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Research Article

Protocol for reducing radiation exposure during pediatric thoracic radiography

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ABSTRACT

Introduction: This work aims to assess if the anode position during chest radiography of pediatric patients with heart congenital disease (HCD) influences medical image results. The approach is to reverse the orientation of the x-ray tube, with the anode end directed towards the patient's face (anode-heel effect).

Methods: Five specialists analyzed 48 images, 24 from the control group (CG) and 24 with the anode end directed towards the patients' face (experimental group, EC). An ionization chamber was used to assess radiation dose received by sensitive organs.

Results: The specialists considered both CG and EC images acceptable. But, the EC group's dose evaluation revealed that the thyroid received 12% less radiation and the gonads presented a 5.9% reduction. Based on the results, a new protocol was developed.

Discussion/conclusion: The standardization of radiographic imaging procedures will reduce acquisition errors, resulting in adequate images in pediatric patients with HCD with less radiation dose, thus increasing patient safety and extending the life of the equipment.

RÉSUMÉ

Introduction : Ce travail vise à évaluer si la position de l'anode pendant la radiographie du thorax de patients pédiatriques atteints de maladies cardiaques congénitales (MCC) influence les résultats des images médicales. L'approche consiste à inverser l'orientation du tube à rayons X, l'extrémité de l'anode étant dirigée vers le visage du patient (effet anode-talon).

Méthodologie : Cinq spécialistes ont analysé 48 images, 24 du groupe témoin (GT) et 24 avec l'extrémité de l'anode dirigée vers le visage des patients (groupe expérimental, GE). Une chambre d'ionisation a été utilisée pour évaluer la dose de radiation reçue par les organes sensibles.

Abstract Graphic Reference (copyright free): Xray vector created by macrovector. https://www.freepik.com/vectors/xray

Ethical approval: The study was performed at the Pediatric Intensive Care Unit IC / FUC in Rio Grande do Sul, RS, Brazil. It was developed according to the International Ethical Guidelines for Biomedical Research and approved following resolution N.466 / 2012 and was registered at ClinicalTrials.gov (NCT02925936).
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Résultats : Les spécialistes ont considéré que les images du groupe GC et du groupe GE étaient toutes deux acceptables. Mais l'évaluation de la dose du groupe GE a révélé que la thyroïde a reçu 12 % de rayonnement en moins et que les gonades ont présenté une réduction de 5,9 %. Sur la base de ces résultats, un nouveau protocole a été élaboré.

Discussion/Conclusion : La normalisation des procédures d'imagerie radiographique réduira les erreurs d'acquisition, ce qui permettra d'obtenir des images adéquates chez les patients pédiatriques atteints de MCC avec une dose de rayonnement moindre, augmentant ainsi la sécurité des patients et prolongeant la durée de vie des équipements.

Keywords: Anode-heel effect; Thoracic radiography; Radiation diagnosis; X-ray in children; Heart; Congenital disease; Radiography; Diagnostic imaging

Introduction

The discovery of X-rays by Wilhelm Conrad Roentgen in 1895 revolutionized medicine, allowing the observation of the human body noninvasively. Almost immediately after its discovery, X-rays were already used in patients to diagnose diseases and locate bullet wounds [1]. X-ray-based techniques have evolved and are now considered universal tools for diagnostic research [2].

The International Committee on Radiation Protection crafted the three fundamental principles of radiological protection: justification, optimization, and dose limitation [3]. When applied to medical radiation, these three principles assume an important role. Justification means that all dose the patient receives must provide a clear benefit. Optimization signifies that all practices must be optimized, and this is achieved by constant evaluation and improvement. Finally, dose limitation implies that a study was made that calculated the lowest dose possible to achieve the outcome. These principles are applied in all areas of radiology: radiation therapy, nuclear medicine, and radiation-based diagnosis.

Thoracic chest radiography (also known as chest X-rays, chest radiography, or thoracic radiography) is one of the most requested diagnostic procedures globally. Pediatric chest radiographs are commonly employed to evaluate congenital heart disease before and after surgical procedures, exposing patients to additional radiation exposure [2]. Congenital heart disease is a general term for a range of congenital disabilities that typically affect how the heart functions. The term congenital means the condition is present from birth. Congenital heart disease is one of the most common types of congenital disability, affecting 1% of babies born in the United Kingdom [4], 1 % in the United States [5], and 9% in Brazil [6].

