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Research Article

Analysis of Radiation Exposure and Thoracic Examinations Techniques in Toddler Patients

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Abstract: Background: There are still shortcomings in the implementation of a truly safe and optimal thoracic examination protocol for toddlers in certain hospital settings. Furthermore, data related to direct radiation dose measurements and evaluation of the effectiveness of thoracic examination techniques for toddlers specifically in the local context in Indonesia are very limited. Objective: To examine the thoracic examination procedure that can be performed with a high level of safety without compromising the quality of diagnostic results and to evaluate the radiation exposure dose and thoracic examination techniques in toddlers at Hospital. Methodology: This study used a mixed methods approach with a convergent parallel design. Quantitative data were obtained from radiation dose measurements and examination parameters, while qualitative data were collected through observation, interviews, and group discussions, then analyzed thematically to understand the factors that influence radiation dose in infant thoracic examinations. Results: Research on thoracic radiology examinations in toddlers at Heart and Vascular Hospital was conducted systematically and in accordance with established procedures. Some limitations emerged from limited radiation dose records and inconsistent use of protective shields. Efforts to reduce radiation exposure include optimizing examinations, proper collimation, selecting exposure parameters, and educating families and staff. Continuous training and strict implementation of standard operating procedures (SOP) are essential to raise awareness of the ALARA principle. Internal policies and routine oversight are also needed to improve radiation dose monitoring, with the hope of improving the quality of radiology services and optimizing protection for toddler patients.

Keywords: ALARA; Dap; Drl; Thoracic Examination; Toddlers

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1. Introduction

In the medical world, particularly in radiology, radiation protection is a crucial aspect, particularly when dealing with infants (1,2). Radiation protection studies indicate that children are more sensitive to the harmful effects of ionizing radiation than adults (3,4). This is due to factors such as faster cell growth and the longer lifespan of infants, which provides more time for radiation to have a negative impact (5,6). Furthermore, radiation can have an effect on the biological tissues of the human body, and the level of damage experienced by a cell type due to radiation varies greatly depending on its level of radiosensitivity.

In recent years, diagnostic imaging techniques in the medical field have advanced rapidly. Technological advances allow for faster and more accurate diagnoses and raise awareness of the importance of early disease detection (7). Thoracic examinations play a crucial role in diagnosing various diseases in infants, such as pneumonia, tuberculosis, and structural lung abnormalities. According to WHO data, pneumonia remains one of the leading causes of death in children under five years of age, with approximately 800,000 deaths worldwide each year (WHO, 2021). Therefore, a timely and accurate thoracic examination can help identify conditions for diagnosis and initiate necessary treatment (8,9).

There are also various radiation protection methods and principles that can be applied to reduce radiation exposure to patients and medical personnel during medical imaging procedures. Based on the ALARA (As Low As Reasonably Achievable) principle, radiation protection aims to reduce radiation exposure that is not beneficial to humans. This principle is also known as the "as low as possible" principle (10). For healthcare workers, staying as far away from the radiation source as possible during an x-ray examination procedure is an effective step to reduce radiation exposure time. Educating and training radiation workers on radiation protection and proper x-ray examination techniques is essential to protect themselves and patients from the effects of radiation (11,12). One important aspect of a thoracic examination is the measurement of the Dose Area Product (DAP). DAP is a measure that describes the total radiation dose received by a patient during an imaging procedure, multiplied by the area exposed to radiation. DAP is measured in units of Gy.cm-2 and is an important indicator in medical imaging, as it provides an overview of the potential risk of radiation exposure to patients used to assess radiation exposure during an examination (13,14). DAP is a parameter that reflects the radiation dose received by a patient, and this value is very important to ensure that the dose given remains within safe limits (15).

Based on BAPETEN Regulation 4 of 2020 concerning Radiation Safety in the use of X-ray machines in diagnostic and interventional radiology, Article 40 states that Patients with high radiosensitivity include infants, children, pregnant women or those suspected of being pregnant (16). The ideal DAP for thoracic examinations in toddlers must be observed so as not to exceed the Dose Reference Level (DRL) limit set by the Technical Guidelines for the Preparation of Diagnostic Guideline Levels or National DRL, and according to a study by Lee et al., in 2021, the ideal DAP value for thoracic examinations in toddlers must be observed so as not to exceed the DRL limit set by the international toddler thoracic standards in the USA 0.1-0.3 mGy, Europe 0.1 mGy, Australia 0.1 mGy Japan 0.1 mGy. The DRL value for examinations using general radiography is 0.2 mGy for the PA thorax and 0.4 mGy for the AP thorax, and based on BAPETEN Head Decree 1211 of 2021, it is 0.3-0.4 mGy for adult thoracic patients (17,18,19). In addition, the low DAP value also indicates that the imaging technique used is efficient in providing diagnostic information without causing excessive radiation exposure (20).

The implementation of thoracic examinations in toddlers in various hospitals shows a significant increase in the number of procedures performed. Data from the Ministry of Health of the Republic of Indonesia shows that in 2022, there were more than 50,000 thoracic radiographs performed on children throughout Indonesia (21). This reflects the high need for lung disease diagnosis in toddlers but also raises concerns about excessive radiation exposure (22). Therefore, it is important to implement strict protocols in carrying out thoracic examinations in toddlers. This includes the use of protective equipment and imaging techniques that minimize radiation dose. Collaboration between radiation protection theory, toddler sensitivity to radiation, and the implementation of thoracic examinations is crucial to ensure the safety and health of toddler patients (1,23).

Based on a preliminary study, researchers observed the thoracic examination of toddlers in the radiology unit, conducted in examination room I using a stationary Digital Radiography (DR) x-ray with a maximum of 150 kV and a maximum of 800 mA. In the thoracic examination of toddlers, patients after registering at the radiology administration counter, the patient is asked to wait in the waiting room, then the administrative officer delivers the request form to examination room one. The officer calls the patient for examination. The patient's companion or parent is asked to help fix the patient so that he does not move during the examination and wears an apron. After the examination, the patient's parent's companion is given a sheet of paper for taking the results.

