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Determination of Pediatric Patient Companion Dose at Thoracic X-Ray Examination

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ABSTRACT

Thorax radiography examination in pediatric patients is one of the most frequent examinations because of many abnormalities that occur in the thorax and have a high probability at children's age. Pediatric patients are assisted by a companion from the adult patient's family. Calculation and measurement of the radiation dose received by the companion are very important as they are in the examination room with the patient during the imaging process. And no matter how small the radiation dose received by the companion, there will be an opportunity for stochastic effect. The Indonesian Nuclear Energy Regulatory Agency regulation Number 4 of the Year 2020 on Radiation Safety in the Use of X-Ray Machines in Diagnostic and Interventional Radiology, regulates the dose received by patient companions must be less than 5 mSv. This study aims to analyze the relationship between the exposure factor and the radiation dose received by the patient's companion. The TLDs used to measure the radiation dose was placed on the companion's chest. The radiation dose was calculated using the Klein-Nishina formula. The results show that the dose received by the companion ranged from 0.39×10^{-5} mSv to 4.64×10^{-5} mSv, which is much lower than the permissible dose.

1. Introduction

The use of ionizing radiation in the form of X-rays in the medical field has been common in medical examinations, including the chest examination for children, due to the number of abnormalities and diseases that occur in the thoracic part has a fairly high probability at the age of children [1]. Then to get good quality Radiograph, the pediatric patient's companion is needed during an examination.

When an X-Ray beam comes to a patient body, there are two kinds of radiation: primary and scattering. Primary radiation consists of photons that have traveled from the X-Ray tube and through the patient without any change of direction, even if the number is reduced. The other is secondary radiation or scattering radiation produced in the body as a result of Compton scattering with random directions irradiating the whole area of the X-Ray room [2]. Some people have the potential to get an effect from scatter radiation, namely radiation workers, communities, and patient companions with certain conditions, for example, in pediatric patients. Pediatric patients who have not been able to be independent in conducting radiography examinations will generally be assisted by a patient's companion who comes from the patient's family and is an adult. The help of a companion or parent of a pediatric patient is very important in positioning the patient and fixation so that the patient's movements during the examination can be minimized.

Calculating and measuring the radiation dose received by the patient companion is very important because the patient companion will be in the examination room with the child patient during the radiation exposure process. The slightest radiation exposure received by the patient's companion can potentially cause stochastic effects on the body, e.g., stimulate cancer and genetic disorders. Therefore, dose monitoring received by the patient companion is also included in the optimization of radiation protection and safety efforts contained in the Indonesian Nuclear Energy Regulatory Agency regulation Number 4 of the Year 2020. In this case, the dose received by the pediatric patient companion should be less than 5 mSv [3]. In the pediatric thoracic x-ray examination, the patient received radiation exposure mainly from primary radiation, which comes directly from the x-ray unit, and the patient's companion arises exposure from scattering radiation due to the patient's position.

Scatter radiation is radiation that arises as a result of X-ray exposure passing through a target object and scattered. The scattered radiation dose is often used as one of the reference quantities of radiation dose limit [4]. The total radiation present at a point can be calculated by the following equation:

$$Stray\ radiation = X-ray\ tube\ leakage + scatter\ radiation \quad (1)$$

Mathematically, the amount of x-ray scatter radiation can be estimated using the Klein-Nishina formula with μSv units, as follows [5]:

$$P(E_\gamma, \theta) = \frac{1}{1 + (E_\gamma/m_e c^2)(1 - \cos\theta)} \quad (2)$$

where; $P(E\gamma,\theta)$ is the estimated total scattered X-ray, $E\gamma$ is the X-ray exposure, θ is the angle between the patient and the detector, $m_e c^2$ is the energy-equivalent of the mass of an electron (511 keV), and c is the speed of light. The exposure $E\gamma$ calculated using Equation 3.

Based on research conducted by Purwantiningsih in 2018, the amount of scatter radiation is influenced by the intensity of radiation exposure in patients [6]. The greater the intensity of radiation exposure to patients, the greater the radiation scattering. Then the hypothesis is formed that the right amount of exposure factors can minimize the dose received by the patient's companion.

