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Choice of tube extremity for emission of the lowest radiation dose in pediatric patients

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ABSTRACT

Aims: To compare the dosage of radiation the thyroid and gonad glands receive in pediatric patients undergoing chest X-rays, in distinct positions, towards the goal of developing of an X-ray tube positioning protocol.
Methods: A randomized controlled clinical trial was carried out in the Pediatric Intensive Care Unit (PICU) at the Institute of Cardiology/University Foundation of Cardiology of Rio Grande do Sul, Brazil from June 2014 to September 2016. Patients were divided into two groups. One group was positioned with the thyroid gland facing the **anode** end of an X-ray tube, and in the other group the thyroid gland faced the **cathode** end. Radiographs were evaluated by five observers, following criteria recommended by the Commission of the European Communities (CEC).
Results: Forty-eight pediatric patients, with a mean age of 2.0 ± 1.3 years, participated in this study. Based on the evaluation of 48 images, it was determined that the thyroid and gonad glands facing the cathode were exposed to 13.3 ± 3.1 μGy and 13.5 ± 4.1 μGy of radiation, respectively ($p = 0.008$). Additionally, the thyroid and gonad glands facing the anode were exposed to 11.7 ± 3.1 μGy and 12.7 ± 3.1 μGy of radiation, respectively ($p = 0.007$). The mean input dose in the center of the chest was 20.8 ± 9.6 μGy in both positions.
Discussion: The proximity of the thyroid gland to the cathode end of the X-ray tube appears to be related to the dosage of ionizing radiation. Adverse effects associated with exposure to ionizing radiation could be minimized by positioning the thyroid gland to the **anodic** end of the X-ray tube.
Conclusion: Patients should be placed facing the anode end of the X-ray tube when taking thoracic X-rays, in order to reduce radiation exposure to the thyroid and gonad glands.
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1. Introduction

Radiological imaging is an extremely valuable diagnostic tool used in pediatrics. Pediatric radiographic chest examinations are commonly used as an accompaniment in congenital heart disease (CHD) related surgical correction procedures, potentially exposing the patients to high levels of radiation [1, 2].

Due to the satisfactory results and low costs, the chest radiography scan is accepted worldwide as an accurate diagnostic method [2]. However, since the developing cells of young patients are particularly radiosensitive, pediatric radiographic examinations need to be performed with greater attention and precision.

With regards to CHD, an accurate diagnosis is essential for a successful treatment and outcome, and several techniques have been utilized. Transthoracic echocardiography (TTE) is a simple and non-invasive technique, but lacks the ability to clearly visualize the malformations of the great vessels. Cardioangiography (CAG) is the gold standard for CHD diagnosis; however, it is an invasive procedure. Multi-slice spiral CT is another non-invasive exam; however, the radiation dose and contrast media-related adverse reactions pose significant risks to children. With pediatric patients, they require the highest quality imaging techniques, so that exams do not need to be repeated [4]. Thus, a great deal of attention has been focused on developing protocols that minimize ionizing radiation exposure [3].

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It is well known that radiation, used in procedures for the diagnosis and/or treatment of diseases and complications, may also cause cancer [5]. In fact, one of the main consequences of X-ray radiographs, among young people, is the substantial radiation exposure to the thyroid gland, which may lead to thyroid cancer [6]. Monte et al. showed that about 10% of neoplasms usually occur in people younger than 21 years old, which represents 3% of all childhood neoplasms. Thus, the carcinogenic effect of radiation is particularly concerning in prepubertal individuals [7]. Worldwide trends indicate that medical radiation exposure has been increasing, due to cardiological procedures, and particularly in cases involving CHD [5].

In recent years, the deleterious effects of radiation exposure have been addressed, and greater attention has been given to the dosage used when taking radiographic images. The Commission of the European Communities (CEC) has developed quality criteria, suggesting the need to develop specific measurements for pediatric patients. The criteria focus on the quality of the images by using, as a rule, the most common exams in pediatric radiographic scanning, as well as the reference values for the Dose Area Product (DAP), which is also known as the Entrance Skin/Surface Dose (ESD) [8].

In 1998, the Brazilian National Health Care Surveillance Agency (ANVISA) published Ordinance N. 453, establishing radiological protection guidelines in Brazil. However, these guidelines were only aimed at adult patients. As a consequence, the pediatric dosage references were only related to adult dosages, without actually referring to the appropriate dosage for children [9].

