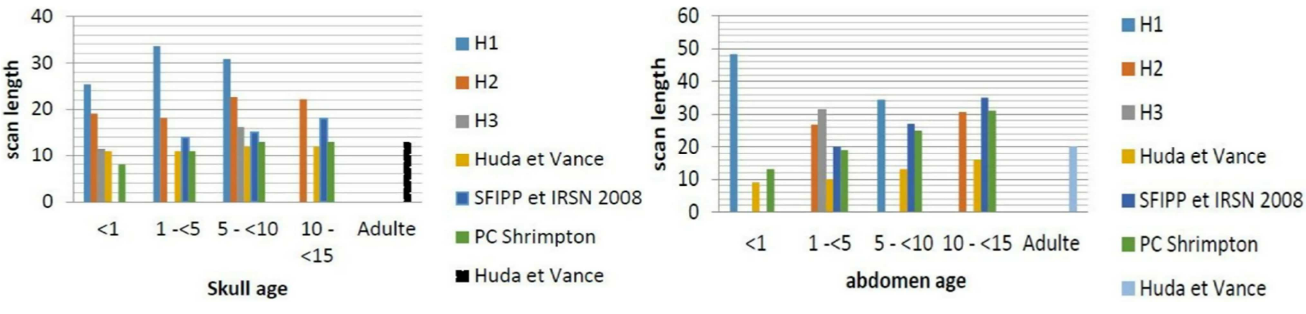

__Figure 11.__ Comparison of scan length averages for the skull and abdomen of this study with the international studies and adult values of Huda and Vance. SFIPP is the French Society of Pediatric and Prenatal Imagery and IRSN is Institute of Radioprotection and National Safety. H_1, H_2, and H_3 are the three hospitals of this study.

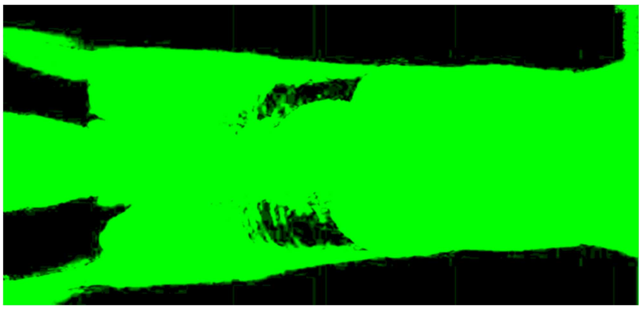

Figure 12. *Topogram (scout view) of the spine of a 65 years old adult at hospital number 2 (H_2). Scout view of the abdomen of an adult patient who takes practically his whole body. Which does not respect the principles of radiation protection*

4. Discussion

We have proposed a novel method to protect radiosensitive organs of children during a CT acquisition in developing countries. Further, our proposed new method is very simple and easy to perform. Therefore, it will be useful for each hospital to use it, as European countries use it for example (see Figures 5 to 11).

In particular, our proposed method will be useful for CT technicians, because they are going to contribute to optimization of CT pediatric in their country. However, from the results of this study (survey done in 2018 for 2 months), radiosensitive organs of children will be protected on adult scanner. Other studies have shown a small reduction in the radiation dose to the eyes using both the supra-orbital baseline and bismuth eye shielding [21]. Yeoman, Howarth, Britten and al. [22] 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 children's scanners 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 ghost placed respectively on a height-adjustable support (see Figure 10) [18] and on the eyes (Figure 11) [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 [23]. 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 general doctor 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. For hospitals that do not have a pediatric scanner, solutions need to be established. When the hospital is not able to buy restraints for pediatric patients, we can manufacture them with equipment that is easy to acquire. That is why, with this material, we can improve the constraints used in hospitals. To expose a child to ionizing radiation on an adult scanner, the child must first be prepared. The preparation is important because it allows informing the parents and even more the children major (over 5 years old) of the behavior to follow for the good progress of the examination; then choose a contention or sedation related to the age of the pediatric patient and his behavior. The restraints used here (Figure 2) are not suitable for agitated or unconscious pediatric patients. They do not prevent frightened and restless patients from moving on the examination table. Depending on the indication of the requested examination (with a contrast medium for example) and the behavior of some children (agitated), it is necessary to use sedation, especially in children under 5 years of age monitoring of anesthetist doctor. The immobilization (constraint) of pediatric patients (children aged 0 to 7 years), as shown in Figures 4 [24], to avoid the use of sedatives, is also an important factor in limiting acquisition [25]. The display of radiological parameters (IDSV, scan length, etc.) and non-radiological parameters (high voltage, load etc.) recommended in the international control room literature allows all imaging technicians to access them without constraints. This is a considerable reduction factor of absorbed doses for patients.

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.

Our study had several potential limitations. Mainly the use of a lead apron to protect the crystalline. The impact of lead apron movement artifacts and image noise in clinical images will be addressed in a future study.

5. Conclusion

We proposed a new method to protect children's radiosensitive organs during an acquisition on adult scanners. The use of shields to protect highly radiosensitive organs (crystalline, thyroid, breast and gonads) from ionizing radiation is beneficial. The use of the lead apron is an optimization start for the protection of children's radiosensitive organs on adult machines in developing countries that still use old generation scanners. The use of radiological protocols and procedures that are not suitable for pediatric examination delivers great lengths of scan resulting in exposure to IR of some unnecessary parts in an examination. These useless parts usually contain organs very sensitive to ionizing radiation. The practice of radiology in small children requires having equipment appropriate to their body. Examinations must be age-appropriate.

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Compliance with Ethical Standards

Conflict of Interest

The authors declare that they have no conflict of interest.

Ethical Approval

Our institutional ethical review board approved the protocol of this study (data collection and post-processing).

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