This study aims to analyze the radiation exposure dose received by toddlers from thoracic examination techniques and to evaluate the effectiveness and safety of these examination techniques in the context of child health. Therefore, the researcher is interested in conducting further research on the analysis of radiation exposure doses and thoracic examination techniques in toddlers. It is hoped that this research can make a significant contribution to the practice of toddler radiology and improve patient safety in hospitals.

2. Literature Review

2.1. Radiation Dose

Radiation dose refers to the amount of radiation energy absorbed by body tissue, measured in grays (Gy)(24). There are several types of radiation dose that need to be understood in the context of medical imaging, including the effective dose and the accumulated dose(11). The effective dose is a measure that takes into account the sensitivity of various organs to radiation, providing a more accurate picture of the potential health risks (IAEA, 2019)(25,26). The accumulated dose, on the other hand, is the total radiation dose received by a patient from various imaging procedures over a specific time period (27,28).

Radiation exposure can have significant health consequences, especially in more vulnerable populations such as infants (29,30). Studies have shown that children are at higher risk of side effects from radiation compared to adults, because their developing tissues are more sensitive to DNA damage (31,32). In addition, radiation exposure at an early age can increase the risk of cancer later in life, which is a major concern in medical imaging practice (33).

In the context of chest examinations in infants, understanding radiation dose is crucial. For example, a study by Pearce et al. (2012) found that children who received high-dose chest examinations had a higher risk of cancer later in life. Therefore, it is crucial for medical practitioners to minimize radiation dose without compromising the image quality necessary for accurate diagnosis (21,34). Overall, understanding radiation dose and its impact on children's health is crucial for clinical decision-making. This also emphasizes the importance of using safer and more efficient imaging techniques in the context of the infant population, where the health risks of radiation must be carefully considered (35,36).

2.2. Dose Area Product (DAP)

DAP is a measure that describes the total radiation dose received by a patient during an imaging procedure, multiplied by the area exposed to radiation. DAP is measured in units of $Gy \cdot cm^{-2}$ and is an important indicator in medical imaging, as it provides an overview of the potential risk of radiation exposure to the patient (37). In the context of thoracic examinations in infants, understanding DAP becomes particularly relevant, given that children have smaller body sizes and are more sensitive to radiation (38).

DAP measurements can be performed using a special device attached to an imaging machine. DAP data can help doctors evaluate the radiation dose received by a patient and compare it to established dose standards. For example, a study by Mc Gowan et al. (2016) found that using DAP can help identify procedures that result in higher-than-expected radiation doses, allowing precautions to be taken to reduce radiation exposure (37).

The relevance of DAP for infant patients cannot be overstated. Infants are at higher risk of adverse effects from radiation, and by using DAP, medical practitioners can ensure that the radiation dose received is within safe limits. Furthermore, DAP can be used to educate parents about the radiation risks associated with imaging procedures, allowing them to make more informed decisions regarding their infant's healthcare (17). In clinical practice, it is important to integrate DAP measurements into imaging protocols. This will not only improve patient safety but also increase parental confidence in medical procedures performed on infants (39,40). Thus, DAP is a crucial tool in efforts to reduce the radiation dose received by infants during thoracic examinations (40).

2.3. *Dose Refrence Level* (DRL)

The DRL is a radiation dose standard established to assist in the management and control of radiation doses in medical imaging practices. The DRL is established based on dose data collected from various medical centers and serves as a reference for evaluating the radiation dose received by patients (41) (European Commission, 2014). In the context of thoracic examinations in infants, establishing the DRL is crucial to ensure that the radiation dose received is within safe and effective limits (42).

The importance of DRLs in clinical practice cannot be overstated. DRLs help medical practitioners identify procedures that may result in higher-than-expected radiation doses. For example, a study by Vassileva et al. (2019) found that many medical centers do not adhere to established DRLs, potentially increasing health risks to patients, especially infants. Therefore, implementing DRLs in clinical practice is crucial to ensure patient safety.

In addition, the Dose Reference Level (DRL) also serves as a tool to raise awareness among medical practitioners regarding the importance of radiation dose management. By knowing and adhering to the DRL, physicians and radiology technologists can take the necessary steps to reduce the radiation dose received by patients. For example, they can choose more efficient imaging techniques or use devices designed to reduce radiation exposure (43).

In the context of infants, where the risk of radiation exposure is higher, DRLs allow medical practitioners to ensure that children receive a safe radiation dose appropriate to their clinical needs. This will not only protect the child's health, but also provide peace of mind for parents regarding medical procedures performed on infants (44). Overall, DRLs are a key component in radiation dose management in medical imaging, particularly in infants. Establishing and implementing appropriate DRLs can help reduce the health risks associated with radiation exposure, as well as improve the quality of healthcare provided to infants (45).

The local DRL value for each hospital is estimated using the median or second quartile (Q2) value. Meanwhile, the national DRL value can be determined using the third quartile, which is 75%. In 2021, BAPETEN Regulation No. 1211/K/V/2021 issued technical guidelines for the preparation of national diagnostic guidelines or DRLs for general radiography (46,47), as presented in Table 1 below.

Table 1. (DRL) Decision Ka. BAPETEN 1211 (13).

Jenis Pemeriksaan	**ESAK (mGy) ***	**INAK (mGy) ****
Abdomen AP	2,0	1,4
Ankle joint	0.2	0.1
Antebrachia	0,1	0,1
BNO AP	1,7	1,3
Chest AP	0,4	0,3
Chest PA	0,4	0,3
Cervical LAT	1,4	1,0
Cervical AP	0,7	0,5
Femur AP	0,5	0,4
Genu AP	0,4	0,3
Genu LAT	0,4	0,3
Lumbar Spine AP	2.0	1,4
Lumbar Spine LAT	4,4	3,1
Manus AP	0,2	0,1
Pedis AP	0,2	0,1
Pelvis AP	1,8	1,4
Shoulder	0,4	0,3
Skull AP	1,3	0,9
Skull LAT	1,2	0,9
GR-Cruris-Tibia Fibula	0,3	,2
Wrist joint AP	0,2	0,2
Waters	1,7	1,2

2.4. Toddler

Toddlers are children under 5 years old with growth characteristics such as at the age of 0-1 years experiencing rapid growth where body weight at the age of 5 months is 2 times the birth weight, at the age of 1 year the body weight increases 3 times and increases 4 times the body weight at the age of 2 years. Growth will slow down during the preschool period with a weight increase of approximately 2 kg per month and constant growth begins to end (49).

