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Evaluation of diagnostic reference levels (DRL) in pediatric appendicogram examination for radiation safety improvement

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Abstract. Appendicogram examination usually uses fluoroscopy that can increase radiation exposure, especially in children who are more sensitive to the long-term effects of radiation. This study aims to evaluate the effectiveness of applying radiation protection principles to pediatric appendicograms using computed radiography (CR), as well as assess the suitability of exposure parameters with international reference dose limits.This study used a mixed methods design combining qualitative and quantitative research. The study was conducted using parameters of 60 kVp, 20 mAs, 100 cm FFD. The dose values evaluated included ESD, DAP, and ED, which were compared with DRL from BAPETEN, ICRP and European Commission PiDRL. The results showed an average ESD of 2.09 mGy, DAP of 0.31 Gy·cm², and ED of 0.046 mSv. 2,089 mGy, which is still within the reference range set by BAPETEN 2-3 mGy for pediatric abdominal examinations.The radiologist's assessment of the visualization of the anatomy indicated that the diagnostic images produced were sufficient to establish a diagnosis on an appendicogram examination.Pediatric appendicogram examination using CR without fluoroscopy with the applied parameters results in a low radiation dose within the DRL limits, with good diagnostic image quality. Optimization is still needed, particularly with reduced mAs to support the ALARA principles.

1 Introduction

Acute appendicitis can also occur in preschool children aged 3-6 years, in Southeast Asia, Indonesia ranks first with the highest incidence of acute appendicitis, namely 0.05%, followed by the Philippines at 0.022% and Vietnam at 0.02%. The prevalence of acute appendicitis in Indonesia is around 24.9 cases per 10,000 population [1]. This examination is

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usually carried out with fluoroscopy or radiography which provides direct radiation exposure to the abdominal area, an appendicogram itself is a radiological examination of the gastrointestinal system, specifically on the appendix organ using contrast media, the advantages of an appendicogram are that it can measure the length of the appendix, show the presence of classification (other indications), show fluid levels in the cecum and terminal ileum, increased soft tissue density in the lower right quadrant, fecalith in the right iliac fossa, air filling the appendix, and intraperitoneal gas using barium sulfate (BaSO4) contrast media dissolved in water and administered orally, this examination is a radiological examination that shows the terminal ileum and ileocecal areas with the help of a fluoroscopy x-ray machine and is equipped with a compression aid that functions to expand the surface of the organs in the ileocecal area [2], although it provides high diagnostic value, the use of ionizing radiation is not free from biological risks, especially in the pediatric population Children have a higher sensitivity to the effects of radiation than adults. This is due to two main factors, namely a faster rate of cell division and a longer life expectancy, so that long-term effects of radiation exposure, such as cancer, have a greater chance of appearing. Based on a report from the International Commission on Radiological Protection (ICRP), the risk of developing cancer due to radiation in children can reach 2–3 times higher than in adults for the same dose, in this condition, it is important to ensure that the radiation dose given is within safe limits and in accordance with the principles of radioprotection, especially the ALARA principle (As Low As Reasonably Achievable), however, in clinical practice, the application of radiation protection in children still faces various challenges, such as the lack of specific pediatric protocols, the use of technical parameters that are not adapted to the child's body size, and the limited availability of appropriate protective equipment [3-4]. Previous studies have shown that the effective dose of fluoroscopy in pediatric hospitals ranges from 0.001mSv to 0.44mSv, with a DAP to effective dose conversion of 0.04 to 2.48mSv/Gy·cm² (number 5), another study recorded the screening duration, DAP, and effective dose of 90 pediatric MBS examinations. The mean effective dose was 0.0826mSv, the average screening duration was 2.48 minutes, and the DAP was 28.79cGy·cm². The effective dose varied by age group: ≤1 year: 0.1188mSv; 1–3 years: 0.0651mSv; >3 years: 0.0529mSv [4]. Dose recordings from several studies state that it does not exceed the limit, but there has been no research on radiation protection in appendicography examinations without using fluoroscopy so that research is still needed by paying attention to the importance of radiation protection in appendicogram examinations. Research needs to be carried out with the aim of assessing the effectiveness of applying the principles of radiation protection in appendicogram examinations in children, as well as providing recommendations for optimal parameters to minimize radiation doses.