Children's radiation-based diagnostics and therapies have received increased negative attention [7]. In the late 1990s, the Commission of the European Communities (EC) developed QC criteria and proposed that specific guidelines be developed for pediatric patients [8,9] In 1998, the Brazilian National Health Care Surveillance Agency (ANVISA) published Ordinance N. 453 [10], establishing radiological protection guidelines for adult patients. However, the reference dose used for pediatric patients was extrapolated from adult values without a proper study to adjust radiation doses or techniques [10]. Adding to the difficulties is that pediatric imaging is challenging [11]. From the child's point of view, the environment is scary and filled with big machines. The difficulties in acquiring radiographs include struggle in synchronizing inspiration/expiration, the likelihood of motional blur, a wide range of tissue densities, and the need to minimize radiation dose [11,12]. As for advantages, chest radiography information is acquired in a painless and fast manner, allowing easy assessment and action. Additionally, radiography is one of the most financially accessible and technically feasible exams, with portable units available [13].

As with other radiation-based techniques, chest radiography is subject to quality control (QC) standards, ensuring high-quality images, using the lowest possible doses of radiation at a minimal cost. Interestingly, it has been reported that chest radiography image quality improves with lower doses of radiation [14,15]. Bontrager [16] and Takagi [14] stated that lowering the tube current (mAs) will result in low contrast, higher grayscale, less blurring artifacts, and lower image noise.

Taking advantage of the anode heel effect could be an interesting approach to minimize radiation dose. To increase the penetration of the X-ray beam, it is known that the orientation of the tube, the negative end (cathode), should be directed to the thickest part of the radiographed structure. This generates a more intense beam, a phenomenon known as the anode heel effect (Fig. 1) [17]. Despite the cathode being directed to the thicker parts in adults, children (0-4 years old) usually have the same thickness within the chest and abdominal region. So, it is possible to choose the patient side and tube position, planning the radiography before exposure to result in a reduced dose in the radiosensitive organs [18]. The recommended positioning for performing chest radiographs in pediatric patients is shown in Fig. 2.

In our "Choice of tube extremity for emission of the lowest radiation dose in pediatric patients" previous study [29], forty-eight pediatric patients were evaluated. Ten different heart congenital diseases were investigated. The conclusion was that the patient positioning yielded no difference in diagnosing these conditions. For the results to be implemented in clinical practice, creating and using a medical protocol is necessary. They allow health care providers to offer efficient care services to patients, use the equipment correctly, and stimulate periodic training [20].

This work aims to use real clinical data to develop a protocol that standardizes chest radiographic imaging procedures in children that will reduce dose and acquisition errors. The goal is to lead to the same image quality in pediatric patients without the need for repetition and, as a secondary result, increase the lifespan of the equipment.