Growth is the increase in the size and number of intercellular tissue cells, which means an increase in the physical size or structure of the body in part or in whole, so it can be measured through units of length and weight. While development is the increase in the structure and function of the body more complex with the ability of gross or fine motor skills, as well as socialization and independence, speech and language (51,52). Nutrition is the most important part of growth and development which has a close relationship with health and intelligence. So consuming food greatly influences the assessment of a child's nutritional status. The emergence of malnutrition in children or toddlers is not only a lack of food intake but is caused by disease. Based on the Regulation of the Minister of Health of the Republic of Indonesia 25 of 2014 concerning Child Health Efforts, the child's age category is divided into:

(a) A child is a person up to 18 years of age, including children still in the womb.
(b) A newborn is a baby aged 0 to 28 days.
(c) An infant is a child aged 0 to 1 year.
(d) A toddler is a child aged 12 months to 5 years.
(e) A preschooler is a child aged 5 to 6 years.
(f) A school-age child is a child aged 6 years and older up to and before the age of 18.
(g) Adolescents are the age group from 10 to 18 years.

2.5. Anatomy of the Toddler Thorax

The muscles of the chest wall and abdominal wall are arranged in several layers, namely the external layer, the medial layer, and the internal layer. For the thoracic wall, the external, medial, and internal layers are, respectively, the external intercostal muscles, the internal intercostal muscles, the subcostal muscles, and the transversus thoracis muscles (52). Other muscles that contribute to the thoracic wall are included in the group of muscles of the superior limb. The abdominal wall muscles and certain muscles of the back are all located external to the ribs and intercostal spaces. The levator costarum muscles are related to the back muscles, but are functionally related to the intercostal muscles. During quiet inspiration, the movement of the diaphragm contributes 75% of the change in intrathoracic volume. The diaphragm is attached to the floor of the thoracic cavity, it curves over the liver and moves downward like a piston when it contracts. The distance of movement ranges from 1.5 cm to as far as 7 cm with deep inspiration (52).

The other major inspiratory muscles are the external intercostal muscles, which run obliquely up and down from rib to rib. The rib shafts articulate with the vertebrae, so that when the external intercostal muscles contract, they elevate the lower ribs. This pushes the sternum outward and increases the anteroposterior diameter of the chest. The transverse diameter actually changes little or not at all. Neither the diaphragm nor the external intercostal muscles themselves can maintain adequate ventilation at rest. Transverse spinal cord section above the third cervical segment is fatal without artificial respiration, but transection below the origin of the phrenic nerve supplying the diaphragm (third to fifth cervical segments) is not fatal.

In contrast, in patients with bilateral phrenic nerve paralysis, respiration is sufficient to sustain life. The scalenus and sternicleidomastoid muscles of the neck are accessory muscles of inspiration that help raise the thoracic cavity during deep breathing. A decrease in intrathoracic volume and a forceful expiration occur when the expiratory muscles contract. The internal intercostal muscles have this action because they run obliquely downward and posteriorly from rib to rib and therefore pull the thoracic cavity downward when they contract. Contraction of the muscles of the anterior abdominal wall also aids expiration by pulling the rib cage downward and inward and by increasing intra-abdominal pressure, which pushes the diaphragm upward (52).

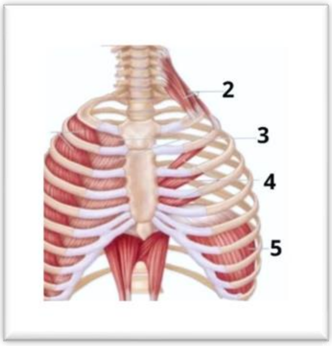

Figure 1. Respiratory muscles in the chest wall (52)

Description:
1. External Intercostals
2. Scalenes
3. Internal Intercostals
4. Transverse Thoracic
5. Diaphragm

3. Proposed Method

This type of research is Convergent parallel with Mixed Method method. According to Creswell J.W (2014), Mixed Method is combining quantitative and qualitative approaches to gain a more comprehensive understanding of the research phenomenon. According to Ghaffari (2024) Convergent parallel is combining quantitative and qualitative data in parallel. Where in this study has the aim of analyzing radiation exposure in thoracic examinations in the Diagnostic Radiology Unit of Hospital X (Quantitative) and knowing the technique of implementing thoracic radiology examinations in toddlers, as well as knowing efforts / suggestions / recommendations so that thoracic examinations of toddlers in the Diagnostic Radiology Unit of Hospital X provide the lowest possible dose (Qualitative).

This study aims to analyze radiation exposure in thoracic examinations which produce output in the form of radiation exposure dose values for toddlers and to find out the technique of implementing thoracic radiology examinations on toddlers which produces output in the form of a description of toddler thoracic examinations so that it is hoped that it can provide efforts / suggestions / recommendations so that toddler thoracic examinations in the diagnostic radiology unit of Hospital X provide the lowest possible dose, resulting in recommended efforts in reducing the dose.

This study has independent variables, namely toddler thoracic examination without intervention and thoracic examination with intervention, while the dependent variable is the dose of radiation exposure DAP toddler thoracic examination without intervention and radiation exposure dose with intervention. The control variables are Toddler Age, BB, TB and BMI and Digital Radiography equipment. The population in this study were all toddlers aged 1 to under 5 years who had undergone thoracic examination at the hospital. The sample was toddlers aged 1 to under 5 years who underwent thoracic X-ray examination in the Diagnostic Radiology Unit of Hospital X in examination room one. In this way, it is expected to obtain representative and relevant data for DAP analysis in toddlers.