With the increase in the number of available technologies in radiology, it is imperative that the techniques chosen expose the patients to minimal doses of radiation when performing radiographic exams, without losing the pattern quality needed for proper and accurate diagnosis [10, 11].

Thus, the objective of this study was to compare the dosage of radiation exposed to the thyroid and gonad glands of pediatric patients undergoing chest radiographies in distinct positions, so as to develop a standardized protocol that reduces radiation exposure, in these patients.

2. Methods

A randomized controlled clinical trial was developed and conducted from June 2014 to September 2016.

2.1. Population and place of study

After randomization, 48 patients aged 0 to 4 years old were included in the study (Fig. 1). The individuals were divided into two groups (24 for the **anode** end position and 24 for the **cathode** end position). Routine exams were performed at the request of the cardiologist. Data were collected from patients admitted to the Pediatric Intensive Care Unit (PICU) at the Institute of Cardiology/University Foundation of Cardiology (IC-FUC) of Rio Grande do Sul, Brazil.

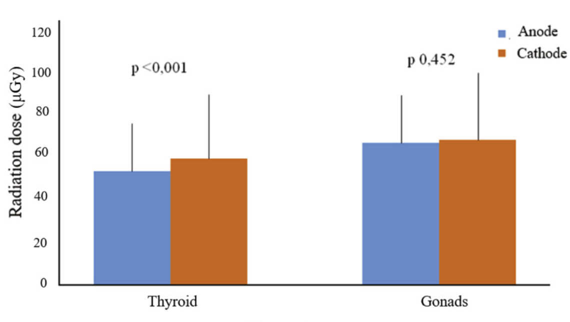

Fig. 1. Comparison of radiation dosages in the thyroid gland and gonads, at two X-ray tube positions.

2.2. Sample

According to the *Evaluation of dose patterns in pediatric radiology* [12], sample calculations considered differences significant when there was a significance level of ≤5%, with 80% of power with a standard deviation of 0.026 for the Dose Area Product (DAP) or Entrance Skin/Surface Doses (ESDs) in µGy, and an expected difference of 0.01 in mGy. The total number of subjects was 48, and 48 radio-photographic images were analyzed.

2.3. Inclusion criteria

The subjects who were included in the trial at the Pediatric Intensive Care Unit (PICU) had to be undergoing cardiac surgery at the IC/FUC of Rio Grande do Sul, were considered infants with an age of 0 (minimum age) to 4 years (maximum age), and had a chest X-ray exam requested by doctors.

2.4. Exclusion criteria

The individuals not admitted for the trial were pediatric patients with scans that failed to comply with the technical quality criteria for diagnostic radiographic images proposed by the CEC, as evaluated by the radiologist responsible for that exam report [8].

2.5. Ethical considerations

The study was designed in accordance with the International Ethical Guidelines for Biomedical Research Involving Human Subjects, Resolution N. 466/12. The project was approved by Research Ethics Committees (RECs) at IC/FUC of Rio Grande do Sul, under the number 4769/12 and was registered at ClinicalTrials.gov (NCT02925936).

2.6. Logistics

After being properly informed about the study, caregivers signed an Informed Consent Form. The variables evaluated in this study included: focal-receptor image distances, thickness of the thorax, as well as radiation exposure to the thorax, thyroid gland and gonad glands. Sociodemographic and clinical characteristics of each subject were also evaluated, and included weight and height for Body Mass Index (BMI) calculations, so as to determine if the children would be considered low weight.

The subjects were selected from pediatric patients in the Pediatric Intensive Care Unit of the IC/FUC of Rio Grande do Sul, who were administered an in bed chest X-ray exam. Twenty-four patients were radiographed with the **cathode** end of the X-ray tube facing the region to be studied (control) and the others were radiographed with the **anode** end facing the region to be evaluated (intervention).