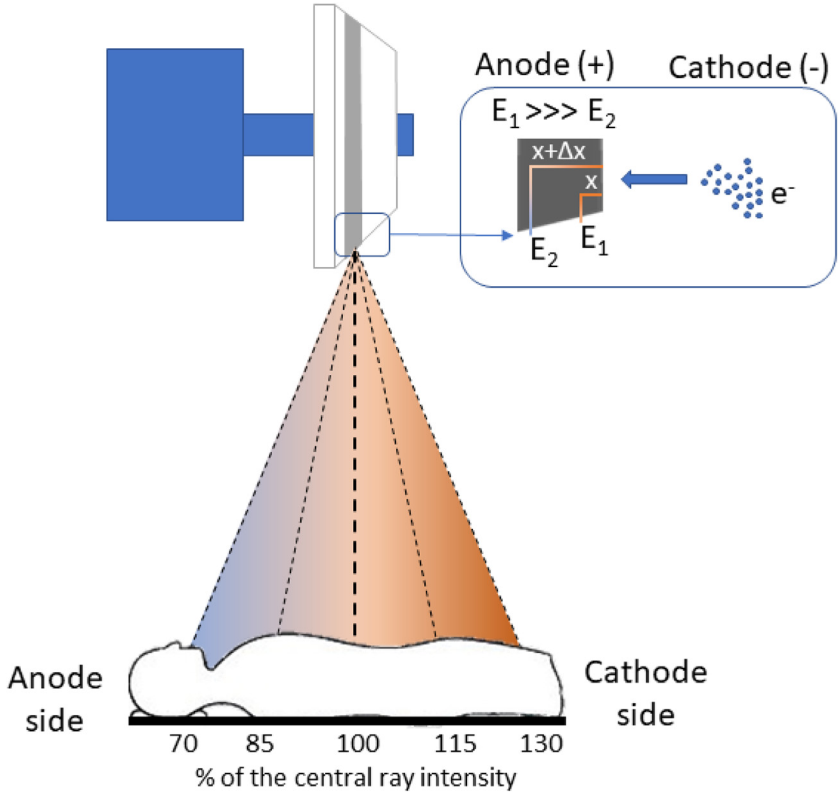

Fig. 1. Anode heel effect in relation to central x-ray intensity [6].

Fig. 2. Pediatric chest radiograph with patient in the supine position on the equipment bed. Focus on the X-ray tube position: Anode (+) facing the face [19].

Methodology

For the protocol development, the results of Rodrigues et. al. [29] randomized clinical trial study were reevaluated. The study was performed at the Pediatric Intensive Care Unit (IC) of the University Foundation (FUC) in Rio Grande do Sul, RS, Brazil. It was developed according to the International Ethical Guidelines for Biomedical Research and approved following resolution N.466 / 2012, and was registered at ClinicalTrials.gov (NCT02925936).

A randomized controlled clinical trial was developed and conducted from June 2016 to September 2019. After randomization, 48 patients aged 0 to 4 years old were included. The individuals were divided into two groups: 24 for the anode end position, called the experimental group, and 24 for the cathode end position, called the control group.

The subjects included in the trial at the Pediatric Intensive Care Unit (PICU) had to be undergoing cardiac surgery at the IC/FUC located in Rio Grande do Sul, RS, Brazil, considered infants with an age of 0 (minimum age) to 4 years (maximum age) and had a chest radiography exam requested by a cardiologist. After being properly informed about the study, caregivers signed an Informed Consent Form. The individuals not admitted for the trial were pediatric patients who did not meet the criteria. For example, they had a visual abnormality that would yield different thicknesses throughout the thoracic area (such as pneumothorax, emphysema, or pleural effusion), or the caregiver did not consent.

The exams were carried out supine on the machine bed with an anteroposterior (AP) projection and the central ray oriented towards the center of the chest at the nipple line. The X-ray tube must be positioned perpendicularly, without a Potter-Bucky

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Table 1
Protocol used for obtaining pediatric chest radiographs. Parameters are in accordance with established data of the Commission of the European Communities (CE), 1996 [8] and by European Union (EU) in 2014 [9].

Parameter	Description/Value Used
Patient position	Dorsal decubitus
X-ray tube position	Anode (+) facing the patient's face
Central ray position	Anteroposterior, perpendicular, and oriented in the nipple line
Focus-receiver distance	99–105 cm
Average kV	65–77
Average mAs	1–1,4
Average chest thickness	9–11
Potter / Bucky Grid	Not used
Equipment	Portable device with Computerized Radiography (CR) System

grid. A summary of the variables used is presented in the area proposed in Table 1.

The patient must first be placed in dorsal decubitus to perform the exam properly. The image receptor is situated under the thorax. The X-ray tube is positioned at a minimum distance of 100 cm, with the tube oriented perpendicularly. The central ray should cross at the center of the nipple line in the central chest region. The anode side of the tube must be facing the face (experimental group) or the cathode facing the face (control group).

It is proposed that this approach be employed as a component of a standardized protocol for radiographic chest imaging of pediatric patients with congenital heart disease. Standardizing radiographic imaging procedures will reduce acquisition errors, resulting in adequate images in pediatric patients without the need for an additional dose of radiation, thus increasing patient safety and extending the life of the equipment.

All of the radiological images must fulfil the criteria recommended by [8,9] including:

- symmetrical reproduction of the chest without any observable rotation or basculation;
- reproduction of the costal grid above the diaphragm;
- clear reproduction of pulmonary vascularization (mainly in the periphery), trachea, proximal segment of the bronchi, diaphragm, cost-phrenic angles, heart and aorta;
- visualization of the retrocardiac region of the lungs, mediastinum, and vertebral column (through cardiac shadow) [8,9].