Theoretically, radiation exposure can be formulated as follows [2]:

$$E\gamma = \frac{P.V^2.i.t}{d^2} \quad (3)$$

Then the relationship between radiation exposure and the dose of radiation received by the body is as follows:

$$D = f \times E\gamma \quad (4)$$

$$D = f \times \left(\frac{P.V^2.i.t}{d^2}\right) \quad (5)$$

where; $E\gamma$ is the X-ray exposure (mR), P is constants of equality (generally worth 15) [2], V is tube voltage (kV), i is tube current (mA), t is the exposure time (s), d is the distance between focus to an imaging plate (cm), D is radiation dose (rad), and f is the conversion factor from the rate of radiation exposure to the rate of absorption dose (rad/R). For medium air, the value of f is 0.877 rad/R.

In addition, the radiation dose value can also be obtained from measurements with ThermoLuminescent Dosimeter or TLD. TLD has fairly high accuracy and is relatively the same as human body tissues. TLD is also relatively stable in various conditions and has wide linearity to the dose to be measured [7].

The safety of a pediatric patient's companion needs to be considered by the principle regarding radiation protection optimization and safety. This study is titled Determination of Pediatric Patient Companion Dose at Thoracic X-Ray Examination. The selection of thoracic examination is based on the number of abnormalities in the thoracic part and has a fairly high probability at the age of children. Therefore, the patient's companion will play an important role during an examination. The patient's companion dose value will be determined in two ways: directly using TLD and calculation using the Klein-Nishina equation. Hopefully, this research can be used as one of the applications of the principles of radiation protection and safety optimization for pediatric patients' companions.

2. Methods

Tools and materials

The tools and materials used to support this research are the X-ray unit Siemens - Luminus Agile Max, BARC TLD $CaSO_4$:Dy, tapeline, scales, excel, and stationaries.

Research Procedures

1. Selection of Research Case Sample

The technique used to take samples in this study is the technical withdrawal of purposive samples, i.e., by taking samples in a population with parameters by the research to be carried out. The parameters used are examinations that require a companion in pediatric patients on thoracic examination and patient companion following the requirements under the Indonesian Nuclear Energy Regulatory Agency, Regulation Number 4 the Year 2020.

2. Determination of Variation in Exposure Factors

Before determining the variation of factors used, a recording of the age of pediatric patients, as well as height and weight, will then be used to calculate BMI (Body Mass Index) with the following formulation:

$$BMI = \frac{weight\ (kg)}{(height\ (m))^2} \quad (6)$$

The exposure factors used in this study were tube voltage (kV) and tube current time (mAs), with variations in exposure factors using standard voltage [kV] techniques and high voltage [kV] techniques. Based on the reference, the exposure factor in the form of tube voltage in pediatric patients should be below 85 kV so that the parameters of time exposure factors become short. It aims to reduce the chances of position and movement of pediatric patients and reduce radiation doses to patients [8]. Here is the formulation of the high kV technique [9]:

$$(it)_2 = \left(\frac{V_1}{V_2}\right)^4 \times (it)_1 \quad (7)$$

where $(it)_2$ is tube load for high kV techniques (mAs), $(it)_1$ is tube load for standard kV techniques (mAs), V_1 is tube voltage for standard kV techniques (kV), and V_2 is tube voltage for high kV techniques (kV).

3. Measurement of Patient Companion Radiation Dose and Patient Radiation Dose

Before the thoracic examination in pediatric patients, the radiographer will position the patient and companion following the needs of each examination so that the radiation dose received by the patient and the patient's companion can be minimized. The positioning of the patient's companion also applies the principle of heel effect, namely by placing the patient's companion's body part close to the anode [10]. Here is the floor plan for the pediatric patient companion position:

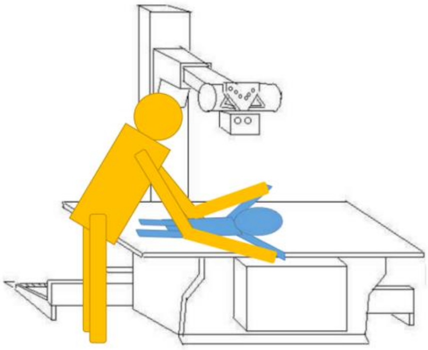

Fig.1: Pediatric patient companion position plan.

At this stage, measurements are taken to determine the relationship between variations in exposure factors to radiation doses received by the pediatric patient's companion. Patient companion dose measurements use TLDs placed on the pediatric patient's chest and at the pediatric patient's companion and are the arm of the pediatric patient.

4. Data Processing and Analysis
Measurable radiation dose data will be recorded in an observation table containing information about the patient's age, BMI, tube voltage, tube load, companion dose, and radiation dose. In addition to the measurement data, the scatter radiation dose will also be calculated using the Klein-Nishina equation. Then the results of these calculations will be analyzed and compared with the results of the measurements.