The radiological imaging was performed by the researcher and four radiology professionals, and the exams were carried out using an in bed anteroposterior (AP) view, with a central ray oriented towards the center of the thorax at the nipple line [10]. A portable Shimadzu X-ray instrument, with 500 mA of current, was used for data collection [11]. Radiological imaging resulting from AP incidences fulfilled the criteria recommended by European Commission [8]. For the AP projections the following criteria were taken into consideration: symmetrical reproduction of thorax without rotation or basculation, reproduction of the costal grid above the diaphragm, clear reproduction of pulmonary vascularization (mainly in the periphery), clear reproduction of the trachea and proximal segment of the bronchi, clear view reproduction of the diaphragm and cost-phrenic angles, clear reproduction of the heart and aorta, visualization of the retrocardiac region of the lungs and mediastinum, and visualization of the vertebral column through cardiac shadow.

The images were processed using a Carestream computerized radiography (CR) system. The CR cassettes were in contact with the posterior thorax, without the use of the Potter-Bucky grid [11]. The ionization chamber consisted of a *Radcal* model 9015 and a PROBE 60 cm^3, with 5% of variation. Quality control tests were performed according to ANVISA (the Brazilian National Health Surveillance Agency) Ordinance N. 453 [9].

The doses of radiation emitted by the anode and cathode end positions were transformed, assessed and quantified by the ionization chamber (equipment validated by ANVISA). The camera was positioned centrally because of the largest human organ concentration [9]. The chest diameters were measured using the Konex thickenometer and measurements were made in the anteroposterior direction in the mammary and central regions of the thorax. Measurements of the kerma in the air (air kerma) (mGy) and Dose Area Product (DAP), or Entrance Skin/Surface Dose (ESD) were calculated using the following equations [8, 9]:

(1) For readings in exposure units, convert to kerma units in the air:

- air kerma (mGy) = exposure (mR) × 0.0087.

(2) Tissue-air ratio, i.e., (Reference air kerma and kerma-area product as estimators of peak skin dose)

$$DEP = k_{ar} \cdot BSF \cdot k_{P,T} \cdot F_c$$

Dose Area Product (DAP) and SED = skin entrance radiation [8, 9].

RAK = Reference Air Kerma or Kerma-Area Product (KAP) [8, 9].

BSF = Backscatter Factor: retro-scattering factor in water for the geometry and quality of the radiation.

kPT = correction factor for temperature and pressure.

CF = calibration factor of the ionization chamber for the beam quality.

2.7. Statistical analysis

Student's *t*-test was used to compare each group, through the mean absorbed radiation in relation to the CEC reference values [8].

To correlate the radiation doses, in relation to the thoracic diameter of each group, a Spearman correlation coefficient was used. The sample size calculation was based on similar studies [12, 13]. For statistical analyses, *SPSS* and *Minitab* statistical software were employed.

3. Results

The sample consisted of pediatric patients with an average age of 2.0 ± 1.3 years, with a low predominance of males (59.5%). Of the 48 children evaluated, 20 were <28 days old (newborns), 20 were older than 28 days (post-newborn period), and 8 were over 2 years of age. The groups were divided according to the recommendations set forth by the European Commission Clinical. The sociodemographic characteristics of the subjects are presented in Table 1.

Table 1
Clinical and sociodemographic characteristics of sample ($n = 48$).

Variables (patients)	Mean ± SD (%)
Age (years)	2.0 ± 1.3
Gender (male)	59.5%
Weight (kg)	6.5 ± 3.9
Height (cm)	63.9 ± 15.1
Thorax thickness (cm)	9.5 ± 7.1

Table 2
Congenital anomalies identified among study participants ($n = 48$).

Alterations	N	%
Intra-Atrial Communication (IAC)	9	18.75
Ventricular Septal Defects (VSD)	21	43.75
Hypoplastic Left Heart Syndrome (HLHS)	4	8.33
Tetralogy of Fallot (TOF)	6	12.50
Patent Ductus Arteriosus (PDA)	9	18.75
Pulmonary Atresia (PA)	4	8.33
Coarctation of the Aorta (CoAo)	4	8.33
Anomalous pulmonary venous drainage	1	2.08
Myocardiopathy	2	4.16
Double outlet right ventricle (DORV)	2	4.16

Incidence of changes in male patients.

The BMI was found to be reduced according to age, and 17% of the subjects were in the 3rd percentile, or less. Table 2 shows the prevalence of congenital anomalies identified in the participants of the study. Notably, there was a prevalent and significant change in the percentage of subjects with Ventricular Septal Defects (VSD): 43.75% and Intra-Atrial Communication (IAC): 18.75%.