The doses of the anode and cathode end positions were assessed using an ionization chamber. The ionization chamber (Radcal, model 9015) was positioned in the neck (thyroid region) and the gonadal area. The equipment was calibrated and used in accordance with ANVISA 453/98 [10] and RDC/ANVISA 330 [21]. Finally, the data conversion to the deposited dose was done using the mathematical correlation presented here.

Table 2
Image evaluation criteria.

Parameter	Response
1. Symmetrical reproduction of the chest	☐Yes ☐No
2. Any observable rotation or basculation	☐Yes ☐No
3. Reproduction of the costal grid above the diaphragm	☐Yes ☐No
4. Clear reproduction of pulmonary vascularization (mainly in the periphery), trachea, proximal segment of the bronchi, diaphragm, cost-phrenic angles, heart and aorta	☐Yes ☐No
5. Visualization of the retrocardiac region of the lungs, mediastinum, and vertebral column (through cardiac shadow)	☐Yes ☐No
6. Were you able to conclude a diagnosis	☐Yes ☐No
7. In your experience, is the image of good quality	☐Yes ☐No
How would you rate the image	☐ A – accepted* ☐ C – still visible, but bad quality ☐ F- rejected

* Only mark A if you answer NO for question 2 and YES to the other questions.

Ionization chambers are the most commonly used detectors in medical X-ray assessment [22,23]. The device contains two electrodes within an enclosed volume of gas to create an electric field. When radiation hits the gas, ion pairs are formed and drifted under the influence of this field. An electrical current is formed, and the intensity of this current is proportional to the incident radiation [22].

The ionization chamber measures radiation exposure. For obtaining the dose value, it should be converted following Eq. (1).

$$D\left(mGy\right) = M \times 0.0087 \times f_{BSK} \times f_{P,T} \times f_C \tag{1}$$

where M is the measured exposure value (mR), f_{BSK} is the backscatter factor, $f_{P,T}$ is the correction factor for temperature and pressure, and f_C is the calibration factor of the ionization chamber for the beam quality. f_{BSK}, $f_{P,T}$, and f_C are obtained during the quality control tests of the equipment and chamber.

The images were assessed by five professionals: three radiology physicians (RP), one medical physicist (MP) and one radiology technologist (RT). Besides the EC/EU criteria, the professionals used their experience to judge the quality of the images. They were asked to fill out a form with the evaluation criteria (Table 2) and rate the images from A – accepted, C – still visible, but bad quality, or F- rejected. Information on the five professionals is in Table 3.

Results

Table 4 presents the results of the professional's evaluation and the average measured and converted (using Eq. (1)) to radiation dose.

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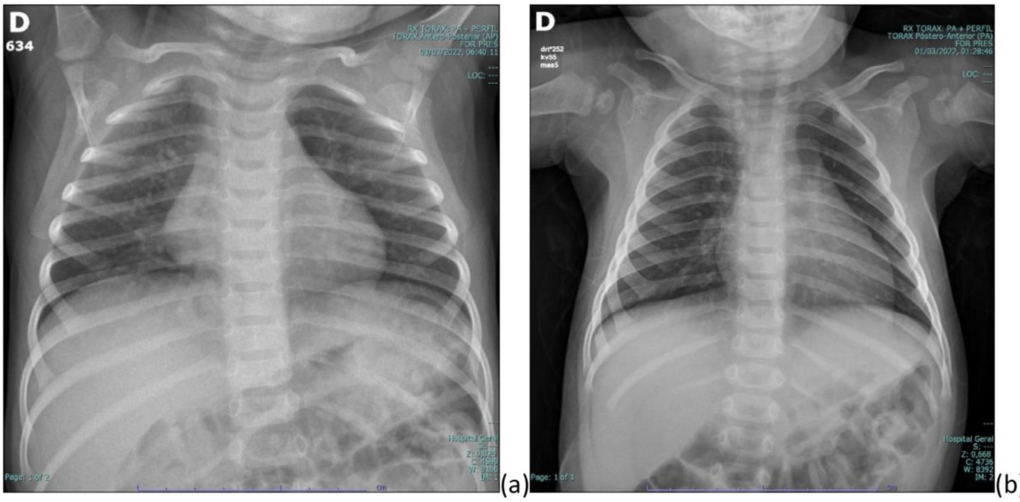

Fig. 3. Chest radiography of (a) patient 10 with the anodic end facing the face and (b) patient 30 from the control group, cathodic end to patient's face.