2 Method

This study uses a research design that combines qualitative and quantitative research or commonly called mixed methods. This study began with the preparation of observation instruments, interview guidelines, and the collection of literature related to radiation protection and pediatric appendicogram examinations, the objects of the study were pediatric appendicogram examination techniques, radiographers and radiologists in one of the hospitals in Central Java with the inclusion criteria for this study sample being children aged 5-10 years, the criteria for this research object are pediatric patients with a diagnosis of appendicogram. The implementation of this study began with direct observation of the pediatric appendicogram examination process, interviews with 3 radiology specialists and 9 radiographers with the aim of gathering in-depth information regarding the radiation protection applied and the appendicogram examination technique and reviewing hospital documents/SOPs which functioned to add other information regarding the implementation of examinations and radiation protection in accordance with the agreements contained in the SOP, this study only conducted 2 interviews with each informant followed by the calculation of effective doses and ESD using 30 samples from pediatric appendicogram examinations to determine the DRL in pediatric abdominal organs. This data analysis uses SPSS and was carried out by processing data from observations, interviews, and calculations of effective doses and ESD to determine the DRL value. the average value of Entrance Surface Dose (ESD) is calculated using the formula:

a. ESD (mGy) = Output × mAs × $(100 / FFD)^2$ × BSF
b. BSF = 1.35 (radiographic abdominal examination; with a range of 1.30–1.40)
c. DAP = ESD/1000 x area (cm^2)
d. k = 0.15mSv/Gy.cm^2 k value that is often used in pediatric abdominal examinations is around 0.15mGy/Gy.cm2 in pediatric abdominal examinations)

3 Results and Disscusion

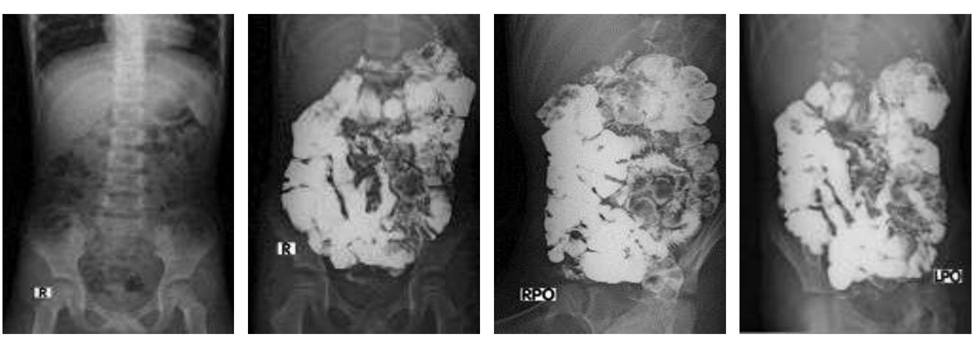
3.1 Result

3.1.1 Evaluation of the effectiveness of applying radiation protection principles to pediatric appendicogram examinations.

Table 1. Summary of interview results in the application of the ALARA principle

Radiation Protection Principles	Radiology specialist	Radiographer
Justification	Appendicogram examination without fluoroscopy can be performed by attention examination request according to the doctor.	Ensure that examination requests are in accordance with the clinical indications requested by the doctor.
Optimization	Monitoring implementation of the ALARA principle by radiographers, exposure factors are adjusted to pediatric patients.	Use of 60 kVp, 20 mAs and FFD 100 cm, collimation with adjustment to the pediatric patients and no radiation protection equipment
Dose Limitation	Review each test request to ensure minimal dose in pediatrics.	Radiographers minimize the repetition of projections during appendicogram examinations, the radiographer has carried out patient dose monitoring and environmental surveillance..