3. Results and Discussion
Patient Companion's Radiation Dose
1. Dose Measurement Results
Dose measurements in the patient companion used a TLD detector placed on the patient's companion chest at an angle between the radiation source and the detector of 90°, and a Focus Film Distance (FFD) value was 100 cm. The measurements were focused on obtaining a companion dose for the patient that corresponded to field conditions and standard operating procedure (SOP) at Pandan Arang Boyolali Hospital, so the exposure factor used in this study was an exposure factor commonly used for pediatric patients.

Based on the results of dose measurements received by the Patient's companion using TLD, the following results were obtained and shown in table 1 and table 2. Therefore, the Patient's companion doses were very low and equal to zero due to lower than the detection limit of TLD, namely less than 5 mSv as the maximum permissible dose for pediatric Patient's companion and pediatric patient doses were also low both for standard voltage [kV] and high voltage [kV] techniques.

Table 1. Dose measurement results for standard kV techniques.

No.	Patient Age (year)	Patient BMI	Patient Companion Age (year)	Patient Companion BMI	Tube Voltage (kV)	Tube Load (mAs)	Patient Companion Dose (mSv)	Patient Equivalent Dose (mSv)
1	2,5	19,4	38	22,1	58,50	8,05	0,00	0,084 ± 10%
2	10	25,2	47	25,2	49,90	5,01	0,00	0,107 ± 7%
3	4	19,8	41	18,7	45,80	2,51	0,00	0,025 ± 11%

Table 2. Dose measurement results for high kV techniques.

No.	Patient Age (year)	Patient BMI	Patient Companion Age (year)	Patient Companion BMI	Tube Voltage (kV)	Tube Load (mAs)	Patient Companion Dose (mSv)	Patient Equivalent Dose (mSv)
1	5	20,7	34	21,4	82,80	2,01	0,00	0,117 ± 9%
2	7	17,5	41	23,7	74,80	1,02	0,00	0,070 ± 12%
3	5	19,8	43	19,5	67,80	0,51	0,00	0,00

*) Description: A value of 0.00 mSv means that the dose value received by the patient's companion is smaller than the measurable radiation dose limit using a TLD of 0.003 mSv on a 40 kV calibration curve, 0.004 mSv on an X-ray calibration curve of 60 kV, 0.007 mSv on an X-ray calibration curve of 80 kV and 0.011 mSv on a 100 kV X-ray calibration curve.

2. Dose Calculation Results
Based on the results of the X-ray unit conformity test conducted on February 3, 2021, it was known that the leak of the X-ray unit tube was 0.00 mGy or 0.00 mSv. Mathematically, the amount of scatter radiation can be estimated using the Klien-Nishina formula. The Klein-Nishina scattering equation is based on the Dirac equation [11]. The dose calculation results show in Tables 3 and 4. The dose calculation results for the patient's companion were also very low in the order of (mSv). Therefore, it was consistent with the measurement results.

Table 3: Dose calculation results for standard kV techniques

No.	Patient Age (year)	Patient BMI	Patient Companion Age (year)	Patient Companion BMI	Tube Voltage (kV)	Tube Load (mAs)	Patient Companion Dose ($\times 10^{-5}$mSv)
1	2,5	19,4	38	22,1	58,50	8,05	4,64
2	10	25,2	47	25,2	49,90	5,01	2,10
3	4	19,8	41	18,7	45,80	2,51	0,89
Average					51,40	5,19	2,55
Standard Deviation					6,48	2,77	1,92

Table 4: Dose calculation results for high kV techniques

No.	Patient Age (year)	Patient BMI	Patient Companion Age (year)	Patient Companion BMI	Tube Voltage (kV)	Tube Load (mAs)	Patient Companion Dose ($\times 10^{-5}$mSv)
1	5	20,7	34	21,4	82,80	2,01	2,32
2	7	17,5	41	23,7	74,80	1,02	0,96
3	5	19,8	43	19,5	67,80	0,51	0,39
Average					75,13	1,18	1,23
Standard Deviation					7,51	0,76	0,99

3. Reduction Percentage of Patient Companion Dose for Standard kV Techniques Compared to High kV Techniques

Percentage of dose reduction using the patient's companion dose of the calculation results, with the following equation:

$$\text{Reduced Percentage Dose} = \frac{\text{standard kV techniques dose} - \text{high kV techniques dose}}{\text{standard kV techniques dose}} \, x \, 100\,\% \quad (8)$$

Based on table 3 and 4, patient's companion doses with high voltage [kV] technique lower than the standard voltage [kV] technique, and using the above equation, it could be known that the use of high kV techniques in pediatric thoracic ordering that requires a companion, can be reduced the companion dose starting from 49.98% to 55.47%.