The data collection technique in this study was through direct observation and observation of how the examination was implemented. Then, interviews were conducted with radiologists, PPRs, and PJ radiology. After that, a Focus Group Discussion (FGD) was conducted with radiographers, Medical Physicists, and PPRs, which is an effective method in qualitative research, especially in a qualitative approach. Then, DAP measurements were conducted on 60 samples. After that, the data were processed statistically using the SPSS application to see a comparison of the DAP results of thoracic radiology that did not undergo intervention with those that did.

4. Results

4.1. Implementation of Toddler Thoracic Examination in the Radiology Installation of Hospital X.

The implementation of thoracic radiology examinations on toddlers at the Radiology Installation of Hospital X is the main focus in ensuring the safety of pediatric patients, the effectiveness of thoracic examinations, and compliance with standard operating procedures (SOPs). This study was conducted through direct observation methods, document review (SOP for Patient Examination Flow, SOP for Toddler Thoracic Examination, and SOP for Result Collection), in-depth interviews with three key informants (radiologists, radiology unit personnel, and radiation protection officers/PPR), and Focus Group Discussion (FGD) with six participants consisting of two radiographers, two medical physicists, and two PPRs.

Interviews with three radiologists, a radiologist (radiographer), and a radiation protection officer (PPR) indicated that the x-ray equipment was in good condition, and the thoracic examination techniques for toddlers had taken into account the principles of radiation dose reduction, such as limiting collimation to the thoracic area only, adjusting the distance between the tube and the patient, and avoiding repeated images. However, positioning toddlers remains a major challenge, given the characteristics of children who are difficult to control, cry easily, and tend to move around a lot. Therefore, cooperation between the radiographer and the patient's companion, usually a parent or family member, is essential to help stabilize the child's position during the examination.

From a patient safety perspective, family support is considered a key strategy for maintaining toddler comfort and stability during the examination. Furthermore, body positioning and radiation protection for caregivers have been implemented. However, inconsistent practices regarding toddler protection, such as the use of lead aprons and gonad shields, have been observed. Some staff routinely use them, while others only occasionally or not at all. This situation highlights the need to strengthen discipline and adherence to radiation safety protocols, particularly for vulnerable age groups.

Procedurally, thoracic examinations in infants generally followed applicable protocols and standard operating procedures (SOPs), demonstrating a good level of understanding and implementation of service standards. While DAP measuring devices were available and installed on radiography equipment, documentation of DAP values was not consistently performed by all staff. Recording DAP values is crucial for monitoring cumulative patient doses and as part of a clinical audit system to improve the quality of radiology services.

Regarding the width of the radiation field, most officers stated that they had adjusted it to the thoracic object being examined. However, inconsistencies were still found in practice, indicating the need for improvement through retraining, regular supervision, and monitoring of the implementation of standard examination techniques. Thus, the implementation of thoracic examinations for toddlers in the Radiology Unit of Heart Hospital X has been carried out systematically, but there are still several technical and procedural aspects that need to be improved to achieve optimal quality of service and safety for pediatric patients.

The following is a table of categorization of interview resource groups with one Radiology Specialist Doctor, one Person in Charge (PJ) of the Radiology Unit, and one Radiation Protection Officer, from the Implementation of thoracic radiology examinations on toddlers at the Radiology Installation of Hospital X:

Table 2. Categorization Table According to Radiology Specialists.

No	Keywords/Sentences	Category
1	Radiology officers must be more competent in handling toddlers. Apart from that, medical physicists must also be careful in carrying out quality control on existing equipment.	The Challenge of Minimizing Radiation Dose
2	Techniques for positioning toddlers properly so they do not move during the examination.	Toddler Thoracic Examination Techniques
3	Efforts made by the officers hmmm toddler to be accompanied by his family for fixation of the toddler.	Safety of Toddler Patients
4	Officers must ensure accurate exposure factors and position the infant correctly during X-ray imaging. Furthermore, officers must be behind a shield or in the operator's area. A protective apron is provided for the infant's companion.	Radiation Protection
5	Special recommendations for radiographers, as they are directly involved in the field, must understand the SOP. Also, staff in the unit must work together solidly in the radiology unit.	Examination Recommendations
6	In order to comply with the DRL value standards on marketed x-ray equipment, the manufacturer must have first carried out tests to comply with government regulations, especially Bapeten regulations.	Bapeten DRL Value
7	The presence of DAP values on the monitor screen at each examination	DAP Value Results
8	Compliance with inspection protocols in accordance with SOP	Thoracic Examination SOP

Tabel 3. Tabel Kategorisasi Menurut Pj. Radiologi.

No	Keywords/Sentences	Category
1	The challenge is always to remind radiologists to limit the size of the examination field.	The Challenge of Minimizing Radiation Dose
2	Techniques used: accuracy in the use of exposure factors, adjusting the area of the examination field according to the thorax object, no repetition.	Toddler Thoracic Examination Techniques
3	Ask the patient's family to accompany the patient during the examination, provide radiation protection equipment to the patient's companion, ensure that the radiology staff complies with the SOP.	Toddler Patient Safety
4	Accuracy in the use of exposure factors and using fast time during the examination.	Radiation Protection
5	Collaborate with other officers in the radiology unit and have to learn a lot more, such as diligently attending seminars in an effort to increase insight.	Examination Recommendations
6	In accordance with BAPETEN DRL values	Bapeten DRL Value

7	The presence of DAP value on the monitor	DAP Value Results
8	Compliance with the implementation of Thorax SOP	Thoracic Examination SOP

Table 4. Categorization Table According to Ppr (Radiation Protection Officer).