The principle of justification for pediatric appendicogram examination with conventional x-ray machine without fluoroscopy is one of the alternatives that can be done if the hospital does not have a fluoroscopy machine to support the appendicogram examination, the radiologist explained that the appendicography examination is carried out if there is a request from the referring doctor that is in accordance with clinical indications by prioritizing the urgency of the examination in supporting the further action that will be given to the patient. This aims to ensure that the examination is truly necessary and the benefits obtained are greater than the radiation risk received by the patient, especially pediatrics, radiographers also agree with this, namely ensuring that the examination request is in accordance with the medical indications of the referring doctor, thus, both radiologists and radiographers play a role in ensuring that each examination has a strong clinical reason, so that radiation exposure is not given in vain. The application of optimization aspects, radiologists play a role by monitoring the application of the ALARA (As Low As Reasonably Achievable) principle carried out by radiographers. The exposure factor used must be adjusted to the condition of the pediatric patient so that the quality of the radiograph is optimal by paying attention to excessive radiation doses. The radiographer stated that the use of exposure techniques in pediatrics with an age range of 5-10 years in the usual appendicogram examination uses an exposure factor of 60 kVp and 20 mAs and an FFD of 100 cm, then adjusted to the child's body size, in addition, collimation is carefully considered so that the irradiation area only affects the relevant organs, so that the dose received by the surrounding tissue can be minimized, however, the radiographer acknowledged that PPE (Personal Protective Equipment) such as gonad shields or lead aprons were not used during this appendicogram examination (this is shown in table 1), so that it is an important note for the evaluation of radiation protection in children, while on the principle of dose limitation, the radiologist emphasized the importance of reviewing the examination request before it is approved, so that pediatric patients only receive the minimum radiation dose that is truly needed. The radiographer explained that they try to minimize repeat examinations by retaking certain projections of the appendicogram examination, because each repetition has the potential to increase the patient's dose. In addition, the radiographer also mentioned the existence of periodic patient dose monitoring and environmental monitoring as part of efforts to control radiation exposure. This shows that there is attention to patient safety as well as the safety of staff and the work environment.



(a) (b) (c) (d)

Fig.1. (a) AP projection.(b) AP projection with barium enema.(c) RPO with barium enema.(d) LPO projection with barium enema

Description:
AP: Antero Posterior

RPO: Right Posterior Oblique
LPO: Left Posterior Oblique

Table 2. Radiographic image assessment of appendicogram examination

Anatomical Structure	Average score	Explanation
Small intestine	3	All radiographs show the small intestine has good and clear contrast.
Caecum	3	Appears firm, distinguishable from surrounding structures.
Colon ascendens	2.9	The majority are clear, some samples are quite clear but still interpretable.
Appendix	2.8	It is clearly visible in almost all samples, especially in projections with contrast.
Contrast filling of the appendix	2.9	Contrast can be assessed well and consistently in most samples..

Description:
Radiographic image grading scale [5]
Score 3:Anatomical structures are clearly visible, with clear boundaries, and optimal contrast, sufficient for diagnostic interpretation.
Score 2:Fairly clear → Structures can still be identified, although there are limitations (poor sharpness, uneven contrast, or overlapping), and can be used for interpretation.
Score 1 :Unclear → Structures are difficult to identify, with indistinct boundaries, poor contrast, or interfering artifacts, and inadequate for diagnostic interpretation.

For the AP projection before contrast, we see if there are stones, whether it costs a lot, or whether the patient has ileus, that can be evaluated. Then the AP contrast sees the median contrast entering the appendix seen from the front. Then the RPO LPO we see the appendix seen from slightly to the right and slightly to the left so that the position, for example, from the AP, it is not visible, this superposition of the cecum, then we look at it from the right oblique, can it be seen? Wow, the right oblique, for example, is still superposed with the cecum, we look at it from the oblique to the left to clarify (I/Radiographer).

Judging by the radiologist's evaluation, on average, three projections are sufficient to establish a diagnosis. The goal is to reduce the radiation dose. The AP pre-contrast is to assess the patient's preparation. Then, the AP post-contrast, with a time of 4-5 hours, is to determine whether the ingested contrast medium has reached or filled the appendix. The RPO projection is used to assess the anatomical tilt of the appendix from the right oblique side. The LPO projection, tilted to the left, is used to assess whether the appendicogram can be seen from the side. Therefore, assessing the size of the appendix, if visible in these projections, can confirm the diagnosis of appendicitis based on its size and diameter (I/Radiographer).