Relationship between Variations in Exposure Factors to Radiation Doses in Patient's Companion

The relationship between variations in exposure factors to radiation doses in a patient's companion could be known in several ways, including simple ways using graphs. Mathematically based on radiation exposure equations comparable to the patient's companion dose, the exposure factor in the form of tube voltage and tube load (kV^2.mAs) has a linear relationship with the patient's companion dose [2,9].

$$D \sim V^2 \times i \times t \quad (9)$$

Based on the Graphs in Fig 2 results of the dose measurements and calculation, a correlation coefficient value of exposure factor variation in the form of tube voltage to the patient's companion dose was 1,000. The value of the positive correlation coefficient indicates that the relationship between the two variables was unidirectional, so if the exposure factor in the form of tube voltage and tube load increased, the scattered dose would be increased, and vice versa. Tube voltage becomes the exposure factor that most affects the patient's companion dose because the relationship between dose and voltage was quadratic in mathematical equations, and the others were linear. Therefore, when the tube voltage slightly increased, the dose of the patient companion increased significantly.

After knowing there was a relationship between the exposure factor and the dose received by the patient's companion, the next is to look for the relationship between both study variables using graphs. Here is the relationship of variation in exposure factors V^2xit (kV^2.mAs) to the patient's companion dose (mSv).

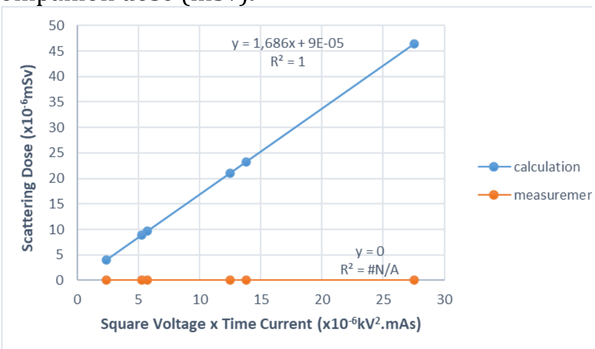

Fig.2: Graph of the relationship between the variation of exposure factors and patient's companion dose.

Based on the graph above, the results of the relationship between variations in exposure factors to the patient's companion dose as follows:

$$y = (1{,}686 \times 10^{-9})x + 9 \times 10^{-11} \quad (10)$$

where; y is patient companion dose (mSv) and x is expose factor V^2xit (kV^2.mAs).

The pediatric patient companion was not given radiation protection at the study site, especially during the thoracic examination. Based on the results of radiation dose measurements received by the patient companion with various variations in exposure factors, the result of 0.00 mSv due to the dose value received by the patient companion was smaller than the radiation dose detection limit that can be measured using TLD. While in the results of calculations with various variations of exposure factors obtained dose results that ranged from 0.39×10^{-5} mSv to 4.64×10^{-5} mSv. The radiation dose received by the pediatric patient's companion, especially on thoracic examination, was much lower than the maximum permissible dose threshold by the Indonesian Nuclear Energy Regulatory Agency, Regulation Number 4 the year 2020 on Radiation Safety in The Use of X-Ray Machine in Diagnostic Interventional Radiology, even without the use of radiation protection equipment. These studies' results were compared with Kim et al.'s work for x-ray irradiation doses between 0.52 ± 0.08 to 46.74 ± 11.22 μSv [12]. Based on research conducted by Farzanegan et al. in 2020 in five teaching hospitals, out of 26 examination samples, only 1 radiography examination using radiation protection equipment [13].

4. Conclusion

The dose measurements result received by the pediatric patient's companion on thoracic examination shown by the TLD reader are 0 mSv on all variations exposure factors value used for this study due to smaller than the dose detection limit of TLD. While the dose calculation results using the Klein-Nishina equation were received by the pediatric patient's companion on thoracic examination, starting from 0.39×10^{-5} mSv to 4.64×10^{-5} mSv.

Based on the graph and Pearson correlation tests, the relationship between exposure factors V^2xit (kV^2.mAs) and patient companion dose (mSv) in the high kV technique was linear as $y = (1{,}686 \times 10^{-9})x + 9 \times 10^{-11}$ strongly related.

5. Conflict of Interest

The authors declare that they have no conflict of interest.

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