Table 3
Experience information on the five professionals.

Professionals	Experience
radiology physician 1	40 years of experience in pediatric cardiology
radiology physician 2	40 years of experience in pediatric intensive care unit
radiology physician 3	20 years of experience in cardiac image diagnosis
medical physicist	15 years of experience in pediatric medical diagnosis
radiology technologist	30 years of experience in pediatric medical diagnosis

Fig. 3 shows an example of chest radiography taken cathodic end to the patient's face (a) and anodic end facing the face (b). Quality of the images was considered at the same level by the experts.

The results revealed that the five professionals approved all images, not finding significant differences between the control and experimental groups. However, the control group was exposed to larger doses of radiation (12% more in the thyroid and 5.9% more in the gonads) compared to patients imaged with the alternative X-ray tube configuration. This demonstrates that changing the X-ray tube's orientation can yield the same quality diagnostic images and reduce radiation exposure.

The need for this protocol arose from observing the staff's day-to-day routine. The points considered were:

- The staff have a heavy workload and face a variety of cases in a short amount of time. Having all information with easy access and comprehension was key wide for implementation;
- The staff felt more comfortable having the information with easy access.

After considering all the results, the final protocol was curated, as presented in Fig. 4.

The implementation of the protocol required a two-hour training session (when Fig. 2 was obtained). This training was well received by the staff. As a result, all pediatric patients with heart congenital disease now follow the protocol.

Discussion

This work has shown that chest radiography image quality does not depend on X-ray tube orientation, but directing the anode towards the patient's face enhances patient safety by reducing radiation exposure. However, many other variables can play a major role in image acquisition and image quality, including pediatric chest positioning and rotation, exam interpretation, selecting the most appropriate X-ray equipment, and regular QC (equipment and personnel) [3].

In pediatric care, radiological imaging is an extremely valuable diagnostic tool. In pediatric congenital heart disease assessment, these young patients are often exposed to additional exams [25]. Young children are highly radio-sensitive patients

Table 4
Evaluation results by the professionals and dose at the thyroid and gonads.

Criteria	RP1	RP2	RP3	MP	RT	Average dose received - Thyroid	Average dose received - Gonads
Image quality of control group (cathodic end to patient's face)	A	A	A	A	A	13.3 ± 3.1 μ Gy	13.5 ± 4.1 μ Gy
Image quality of experimental group (anodic end facing the face)	A	A	A	A	A	11.7 ± 3.1 μ Gy	12.7 ± 3.1 μ Gy
Image comparison	All images were approved					-	-

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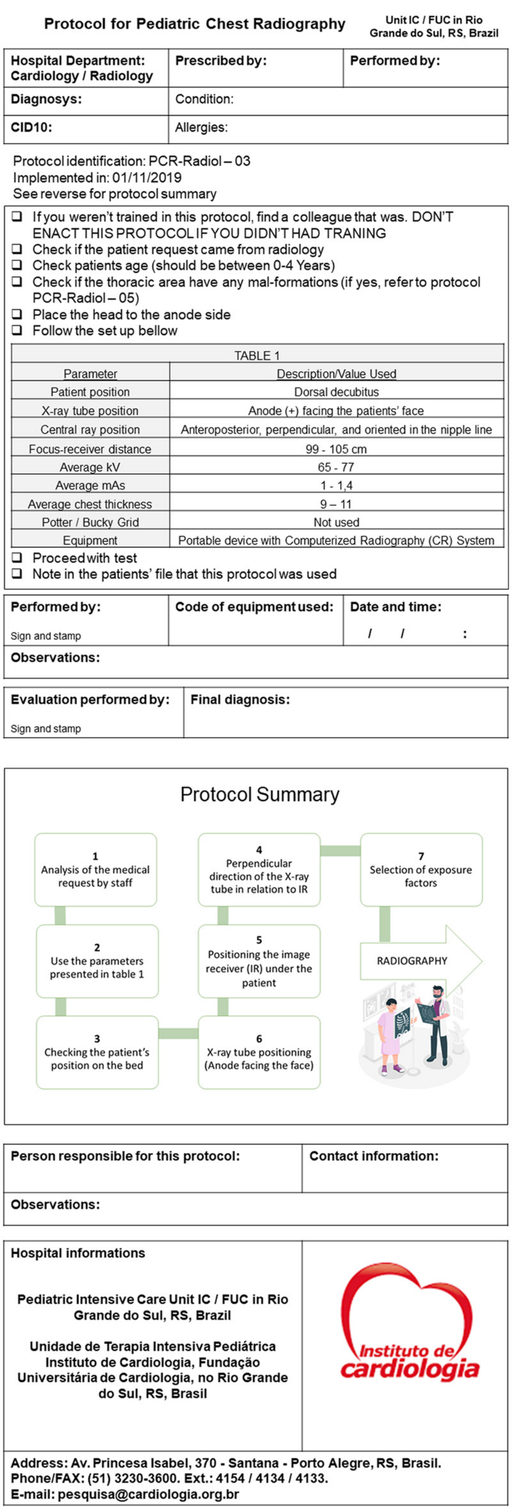