No	Kata/Kalimat Kunci	Kategori
1	Remind staff, especially radiographers, to limit the radiation field, particularly the collimation, to a minimum suitable for the toddler's thorax. Remind them to provide additional protective equipment to toddlers.	Challenges in Minimizing Radiation Dose
2	Accuracy in providing exposure factors and the correct positioning of the toddler so that he does not move too much during the examination so that there is no repetition of the examination.	Toddler Thoracic Examination Technique
3	Our usual approach is to ask the patient's family to accompany the toddler during the examination, and the patient's companion, such as the father or mother, also helps the officer keep the toddler focused during the examination. Therefore, collaboration is needed not only among the officers but also with the patient's family.	Toddler Patient Safety
4	During the inspection, the officer must be in the operator's room. Use as little time as possible during the inspection.	Radiation Protection
5	The recommendation is that there should be good cooperation between officers and patient companions.	Examination Recommendations
6	In order to comply with the DRL value standards on marketed x-ray equipment, a test must have been carried out first at the factory to comply with government regulations, especially Bapeten regulations.	Bapeten DRL Value
7	The presence of DAP values on the monitor screen at each examination	DAP Value Results
8	Compliance with inspection protocols in accordance with SOP	Thoracic Examination SOP

Table 5. Summary of categorization table according to radiologist, PJ. Radiology and Radiation Protection Officer.

No	Theme/Category	Subtema/Aspek	Pernyataan Narasumber	Sumber
1	Imaging Techniques and Radiation Dose.	Toddler placement, exposure factor selection, and repetition avoidance.	"Toddlers should be positioned appropriately to minimize movement, to avoid repetition, and to minimize radiation dose."	RADIOLOGIST
2	Efforts to Ensure Patient Safety.	Parental assistance and toddler fixation.	"Toddlers should be accompanied by family members and provided with fixation assistance to help them remain calm during the examination."	PPR
3	Suitability of the Irradiation Field.	Collimation restrictions according to the object.	"The irradiation area must be limited to the infant's thorax, and must not exceed the area being examined."	PJ RADIOLOGI
4	Implementation of SOPs for Infant Thoracic Examination.	Consistent use of SOPs.	"Protocols must be implemented according to applicable SOPs, even if officers sometimes forget or rush."	PJ RADIOLOGI
5	Availability of Dose Area Product (DAP) Measurement Tools.	The device is installed but underutilized.	"The DAP device is available and displayed on the monitor, but not all staff are aware of it or are using it to record doses."	PPR
6	Documentation of DAP Values.	Not performed by radiologists, the responsibility of medical physicists.	“Radiologists don't document DAP because they focus on image interpretation.”	RADIOLOGIST
7	Use of Additional Protective Equipment.	Lead aprons and gonad shields are not being used consistently.	"Protection should be used, but in practice, many people don't use them because they're heavy or not available specifically for toddlers."	PJ RADIOLOGI

Obtained from qualitative research data, which is based on in-depth interviews with interview informants, namely one Radiology Specialist, one Person in Charge (PJ) of the Radiology Unit, and one Radiation Protection Officer. The first step in this process is to reduce the interview transcripts into a more systematic form, namely a categorization table. In this table, the answers from each informant are classified into thematic categories based on the research focus.

This involves several important interrelated components, ranging from examination techniques and patient management for toddlers, implementation of radiation safety protocols, to the use and documentation of dose measurement tools. One of the main concerns is the thorax examination, which considers the principles of radiation dose reduction through collimation adjustments, tube spacing, and minimizing repetition. However, the uncooperative nature of toddlers makes patient positioning a challenge, requiring active support from family caregivers. This process also revealed variations in the use of radiation protection such as lead aprons and gonad shields, which have not been consistently applied by all staff, as seen in the thematic pathway leading to the PPR and radiographer elements.

In addition to technical aspects, the implementation of procedures has generally followed Standard Operating Procedures (SOPs), but obstacles were still found in documenting DAP values. Although DAP equipment is available and installed in the radiography unit, some officers have not recorded this data routinely, potentially hampering the clinical audit process and the evaluation of the patient's cumulative dose. Inconsistencies were also found in the adjustment of the radiation field width that should be appropriate for the thorax object, where some officers admitted to not having implemented it consistently. The interconnection between field findings and the results of interviews with one Radiology Specialist, one Person in Charge (PJ) of the Radiology Unit, and one Radiation Protection Officer indicates the need for increased training, technical supervision, and enforcement of SOP discipline in maintaining the quality and safety of infant radiology services.

4.2. Radiation dose exposure during thorax examination of toddlers in the Radiology Installation

Chest radiography is frequently performed on infants to detect various lung and mediastinal abnormalities, particularly in cases of respiratory disorders. Given that infants are an age group particularly vulnerable to the effects of ionizing radiation due to ongoing tissue growth, radiation dose control is a crucial aspect of this procedure. One quantitative parameter commonly used to assess radiation exposure is the DAP, which combines the radiation dose with the area of exposure. This section presents DAP values obtained from chest radiography in infants and analyzes the distribution of these values. The measurement results will then be compared with standards or references from national and international institutions to assess the safety and efficiency of radiation use in infants. These results are expected to contribute to efforts to optimize radiation protection in pediatric radiology services.

At the Radiology Installation of Hospital X, researchers took a sample of 60 toddlers who underwent thoracic examinations. They were divided into two treatment groups: 30 toddlers without intervention and 30 toddlers with intervention. The treatment in this case is related to the radiation field space on the object being examined. The purpose of this study was to determine the difference in DAP values received by toddlers who did not receive intervention and those who received intervention. The following are the DAP values for toddler thoracic radiology obtained during the author's research.

Table 6. DAP Value of Toddler Thoracic Examination Results No intervention was performed and intervention was performed with BAPETEN DRL Value.

Patient	DAP Non intervensi (µGyxm2)	Nilai DAP non intervensi (mGyxm2)	Pasient	DAP intervensi (µGyxm2)	Nilai DAP intervensi (mGyxm2)	DRL Decision. Head of Bapeten 1211 year 2021 (mGyxm2)	Description
1	8,7	0.0087	1	2,28	0,0028	0,4	The DAP value for chest examinations of toddlers without intervention is greater than the DAP value for chest examinations of toddlers with intervention.
2	6,25	0,00625	2	0,92	0.00092	0,4	
3	8,52	0,00852	3	2.04	0,00204	0,4	
4	2,76	0,00276	4	2.23	0,00223	0,4	
5	3,05	0,00305	5	1,86	0,00186	0,4	
6	4,08	0,00408	6	1,92	0,00192	0,4	
7	4,34	0,00434	7	1,27	0,00127	0,4	
8	6,47	0,00647	8	2,24	0,00224	0,4	
9	4,37	0,00437	9	1,91	0,00191	0,4	
10	3,43	0,00343	10	1,54	0,0054	0,4	
11	4,43	0,00443	11	2,3	0,0023	0,4	