In Table 3, a summary of the results for radiation exposure to the thorax, thyroid and gonads, by either the anode or cathode end positions, in children below 28 days-old and over 28 days-old are provided. In children below 28 days of age there were significant increases in radiation exposure to the thyroid and gonads. On the other hand, in children over 28 days of age, there was only a significant increase in radiation exposure observed in the thyroid.

The means of the variables evaluated in the present study are shown in Table 4. Values for the transported load, tension, focusing distance, thorax thickness and amount of radiation entry into the chest were recorded and averaged.

Additionally, there was a correlation identified between the radiation dose and thoracic diameter, in both groups, as well as a statistically significant ($p < 0.05$) and strong correlation ($\varrho = 0.84$) between thorax thickness and mean voltage (kV).

4. Discussion

Currently, children undergoing correction surgery for CHD are exposed to a great number of X-ray examinations. In this randomized controlled clinical trial, the amount of radiation exposure to the thorax, thyroid and gonads was measured. The results demonstrated that there was an increase in the amount of radiation emitted by the cathode end of the X-ray tube, when compared to the anode.

According to Donya [14], the biological effects observed in individuals exposed to radiation can have consequences with deterministic and stochastic effects. For example, the authors suggest that, low dose exposure over time can result in DNA lesions and mutations. Thus, pediatric radiation exposure risks are a constant concern.

The recommendations of ANVISA Ordinance N. 453 and from the CEC, which are based on the guidelines of the International Commission on Radiological Protection (ICRP), have established a minimum radiation dose to be used in X-ray exams [8, 9], and several studies have explored methods for reducing radiation exposure, in children with suspected CHD [8, 9, 15].

In the present study, it was shown that low body weight was present in a minority of the patients. Thus, the sample homogeneity suggested that the distribution of results, in relation to body weight or BMI and other variables was not necessary. In a revised article [16], the authors attributed several factors to the prevention of the natural development and growth of children undergoing CHD correction, such as inadequate caloric intake, among other multifactorial events. While these factors seem to strongly contribute to the inhibited development of pediatric individuals, this was not observed in the present study.

When analyzing the prevalence of congenital anomalies, VSD was identified in about half of the subjects. This value is consistent with

Table 3
Evaluation of radiation dose levels in pediatric patients ≤ 28 days old and ≥28 days old at baseline.

Organs	Basal positions					
	Cathode μGy ≤ 28 days old	Anode μGy ≤ 28 days old	P	Cathode μGy ≥ 28 days old	Anode μGy ≥ 28 days old	P
Thorax	20.8 ± 9.6	20.8 ± 9.6	1.000	29.8 ± 13.4	29.8 ± 13.4	1.000
Thyroid	13.3 ± 3.1	11.7 ± 3.1	0.008	15.9 ± 6.6	14.5 ± 6.6	0.004
Gonads	13.5 ± 4.1	12.7 ± 3.1	0.007	19.6 ± 8.9	19.5 ± 8.1	0.964

Continuous variables expressed as mean ± standard deviation. μGy (microgray).

the studies of Abqari et al. (**ref**) and Sani et al. [17], who reported the prevalence of VSD in 38% and 42.9% of pediatric CHD patients, respectively.

Furthermore, Bontrager [10] and Bushong [11] demonstrated that thicker structures require higher kilovoltages in order to sufficiently image the regions of interest. The authors recommended positioning the thicker side of the patient facing the negative end, which is known as the anodic effect. Due to the shorter distance between the focal point and the examined structure, the X-rays are more intense and have a shorter wavelength.

Thukral et al. [18] described specific actions that can be employed for reducing radiation exposure during diagnostic methods, such as CT scan and conventional radiography. In this study, the importance of the image produced with ionizing radiations was highlighted, as well as the use of digital processing, which permits contrast adjustments, following image acquisition.

In contrast to adults, the thoracic thickness is more uniform in children, and, as a consequence, radiology professionals usually do not radiograph infants with the necessary accuracy [1]. In fact, it has been proposed that there should be a well-defined protocol with regards to the positioning of the ends of the X-ray tube, especially with respect to the thyroid and the gonad glands [10].