Protocol for Pediatric Chest Radiography — Unit IC / FUC in Rio Grande do Sul, RS, Brazil

Hospital Department: Cardiology / Radiology	Prescribed by:	Performed by:
Diagnosys:	Condition:	
CID10:	Allergies:	

Protocol identification: PCR-Radiol – 03
Implemented in: 01/11/2019
See reverse for protocol summary

- ❑ If you weren't trained in this protocol, find a colleague that was. DON'T ENACT THIS PROTOCOL IF YOU DIDN'T HAD TRANING
- ❑ Check if the patient request came from radiology
- ❑ Check patients age (should be between 0-4 Years)
- ❑ Check if the thoracic area have any mal-formations (if yes, refer to protocol PCR-Radiol – 05)
- ❑ Place the head to the anode side
- ❑ Follow the set up bellow

TABLE 1

Parameter	Description/Value Used
Patient position	Dorsal decubitus
X-ray tube position	Anode (+) facing the patients' face
Central ray position	Anteroposterior, perpendicular, and oriented in the nipple line
Focus-receiver distance	99 - 105 cm
Average kV	65 - 77
Average mAs	1 - 1,4
Average chest thickness	9 – 11
Potter / Bucky Grid	Not used
Equipment	Portable device with Computerized Radiography (CR) System

- ❑ Proceed with test
- ❑ Note in the patients' file that this protocol was used

Performed by: Sign and stamp	Code of equipment used:	Date and time: / / :
Observations:		

Evaluation performed by: Sign and stamp	Final diagnosis:

Person responsible for this protocol:	Contact information:
Observations:	

Hospital informations

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Fig. 4. Protocol and Flowchart of the procedure performed for radiography in pediatric patients. Radiography image on the flowchart from [24].

since they are at a critical developmental stage characterized by rapid cellular division and growth. Therefore, radiographic examinations within this group of patients should be performed with the utmost attention and precision. Additionally, the small thorax size of this group of patients adds a certain degree of complexity since the positioning of the patient can potentially have devastating effects on image quality [16,26].

Correct positioning is fundamental to the acquisition of high-quality pediatric chest radiographic images. Small rotations and/or incorrect angulations of the X-ray tube can result in misinterpretation of results and misidentification of small structures within the chest cavity. Poor positioning can distort the appearance of anatomical structures, making it sometimes impossible to compare the results of one exam with another [17]. Moreover, the ability to locate and view probes, catheters, and tubes may become compromised when the patient is not in the proper position for acquiring an AP projection, which requires correct tube and chassis alignment [17].

The parameters used in this study were: dorsal decubitus, image receptor situated under the thorax, X-ray tube positioned at a minimum distance of 100 cm, tube oriented perpendicularly, central ray crossing the nipples in the central chest region, and the anode part of the tube must be facing the patient's face. This approach was organized in a standardized protocol for radiographic chest imaging of pediatric patients.

From a dosimetry standpoint, the differences found in the thyroid, 12%, and in the gonads, 5.9%, are small but not to be ignored. In this range, radiation effects fall into the stochastic range. They are proportional to the dose received but do not have a threshold. They are low doses, below the ones proven to yield an immediate effect, but have a probabilistic nature. The principle used is that one single X-ray photon, for example, can cause a mutation that will lead to cancer in the future [27].