12	2,85	0,00285	12	1,6	0,0016	0,4	The DRL value limited by Bapeten is 0.4.
13	6,98	0,0098	13	2,38	0,00238	0,4	
14	2,81	0,00281	14	1,88	0,00188	0,4	
15	2,74	0,00274	15	2,67	0,00267	0,4	
16	4,26	0,00426	16	2,71	0,00271	0,4	
17	10,2	0,0102	17	2,15	0,00215	0,4	
18	5,34	0,00534	18	1,67	0,00167	0,4	
19	15,42	0.01542	19	1,97	0,00197	0,4	
20	6,36	0,00636	20	2,2	0,0022	0,4	
21	4,35	0,00435	21	2,68	0,00268	0,4	
22	3,11	0,00311	22	1,97	0,00197	0,4	
23	2,94	0,00294	23	2,89	0,00289	0,4	
24	11,48	0,01148	24	2,31	0,00231	0,4	
25	8,71	0,00871	25	1,56	0,00156	0,4	
26	3,33	0,00333	26	2,36	0,00236	0,4	
27	6,18	0,00618	27	1,77	0,00177	0,4	
28	6,15	0,00615	28	2,13	0,00213	0,4	
29	3,15	0,00315	29	2,27	0,00227	0,4	
30	6,38	0,00638	30	0,72	0,00072	0,4	

The results of the DAP values obtained were then analyzed using statistical methods using the SPSS application.

Table 7. Descriptive analysis test

Descriptive Statistics					
Description	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Non intervensi (µGyxm2)	30	2.74	15.42	5.6380	3.00735
DAP no intervensi (mGyxm2)	30	.00274	.01542	.0057320	.00309358
DAP intervensi (µGyxm2)	30	.72	2.89	2.0133	.49550
DAP intervensi (mGyxm2)	30	.00072	.00540	.0021593	.00079381
Valid N (listwise)	30				

From table 7 it can be concluded that these descriptive data provide initial evidence that toddler thoracic radiology with intervention (object-specific collimation) has succeeded in significantly reducing the average radiation exposure and also reducing dose variation between patients, making it safer and more consistent for the toddler population who are sensitive to radiation.

Tabel 8. Paired Sample Statistics.

Paired sample statistics					
		Mean	N	Std Deviation	Std error Mean
Pair 1	DAP Non intervensi (mGyxm2	.0057320	30	,00309358	.00056481
	DAP intervensi (mGyxm2	.0021593	30	.00079381	.00014493

Table 9. Paired Samples T-Test.

Paired Samples Test									
		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	DAP no intervensi (mGyxm2) - DAP intervensi (mGyxm2)	.00357267	.00329824	.00060217	.00234108	.00480425	5.933	29	.000

Based on table 9 Paired sample t-test, it was found that the Paired T-test hypothesis test for DAP in mGy·m² units before and after the intervention, accompanied by the hypothesis formulation, basis for decision making, test results and interpretation.

Table 10. Paired Samples Effect Sizes.

Paired Samples Effect Sizes						
			Standardizera	**Point Estimate**	**95% Confidence Interval**	
					Lower	**Upper**
pair 1	DAP no intervensi (mGyxm2) - DAP intervensi (mGyxm2)	Cohen's d	.00329824	1.083	.624	1.530
		Hedges' correction	.00334167	1.069	.616	1.510

Table 10 shows that the Cohen's d value: 1.083 indicates that the intervention effect is very large, both from a statistical and clinical perspective, thus, thoracic examination of toddlers with intervention treatment on the width of the radiation field has been proven effective in increasing radiation safety in toddler patients.

Interventional treatment for infant thoracic examinations by adjusting the radiation field to suit the target has been statistically and clinically proven to significantly reduce radiation exposure. This demonstrates that simple technical practices based on the ALARA (As Reasonably Achievable) principle have a significant impact on improving infant patient safety.

An analysis of radiation dose exposure during chest examinations of infants indicates that the Radiology Department of Hospital X has systems and procedures in place to support patient safety. However, challenges in technical discipline, limited protective equipment, and suboptimal dose recording are areas of concern that require improvement. Recommendations for improvement include ongoing training for medical personnel, internal audits of procedural compliance, and the integration of a technology-based dose recording system. These steps are expected to strengthen the commitment to radiation safety, particularly for vulnerable populations such as infants.

The implementation of the ALARA (As Low As Reasonably Achievable) principle is key to minimizing radiation doses. Staff actively ensured proper patient positioning, adjusted exposure factors, and short irradiation times to avoid re-exposure. All procedures were performed while wearing personal protective equipment and behind the provided shielding. In terms of dose evaluation, interviews with one Radiology Specialist, one Person in Charge (PJ) of the Radiology Unit, and one Radiation Protection Officer indicated that the radiation dose used was in accordance with the established Diagnostic Reference Level (DRL), as the radiology equipment used had been tested by the manufacturer and met BAPETEN standards. These findings indicate that, despite ongoing technical challenges, the Radiology and Nuclear Cardiology Installation of Heart and Blood Vessel Hospital has systematically implemented measures to support pediatric radiation safety.

5. Discussion

5.1. Implementation of Thoracic Radiology Examination on Toddlers at the Radiology Installation

Chest examinations of infants were conducted at the Radiology Unit of Hospital X while adhering to Standard Operating Procedures (SOPs), but faced various technical and procedural challenges. Based on observations and in-depth interviews, the implementation of chest examinations of infants at the Radiology Unit of Hospital X showed that the work process of officers was quite systematic, starting from patient identification, setting exposure factors, to educating companions. However, several inconsistencies were found in the field, including the use of additional protective equipment such as lead aprons and gonad shields that were not routinely used, and the recording of DAP values that were not yet part of standard practice.