The most common information we obtain from an AP plain abdomen is an appendicolith, the presence or absence of vecaloding. We can see whether the patient has an ileus, for example, in cases of high ileus or small bowl obstruction. In cases of appendicitis, if the appendix is already visible, it can cause obstruction, leading to SBO (small bowl obstruction). Then, a plain abdominal radiograph is also used to check for pneumoperitoneum. Post-contrast imaging is used to determine whether the contrast fills the appendiceal lumen, and it's best performed under compression. A RPO is automatic, as the appendix is located on the right side. In theory, it's more clearly visible with an RPO, as the organ we're looking for on the film will provide a more accurate image. However, sometimes, not all patients have a retrocecal appendix, so we need a different projection. In an RPO, the cecum and part of the sigmoid colon sometimes overlap; if it's made obliquely, it will superimpose on the cecum. Therefore, precise timing is crucial. So, sometimes it is not visible at all from the RPO because it is overlapping, so an LPO is needed (I/Radiologist).

The results of the radiograph examination of the appendicogram using the exposure factor parameters of 60 kVp, 20 mAs and FFD 100 cm with a cassette measuring 35 x 35 cm and using a CR plane using a grid produced several images including AP projections with and without contrast, RPO and LPO, from the four radiographs on 30 samples that have been taken, an assessment of image clarity was carried out by 3 radiology specialists who referred to the anatomical accuracy of the examination by conducting a visual assessment of several organs including the small intestine, cecum, ascending colon, and transverse colon, appendix, contrast filling in the appendix, it was found that the assessment of each small intestine anatomy was clearly visible by producing good contrast, without excessive overlapping that obscured anatomical details, the cecum was seen well, the anatomical boundaries appeared firm and could be distinguished from the surrounding structures, the ascending colon was seen with optimal contrast, the intestinal lumen contour was clear, without any artifact images that interfered with the assessment, the appendix was clearly visible in the filling of contrast media so that the appendix lumen could be identified well and could show the anatomical position clearly without overlapping with the cecum so that it was clearly visible. Optimal. Overall, the radiologist's assessment of the four radiograph projections provided clear visualization of the anatomy of the appendix and surrounding organs, with optimal image sharpness for establishing a diagnosis (this is shown in table 2)

3.1.2 Parameters in appendicogram examination

Table 3. Parameters in appendicogram examination

Component	Detail
kVp	60 kVp
mAs	20 mAs
Focus Film Distance (FFD)	100 cm
Collimation	According to the inspection area
Tube output	0.08mGy
BSF	1.35
Projections	AP with and without barium enema, RPO,dan LPO

Explanation:
AP: *Antero Posterior*
RPO: *Right Posterior Oblique*
LPO: *Left Posterior Oblique*

Table 4. Calculation of 30 DRL value data from pediatric (5-10 years) appendicogram examination

Metric	Mean	Median	SD	Min	Max	DRL (75^{TH} Percentile)
ESD(mGy)	2.098	2.083	0.138	1.84	2.381	2.192
DAP(Gy.cm^2)	0.31	0.31	0.02	0.27	0.35	0.32

Metric	Mean	Median	SD	Min	Max	DRL (75^{TH} Percentile)
Effective dose(mSv)	0.0465	0.0465	0.0029	0.0405	0.0525	**0.0480**

Table 4 shows the pediatric appendicogram examination in one of the Central Java hospitals using several examination projections including Antero Posterior (AP) non-contrast, Antero Posterior (AP) with contrast, Right Posterior Oblique (RPO) post-contrast and Left Posterior Oblique (LPO) using an exposure factor of 60 kVp, 20 mAs, FFD 100 cm, 35 x 35 cm cassette without grid with CR plane, collimation is adjusted according to the object being examined, the protocol used is always the same in each projection and patient (30 patients). Table 1.3 is a calculation of ESD, DAP and effective dose to determine the DRL produced in pediatric appendicogram examination, where this data is known appendicogram examination using 30 pediatric samples in the age range of 5-10 years.