All medical radiation exposures must be justified, meaning they should do more good than harm. They should also be optimized, meaning as low as possible to achieve the desired result and have a dose limitation considering the target area and the surrounding healthy areas (the ALARA concept, meaning as low as reasonably achievable). If there is a method and/or equipment capable of achieving lower doses, it should be used. Measuring radiation dose periodically, creating and reevaluating protocols, and re-training staff contribute to the optimization principle and guarantee that the best diagnosis/treatment is being provided to the patient [3,27,28]. The present work contributes to applying radiation protection principles because it presents a dosimetric evaluation, finds a modification (anode position) that will lower the patient exposure yielding the same outcome (image), and creates a new protocol to be followed.

Conclusion

This work used the expertise of five health care professionals to evaluate if the anode position interferes with the quality of chest radiographs undertaken in pediatric patients with congenital heart diseases. According to the experts, changing the tube position did not alter image results, and the diagnosis pro-

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ceeded effectively. Despite that, a difference of 12% dose in the thyroid and 5.9% in the gonads were found. Based on this data, a protocol was created relaying all the steps for pediatric chest radiographs of children with congenital heart diseases. These procedures will now be performed with lower radiation dose.

In the future, the authors will do more assessments with different organs, different dosimetric models, and Monte Carlo Simulation. In addition, the authors will also evaluate other aspects that can lead to radiographical differences, such as collimation, image receptors, equipment, and source to film distance (SFD).

CRediT authorship contribution statement

Carla DARUICH DE SOUZA: Conceptualization, Funding acquisition, Formal analysis, Data curation, Writing – original draft. **Gustavo RICO FREITAS:** Conceptualization, Funding acquisition, Formal analysis, Data curation, Writing – original draft. **Rogério FACHEL MEDEIROS:** Conceptualization, Funding acquisition, Formal analysis, Data curation, Writing – original draft. **Ercilia RAMALHO:** Conceptualization, Funding acquisition, Formal analysis, Data curation, Writing – original draft. **Sergio Chaves RODRIGUES:** Conceptualization, Funding acquisition, Formal analysis, Data curation, Writing – original draft. **Guilherme OBERTO RODRIGUES:** Conceptualization, Funding acquisition, Formal analysis, Data curation, Writing – original draft.

References

[1] Souza CD, Peleias Junior FDS, Rostelato MECM, et al., editors. Work with Iodine-125: 8 years experience in brachytherapy sources production lab. InMed; 2015; Kioto, Japan.

[2] Zewdu M, Berhane EKM. Assessment of pediatrics radiation dose from routine X-Ray examination at radiology department of jimma university specialized hospital, southwest Ethiopia. *J Health Sci*. 2017;27:9.

[3] International Commission on Radiological Protection ICRP 60: Occupational radiological protection in interventional procedures. https://www.icrp.org/publication.asp?id=icrp%20publication%2060: International Commission on Radiological Protection. ICRP Publication 21; 1991.

[4] NHS U.K. Congenital heart disease https://www.nhs.uk/conditions/congenital-heart-disease/#:~:text=Congenital%20heart%20disease%20is%20a,babies%20born%20in%20the%20UK. 2022. Accessed: Mar. 15, 2022.

[5] National Center on Birth Defects and Developmental Disabilities - Centers for Disease Control and Prevention USA. Estimating the number of people with congenital heart defects living in the United States. https://www.cdc.gov/ncbddd/heartdefects/features/kf-chd-estimates-us.html#:~:text==Congenital%20heart%20defects%20are%20the,40%2C000)%20of%20births%20per%20year.&text=CHDs%20are%20present%20at%20birth,defect%20has%20a%20critical%20CHD. 2022. Accessed: Mar. 16, 2022.

[6] Pinto Júnior VC, Branco KM, Cavalcante RC, et al. Epidemiology of congenital heart disease in Brazil. *Rev Bras Cir Cardiovasc*. 2015;30(2):219–224.

[7] Linet MS, Kim KP, Rajaraman P. Children's exposure to diagnostic medical radiation and cancer risk: epidemiologic and dosimetric considerations. *Pediatr Radiol*. 2009;39(1):S4–S26 Suppl 1.

[8] Official Publications of the European Communities. *European Guidelines on Quality Criteria For Diagnostic Radiographic Images*. Luxemburg; 2000.

[9] Remedios D, Cavanagh P, Ashford N, Grenier P, Bezzi M, Chateil JF. Referral guidelines for medical imaging availability and use in the European union. *Eur Comm*. 2014:1681–6803 ISSN.