Thoracic radiology examinations on toddlers at the Radiology Unit of Hospital X, using Digital Radiography (DR) equipment with protocols that are essentially in accordance with references in the journals of Hui et al. (2013) and Lee et al. (2021), which emphasize the importance of the ALARA (As Low As Reasonably Achievable) principle. However, in practice, the average DAP before intervention was still at 0.0057 mGy·m² and only decreased to 0.0021 mGy·m² after intervention in the form of collimation adjustments and fixation techniques. This indicates that there is still room for improvement.

The authors agree with Asogwa et al. (2021) that audits and strengthening of SOPs are necessary to ensure safer pediatric radiology practices. Therefore, the authors recommend that the Radiology Installation conduct routine technical training, strengthen supervision of SOP implementation, and ensure the use of additional protective equipment as a mandatory part of chest examination procedures for toddlers. This is crucial not only for reducing radiation doses but also for building a stronger culture of patient safety within the pediatric radiology service environment.

Thoracic examination techniques for toddlers at the Radiology Unit of Hospital X were carried out with a careful approach and comprehensive consideration of radiation safety principles. The use of collimation adapted to the size of the toddler's thoracic area, optimal distance between the tube and the patient, and selection of appropriate exposure factors were the main strategies to reduce the dose received by the patient. This strategy was also strengthened by efforts to minimize image repetition, considering that repetition will increase cumulative radiation exposure. Based on interviews and observations, the implementation of this technique has been quite good, although there is still room for improvement in consistency among staff.

This is consistent with the findings of Karami et al. (2018) who revealed that exposure techniques tailored to the child's age and body size significantly reduced the dose without sacrificing image quality. In this study, tight collimation and the selection of a minimal but sufficient mAs provided reliable diagnostic results at the lowest possible dose. This demonstrates that optimizing thoracic examinations is crucial for implementation in the context of pediatric radiology, especially at national referral hospitals such as RS X.

This is reinforced by research by Pratikno (2022), which states that the use of low-exposure techniques in infant chest examinations not only reduces the risk of long-term radiation effects but also increases service efficiency by speeding up the examination process. Therefore, integrating chest examinations in accordance with international and national standards is crucial to supporting patient safety and the quality of radiology services.

The DAP meter is an important tool in monitoring the amount of radiation received by patients during radiology procedures. In the Radiology Installation of Hospital X, the results of interviews with one Radiology Specialist, one Person in Charge (PJ) of the Radiology Unit, and one Radiation Protection Officer, showed that all radiography units have been equipped with a DAP meter feature, but its use has not been fully maximized by all officers. Although the presence of this tool supports quantitative dose monitoring, there are still officers who ignore its use because it is not a priority or a lack of understanding of the importance of DAP data in radiation protection.

These findings are reinforced by research by Lubis (2020), which revealed that the utilization rate of DAP measuring devices in various hospitals in Indonesia remains low despite their availability, primarily due to their lack of integration with clinical documentation flows. The study also recommends specific training to improve radiographers' and technicians' understanding of DAP functionality, as well as the integration of DAP data into hospital information systems. This is crucial given that DAPs are not only useful for evaluating individual patient doses but also serve as internal audit tools to assess the effectiveness of examination procedures.

Furthermore, a study by Febrianto et al. (2023) also found that the active use of DAP as part of a standard protocol can help establish a more accurate dose baseline, which can then be used for comparison between units or with the national Diagnostic Reference Level (DRL). Therefore, hospital needs to strengthen internal policies and comprehensive education to ensure that the use of DAP devices truly supports pediatric patient safety goals.

5.2. Analysis of Radiation Dose Exposure in Toddler Thoracic Examination at the Radiology Installation

Based on the Paired t-Test, the results showed that the Dose Area Product (DAP) value in toddler thorax examinations decreased significantly after the implementation of interventions (such as the use of fixation aids, imaging technique settings, or operator training). The average difference of 3.62 $\mu Gy \cdot m^2$, with a statistical significance of $p < 0.001$, indicates that the intervention was effective in reducing the radiation dose received by patients. The large effect size (Cohen's $d = 1.174$) confirms that the influence of the intervention on dose reduction is substantial and clinically meaningful.

Research results show that technical interventions (such as the use of fixation aids, optimizing exposure parameters, or training radiographers) are effective in significantly reducing radiation doses. Therefore, hospital management and healthcare institutions need to establish standard operating protocols (SOPs) that mandate the implementation of these interventions, particularly for radiosensitive patients such as infants.

With evidence of a real and significant reduction in DAP doses, regulatory agencies such as BAPETEN and the Ministry of Health can use these findings to update the DRL specifically for the thorax of children/toddlers to be more conservative. Encourage the collection of national data on actual doses as the basis for DRLs based on the Indonesian population and prioritize an evidence-based approach in the development of pediatric radiation protection policies.

Radiation dose exposure during chest examinations of infants is a critical concern in pediatric radiology practice at the Radiology Department of Hospital X. As a patient group with high sensitivity to the biological effects of radiation, infants require a maximally protective approach. This effort is carried out by balancing the need for accurate diagnostics with strict radiation safety principles. Therefore, analysis of procedures, the competence of healthcare personnel, and the implemented protection systems is crucial to ensure that the radiation dose received remains within safe limits and meets standards.

One of the main challenges faced is the technical ability of radiographers in managing often uncooperative toddler patients. Special expertise is required in calming patients, positioning them correctly, and expediting the examination process without compromising image quality. Meanwhile, medical physicists have a significant responsibility in ensuring that radiology equipment undergoes regular quality control to prevent excessive dose exposure.

Collaboration between technical personnel and medical physicists is crucial for effective dose management.

Technically, restricting collimation to the thorax is a key aspect in minimizing unnecessary exposure. However, in the field, challenges remain in implementing radiation limits according to the target anatomy. Staff need to be constantly reminded not to widen the radiation field, as even a small error can result in increased doses to other organs not being examined. Therefore, procedural oversight and technical standardization are crucial to ensure safe and consistent radiology practices. The application of the ALARA (As Low As Reasonably Achievable) principle is the primary guideline in every infant thoracic examination. This principle is reflected in the selection of appropriate exposure parameters, speed of implementation, and the use of protective shielding. In the Radiology Unit of Hospital X, staff are expected not only to understand this principle but also to implement it in real-world situations, including maintaining a working position behind a lead shield during the exposure process. This practice demonstrates a collective awareness of the importance of radiation protection, not only for patients but also for medical personnel.