ESD (mGy) = 008mGy x 20 x $(100/100)^2$ x 1.35 = 2.16mGy

Effective dose$_{(DRL)}$ = 0.32 x 0.15 = 0.048mSv

The calculation was repeated until the 30th sample obtained an average ESD value of 2,098 mGy where the DRL was 2,192 mGy, meaning that 75% of patients received a dose of ≤ 2,192 mGy, the Dose Area Product (DAP) average value was 0.310 Gy·cm² with a DRL of 0.320 Gy·cm², DAP shows the total radiation energy to the patient's body, this value is relatively consistent (small SD = 0.020), indicating a stable protocol, the average Effective Dose was 0.0465 mSv with a DRL of 0.048 mSv.

3.2 Discussion

3.2.1 Evaluation of the effectiveness of applying radiation protection principles to pediatric appendicogram examinations.

This study shows that pediatric appendicogram examination without using a fluoroscopy machine can be carried out well by paying attention to the parameters used during the examination, namely by using 60 kVp, 20 mAs and FFD 100 cm (table 3) using a 35 x 35 cassette and a CR machine, where this examination begins with the insertion of a barium enema into the patient's body to visualize whether the appendix is filled or not. The use of these parameters is adjusted to pediatric examinations where in pediatric patients the cells in the body are still actively dividing so that the parameters used use low mAs where 60 kVp is used which is still in the kVp range recommended by previous research on pediatric abdominal examinations in the age range of 6-12 years having a kVp range of 60-75 kVp and 5-8 mAs with FFD 100 cm besides that this study used 20 mAs where this value is still considered too high in pediatric abdominal examinations where several previous studies stated that in pediatric abdominal examinations with an age range of 5-10 years using 3-8 mAs is still good in obtaining diagnostic image quality of abdominal examinations, in contrast to BAPETEN which does not provide direct limits on the mAs value but provides a reference ESD (Entrance Surface Dose) of 2-3 mGy for pediatric abdomen, this value is equivalent to the use of low mAs (4-7) at 65-70 kVp for children aged 5-10 years. The use of low mAs will affect the duration of the x-rays produced, low mAs can reduce the dose received by the patient. Increasing the mAs will increase the number of photons produced, so the ESD also increases, as long as kVp and other conditions remain constant.

The use of 20 mAs in this study compared to previous studies is quite large, so the ESD calculation is necessary in this study, which can be seen in table 4 with an ESD value of 2,089 mGy, which is still within the reference range set by BAPETEN 2-3 mGy for pediatric abdominal examinations [6]. This study uses CR where sufficient time is needed to see the movement of contrast media filling the appendix, in contrast to other studies where this examination usually uses an x-ray machine equipped with fluoroscopy which aims to determine the movement of contrast media in real time towards the patient's appendix, several studies state that pediatric appendicogram examination can reduce the radiation dose received by patients where dose reduction with real-time depiction of contrast media filling does not require a long time, minimizing the repetition of image capture due to unclearness in taking radiograph images [7]. Anatomical image assessment is one of the important assessments in determining the evaluation of parameters used in pediatric appendicogram examination so that it can provide an accurate diagnosis. The parameters used in the study can be seen that the resulting anatomy has provided clear information by looking at the assessment of several anatomy by a radiologist including the small intestine, cecum, ascending colon, and transverse appendix. Overall, the radiologist's assessment of the four radiograph projections is able to provide clear visualization of the anatomy of the appendix and surrounding organs, with optimal image sharpness in making a diagnosis. The radiologist will assess the sharpness of organ boundaries, bowel contrast, and the visibility of fine structures (e.g., gas in the small intestine, the contour of the cecum, or the diaphragmatic margin). If structures are poorly visible, the radiologist can recommend adjustments to the technical factors (kVp, mAs, FFD) to the radiographer [8-9].