[10] Agência Nacional da Vigilância Sanitária - Ministério da Saúde. Diretrizes básicas de proteção radiológica em radiodiagnóstico médico e odontológico. 1998. p. 67. https://www.saude.mg.gov.br/index.php?option=com_gmg&controller=document&id=889#:~:text=Aprova%20o%20Regulamento%20T%C3%A9cnico%20que,nacional%20e%20d%C3%A1%20outras%20provid%C3%AAncias. ordinance 453.

[11] Thukral BB. Problems and preferences in pediatric imaging. *Indian J Radiol Imaging*. 2015;25(4):359–364.

[12] Mammas IN, Spandidos DA. The perspectives and the challenges of paediatric radiology: an interview with Dr georgia papaioannou, head of the paediatric radiology department at the 'mitera' children's hospital in athens, Greece. *Exp Ther Med*. 2019;18(4):3238–3242.

[13] Liu Z, Song L, Yu T, et al. Application of low dose radiation and low concentration contrast media in enhanced CT scans in children with congenital heart disease. *Int J Clin Pract*. 2016;70:B22–B28 Suppl 9B.

[14] Takagi S, Yaegashi T, Ishikawa M. Dose reduction and image quality improvement of chest radiography by using bone-suppression technique and low tube voltage: a phantom study. *Eur Radiol*. 2020;30(1):571–580.

[15] Lee W, Lee S, Chong S, et al. Radiation dose reduction and improvement of image quality in digital chest radiography by new spatial noise reduction algorithm. *PLOS One*. 2020;15(2):e0228609.

[16] Bontrager KL. *Tratado de Técnica Radiológica e Base Anatômica*. Rio de Janeiro: Elsevier Koogan; 2015.

[17] Sutton D. *Textbook of Radiology and Imaging*. 7th ed. London, UK: Churchill Livingstone; 2002.

[18] Oberto Rodrigues G, Glotz de Lima G, Jader Feldman C, Fachel de Medeiros R, Goldmeier S. Correlación entre el índice de masa corporal y la absorción de los rayos X en la radiografía de tórax. *Imagen Diagn*. 2016;7(1):19–24.

[19] Rodrigues GO. *Radiologia Convencional: A Arte De Posicionar*. São Paulo, Brazil: Corpus; 2020 228 p.

[20] Heymann T. Clinical protocols are key to quality health care delivery. *Int J Health Care Qual Assur*. 1994;7(7):14–17.

[21] Agência Nacional da Vigilância Sanitária - Ministério da Saúde. Diretrizes de Radiodiagnóstico Médico e Odontológico. 2019. p. 67.

[22] Knoll GF. *Radiation Detection and Measurement*. 3 ed. Michigan University: Wiley; 2000.

[23] Ferdeghini EM. 210 - radiation protection and dosimetry in X-ray imaging. In: Brahme A, ed. *Comprehensive Biomedical Physics*. Oxford: Elsevier; 2014:243–262.

[24] Freepik. Medical vetor created by storyset. Free copyright with attribution. https://br.freepik.com/fotos-vetores-gratis/medico2022. Accessed: Mar. 16, 2022.

[25] Board NNI. Delivering quality imaging services for children. https://www.sor.org/getattachment/Learning-advice/Professional-Practice/Diagnostic-imaging-pathways/Diagnostic-Imaging-Pathways/Paediatric-Imaging/Delivering-Quality-Imaging-Services-for-Children.pdf?lang=en-gb; 2017. reference number: 13732.

[26] Bushong SC. *Radiologic Science for Technologists: Physics, Biology, and Protection*. 11th ed. Maryland Heights, Missouri, USA: Elsevier; 2016 Mosby.

[27] Edwards AA, Lloyd DC. Risks from ionising radiation: deterministic effects. *J Radiol Prot*. 1998;18(3):175–183.

[28] Souza CD, Rostelato MECM, Zeituni CA, et al. Analysis of the necessary radioprotection procedures in manufacture of iodine-125 sources used in brachytherapy: a preliminary study. *Prog Nucl Energy*. 2011;53(1):66–72.

[29] Rodrigues GO, Medeiros RF, Rodrigues SC, Cavalheiro Boll LF, Irigoyend MC, Goldmeier S. Choice of tube extremity for emission of the lowest radiation dose in pediatric patients. *IJC Heart Vasc*. 2018;21:64–68.

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