The radiation dose levels of the pediatric subjects were analyzed and measured. The dosage of radiation from the cathode end was found to be higher than the anode end. It is worth mentioning that the distinct positions did not interfere with image acquisition or diagnostic image quality. Interestingly, Wunderle et al. [19] have promoted safe radiation use, through the utilization of personal protective equipment and a better comprehension of radiation dose effects. In fact, the authors emphasized, throughout the research, that the orientation and positioning of the X-ray tube are crucial for the radiation dosage reduction and subsequent protection.

Prior to the present study, Oliveira et al. [20] evaluated radiation dose patterns in the thorax and gonads, using 21 pediatric radiographs. The results showed that the thorax and gonads were exposed to 0.48 and 1.50 μGy of radiation, respectively. Furthermore, the analysis of the radiation dosage measurements demonstrated that radiation exposure, in the highest transportable cargo (mAs, Milliamperage-second), was greatest in the radiographed organs. In the previously mentioned study [20], an examination room fixed X-ray equipment was used, which in turn had minimum limiters of Milliamperage (mA) and exposure time (ms), with exposition factors between 500 and 1000 mA, thus generating higher doses of radiation. In contrast, the present study used a 300 mA mobile X-ray equipment, which allows for the use of lower mAs, which is more suitable for taking images with children. Recommendations for the follow-up of high radiation doses have been presented in this present trial. It should also be mentioned that the radiation dosages used are lower than the limits recommended by the CEC [8].

Table 4
Means of variables in pediatric patients. (N = 48).

Variables	Mean ± SD
Transportable cargo (mAs)	1.1 ± 0.3
Tension (kV)	71.3 ± 5.8
Focusing distance - image receiver (cm)	99.2 ± 6.5
Thorax thickness (cm)	9.5 ± 7.1
Mean of entry into the chest (μGy)	20.8 ± 9.6

Continuous variables expressed as mean, standard deviation; mAs (milliampere-second unit) kV (Voltage measurement unit) cm (square centimeters) and μGy (microgray).

If this radiological technique, in which the X-ray tube is positioned facing the thyroid and gonads during pediatric chest radiographs is implemented, there will be a reduction in terms of radiation exposure to the patients. The aim of the study by Rodrigues et al. [21] was to correlate both BMI and thoracic thickness with radiation dosages, at the entrance of the skin in patients who underwent thoracic radiography. The results verified that the *mAs transported cargo* variable interfered with the dosages. In other words, patients with greater a higher BMI and increased thoracic thickness, required an increased mA, which resulted in higher doses of radiation at the entrance of the skin.

More recently, another study sought to reduce the dosage of radiation and increase safety, while imaging patients during heart catheterization procedures [22]. They reported that, while maintaining clinical image quality for the diagnosis, specific actions such as: increasing the filtration of the X-ray beams and the removing of the anti-diffusion grid for patients between 0 and 20 kg, bring about surprising outcomes, and also have the potential of reducing the radiation doses in patients. Along these lines, the results from this work show that the thyroid and gonads were exposed to radiation emitted by both the anode and cathode. In a study similar [23], the effect of radiation dosage, emitted by the anode, was evaluated in lumbar spine radiographs, and a variation in the amount of radiation through the X-ray tube, as well as differences in the amounts radiation absorbed by the organs were observed with respect to the proximity of the organ to the cathode and anode. Additionally, the skin entrance dose (SED) of the ovaries, testicles, thyroid and face, which were closer to and facing the cathode, received a higher dosage of radiation in both the lateral and anteroposterior incidences. As a means to reduce radiation exposure to these organs, it was suggested that patients, especially females, undergoing spinal imaging exams be positioned such that the more radiosensitive organs are further away from the cathode end of the X-ray tube.

5. Conclusion

The results from the present study indicate that the thyroid gland is exposed to higher levels of ionizing radiation when facing the cathode end of the X-ray tube. Based on this observation, it is recommended that patients be positioned facing the anode end of the X-ray tube when collecting thoracic X-rays, so as to reduce radiation exposure to the thyroid and gonad glands. Radiation doses were higher when the organs were facing the cathode extremity, maintaining the technical quality criteria recommended by the European Commission. Thus, when taking X-rays it is crucial to choose the side of the patient that exposes the radiosensitive organs to less ionizing radiation.

Conflicts of interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijcha.2018.06.006.

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