The use of protective equipment such as lead aprons and gonad shields should be standard procedure, but implementation in the field still faces disciplinary challenges. In some situations, protective equipment is not consistently used by staff or those accompanying infants entering the examination room. This indicates the need to strengthen the radiation safety culture and stricter oversight of procedure implementation. The use of room shielding and additional protective equipment should be encouraged as a non-negotiable part of daily practice to reduce the risk of secondary exposure.

Evaluation of the administered radiation dose refers to the DRL value as the national reference limit. The Radiology Installation of Hospital X stated that the dose used was in accordance with the DRL because the equipment used had been tested by the manufacturer and met the requirements of the Nuclear Energy Regulatory Agency (BAPETEN). However, dose recording through tool features such as DAP still needs to be improved so that dose evaluation can be carried out systematically and objectively. Dose reporting based on actual data will strengthen the quality system and minimize the risk of uncontrolled exposure.

The authors agree that dose analysis based on DAP values is a relevant and important approach, particularly in the context of protecting infants. However, despite the availability of DAP measurement tools, documentation practices are still suboptimal and have not become an integral part of routine work systems. Therefore, recommendations that need to be considered include encouraging integration between DAP tools and digital medical record systems, training staff in the use and recording of dose values, and strengthening internal regulations so that every chest examination is accompanied by dose documentation as part of ongoing service quality audits and protection of infants.

The radiation dose used in thoracic examinations of toddlers at the Radiology Installation of Hospital x, was in accordance with the DRL value. The average DAP value recorded was 0.0021 $mGy \cdot m^2$, which is far below the internationally recommended DRL threshold, which ranges from 0.1 to 0.3 $mGy \cdot m^2$. This indicates that the use of thoracic examination techniques applied at Hospital has followed the principles of optimal radiation protection, with careful selection of exposure factors and effective limitation of the irradiation field.

These findings are reinforced by Karami's (2018) study, which demonstrated that dose evaluation based on DAP is crucial to ensure minimum dose delivery without compromising diagnostic quality. Hospital X's data demonstrates its strong performance in complying with pediatric patient safety standards. This demonstrates that the use of modern radiography technology, combined with appropriate human resource training, can significantly reduce the risk of radiation exposure in pediatric patients.

Research by Darmadipura (2013) in teaching hospitals in Indonesia also found that regular monitoring and documentation of doses strengthened the hospital's ability to maintain doses according to the DRL. Therefore, the success of Hospital X in maintaining low doses is not only a technical achievement, but also reflects a well-structured radiation safety management system.

In practice, minimizing radiation doses during chest examinations in infants faces various challenges. Research shows that unpredictable infant movements, the inability to provide verbal instructions, and time constraints are the main obstacles. Radiographers must be able to position the infant quickly and precisely to complete the examination in a single exposure. Furthermore, some staff members' lack of understanding of child protection principles remains a challenge.

This is in line with findings reported by Syahda et al. (2020), who stated that the main challenge in pediatric radiology examinations is maintaining adequate image quality without significantly increasing dose exposure. In practice, small technical errors such as excessively wide collimation or excessive mAs selection can result in unnecessary dose increases. Therefore, close supervision and ongoing technical training are essential to reduce practice variation among personnel.

Research by Alifa (2023) also underscores the importance of a multidisciplinary approach in addressing these challenges. Collaboration between radiographers, medical physicists, and Radiation Protection Officers (PPRs) needs to be strengthened to ensure that all technical and safety aspects of pediatric patients are addressed holistically. Through effective coordination and regular competency updates, these challenges can be minimized to achieve maximum protection for young patients.

The application of the ALARA (As Low As Reasonably Achievable) principle is an important foundation in the implementation of thoracic examinations of infants in the Radiology Installation of Hospital X. The results of the study showed that most officers have implemented this principle by selecting appropriate exposure parameters, using the shortest possible irradiation time, and efforts to minimize image repetition. In addition, the use of radiation shielding and working positions behind shielding demonstrate compliance with applicable radiation protection standards.

This finding is reinforced by Putri's (2023) study, which stated that the implementation of the ALARA principle in pediatric radiology examinations is highly dependent on a work culture that prioritizes patient safety and the existence of detailed operational procedures. In hospitals with this culture, the risk of excessive radiation exposure in children can be significantly reduced. Therefore, the successful implementation of ALARA at Hospital demonstrates that this principle has become an integral part of daily practice.

Furthermore, research by Yunus et al. (2025) emphasized that effective implementation of the ALARA principle must be supported by regular dose monitoring and internal audits of technical practices. Hospital X, which has equipped its unit with DAP measuring devices and implemented standard operating procedures for examinations, has demonstrated concrete steps in implementing this principle. Going forward, the sustainability of the ALARA principle at Hospital needs to be maintained by strengthening regular training, evaluating procedures, and developing specific guidelines for pediatric radiology.

6. Conclusions

This study used a mixed methods approach, combining quantitative data through statistical tests and qualitative data through in-depth interviews and focus group discussions (FGDs) with medical personnel (radiographers, radiologists, radiologists, and medical physicists) to gain a comprehensive understanding of the implementation of thoracic examinations in infants and efforts to reduce radiation doses as low as possible. Based on the analysis of both approaches, the following conclusions can be drawn: (a). Thoracic examinations of toddlers are carried out by following Standard Operating Procedures (SOP) and basic principles of radiation protection, the arrangement of the collimation area is still not given enough attention, especially thoracic examinations on toddlers that do not match the object. (b). The statistical results of the paired t-test showed that the intervention in the form of collimation technique settings succeeded in significantly reducing the radiation dose from an average value of 0.005732 mGy·m² to 0.002159 mGy·m² (a decrease of around 64%) with a p value = 0.000 and a large effect size (Cohen's d = 1.083), this value proves that the objectives of this study were achieved.

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