3.2.2 Analysis of parameter usage in appendicogram examination

Pediatric appaendicogram examination parameters that have been carried out routinely by paying attention to several examination parameters including using an exposure factor of 60 kVp, 20 mAs, FFD 100 cm and using a 35 x 35 cm cassette with Antero Posterior (AP) projections without and with contrast, RPO (Right Posterior Oblique) and LPO (Left Posterior Oblique) using the four projections produced an average ESD on the CR plane with a value of 2.09 mGy with a DRL of 2.19 mGy having an international limit of 2-3 mGy, DAP with a mean of 2,098 mGy with a DRL of 2.19 mGy based on ICRP [10], European Commission PiDRL [19], and the IAEA RPOP report. Pediatric abdominal ESD with an age range of 5-10 years is in the range of 2-3 mGy, it can be said that the ESD value in this study is still within the normal range according to the European Commission PiDRL provisions. DAP in this study showed a mean value of 0.31 Gy.cm2 with a DRL value of 0.32 mGy using a CR machine on an appendicogram examination still within the standard range set by the ICRP. Pediatric abdominal DAP is in the range of 0.3 – 0.6 Gy.cm² depending on age and the size of the field of colitis while in the same examination but using a different machine, namely with a fluoroscopy machine, the median DAP value was 0.38 Gy.cm2 [10], [11]. DAP shows the total radiation energy to the patient's body where this value directly indicates the amount of radiation received by the patient where the higher the DAP, the greater the potential effective dose and radiation risk. If the average DAP in an x-ray machine exceeds the DRL, it can be said that the parameters used mean that patients in the hospital receive more radiation on average than the internationally established reference standards, so there needs to be an evaluation of the parameters used because pediatric patients have high radiation sensitivity compared to adults, in addition to the DRL used as a reference (for example, the 75th percentile of dose values) but does not define the specific technique exposure value kVp/mAs for each type of examination (especially pediatric abdomen) [11-13], Effective dose with an average of 0.046mSv and a DRL value of 0.046mSv. Effective dose pediatric abdomen: ranges from 0.05 – 0.15 mSv. Effective Dose (ED) is an estimate of the health risk from radiation, calculated by taking into account tissue sensitivity, if the ED value is higher than the DRL it can be said that the patient's received dose is higher so that optimization of exposure factors such as kVp, mAs and columization settings is required, however if the ED is lower than the DRL it can be said that the parameters used are good in the application of radiation protection that needs to be considered, namely the dose reduction should not be too significant to cause a reduction in the quality of the diagnostic image, in principle the dose should be as low as possible while maintaining consistent optimal diagnostic image quality (ALARA + ALADA = as low as diagnostically acceptable) [13-15]. The ESD, DAP, and Effective Dose values in this study are within or even lower than the international DRL, but it is necessary to pay attention to the occurrence of underexposure where this condition can result in adverse effects including increased noise which causes reduced anatomical detail, non-optimal contrast which makes it difficult to distinguish soft tissue, bones and small organs such as appendix and gas that cannot be seen clearly some of these conditions can cause fatal errors in interpreting radiographs by radiologists which allows for misdiagnosis and repeated examinations by radiographers. Repeated image capture can be detrimental to patients, especially pediatric patients because it can increase the patient's dose where the body's cells are still actively dividing and still in the growth phase so that it can be said to be contrary to the ALARA principle, from this study it can be said that if underexposed radiographs are not safer because they can violate the optimization principle in ALARA, namely low doses but have image quality that remains optimal in producing diagnostic images where repeated photos result in higher doses. This study also obtained information that radiation protection was good, indicated by the low dose produced but still produced optimal diagnostic images, using exposure factor parameters (60 kVp, 20 mAs, FFD 100 cm) and collimation adjusted according to the area of the object being examined. Local DRL (75th P = 2,192 mGy and 0.32 Gy·cm^2) can be used as a reference for hospitals as a dose limit that can be applied to pediatric appendicogram examinations and if in certain cases there are examinations with average values exceeding this limit, it can be used as a reference for hospitals as a dose limit that can be applied to pediatric appendicogram examinations and if in certain cases there are examinations with average values exceeding this limit, it can be used as a reference for hospitals as a dose limit that can be applied to pediatric appendicogram examinations.

4 Conclusion

Pediatric appendicogram examination using 60 kVp, 20 mAs, and a 100 cm FFD using CR produced doses (ESD, DAP, ED) within the international DRL limits, with good diagnostic image quality. Despite the relatively high mAs used, the patient dose remained safe. However, further optimization is recommended to reduce the mAs to reduce the patient dose without compromising image quality. Overall, the application of radiation protection principles in this study was effective and can be used as a basis for local DRL implementation as a reference for pediatric patient safety.

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