Optimization of simulated cranial, thorax, and abdominal examination in paediatric digital radiography

N N Apriliastri\(^1\), Samiyah\(^1\), S Bawono\(^2\), A Susilo\(^2\), L E Lubis\(^1\), A Evianti\(^2\) and D S Soejoko\(^1\)

\(^1\)Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok, West Java, 16424, Indonesia
\(^2\)Department of Radiology, Harapan Kita Maternal and Children’s Hospital, Jakarta, 11420, Indonesia

E-mail: lukmanda.evan@sci.ui.ac.id

Abstract. This study was aimed to obtain optimum parameter combination in simulated cranial, thorax, and abdominal examinations using computed radiography (CR) and direct digital radiography (DDR) systems. Optimization was performed using in-house phantom with contrast objects on Siemens Luminos Agile Max DDR and Siemens Axiom Luminos TF CR. Paediatric patients were separated into four age groups; 0-1 year (group A), 1-5 years (group B), 5-10 years (group C), and 10-15 years (group D). Slab phantoms with different total thickness were used to simulate patients belonging to each age group for different anatomical region (cranial, thorax, and abdomen). Optimization were performed in three steps; first kVp, followed by mAs, and then additional filter optimization. All the steps of optimization were performed based on FOM (figure of merit) values calculated as ratio of squared SDNR (signal difference to noise ratio) and entrance surface dose with the highest FOM representing the optimum condition. The results of this optimization were evaluated based on the highest FOM generated from each exposure. For both CR and DDR, optimum parameters (i.e. highest FOM) are different for each age group and anatomical region. Even with different X-Ray units, the CR device had slightly similar optimized parameters.

1. Introduction

Radiological imaging has undergone rapid development in medical diagnosis and treatment. The existence of digital radiography, such as computed radiography (CR) and direct digital radiography (DDR), has reduced the use of screen-film in conventional radiography. By using imaging plate in CR and FPD in DDR, the imaging chain becomes shorter and it allows images to be processed right after exposure.

Diagnostic radiology examination provides information about the diagnosis of a disorder or disease in a patient. This examination presents its own challenges, especially in paediatric patients. This is because on the one hand, paediatric anatomy only displays a slight contrast due to imperfect bone development. On the other hand, paediatric is more radiosensitive than adults because their cells divide faster\([1–3]\). Therefore, dose delivery to paediatric patients must be kept minimum without reducing the image quality. In this regard, it is necessary to optimize digital x-ray imaging system using CR and DDR for paediatric patients. This is performed to ensure that radiation provides image with adequate quality to establish the diagnosis and that radiation dose received is as low as possible according to the ALARA
(as low as reasonably achievable) principle. Optimization can also minimize the number of imaging repetition requests, thereby reducing the radiation dose and risk in paediatric patients[4]. Optimization of imaging techniques can be performed using figure of merit (FOM) as parameter. This parameter evaluates the image quality and the dose generated from an objective measurement unit.

2. Materials and Methods

2.1. Devices and setup configuration
This study was performed on Siemens OPTITOP 150/40/80 HC model in Harapan Kita Maternal and Children’s Hospital, Jakarta. The device had Siemens Luminos Agile Max unit with the Max wi-D image receptor which is a Caesium Iodide scintillator detector (DDR device) and Siemens Axiom Luminos TF unit with Kodak DirectView Classic CR (CR device). To represent paediatric patients, slabs of polymethyl methacrylate (PMMA) and cork combination was used as an anatomical representation with thickness groups selected from a previous study by Setiadi et al., (2017) and is presented on Table 1. Thicknesses were varied according to age. Varied patient-simulating phantom slabs is positioned on top of in-house phantom sitting on the image receptor.

2.2. In-house phantom
The in-house phantom (Figure 1) was designed to quantify the quality of conventional and digital planar radiographic images. The phantom is made from PMMA with a mass density of 1.18 g/cm$^3$ and size of 250 mm × 250 mm × 10 mm, equipped with four test modules: (1) collimation, (2) contrast linearity, (3) contrast consistency, and (4) modulation transfer function (MTF). Test modules no (3), and (4) were selected for this optimization purpose. The modules contain cylindrical objects with varied size and contrast. A 1 mm thick copper plate angulated by 3 degrees was available for MTF measurement.

2.3. Dose measurement
To obtain dose information, a Radcal® (Radcal Corporation, California, USA) series of the 10x6-6 ionization chamber with a weight of 0.05 kg and an active volume of 6 cm$^3$ detector were utilized. The entrance surface air kerma (ESAK) is measured at the top of the phantom surface.

| Group | Age | Thickness (cm) |
|-------|-----|----------------|
|       |     | Abdomen | Thorax | Cranial |
| A     | 0 - 1 year | 14.0 | 14.0 | 12.5 |
| B     | 1 - 5 years | 16.5 | 17.0 | 14.0 |
| C     | 5 - 10 years | 20.0 | 20.0 | 14.5 |
| D     | 10 - 15 years | 23.0 | 24.0 | 15.0 |

Figure 1. (Left) The schematics of the in-house phantom with modules (1) collimation, (2) contrast linearity, (3) contrast consistency, and (4) modulation transfer function (MTF) and (right) its radiograph.
2.4. **Image quality assessment**

Raw images in DICOM format were acquired and assessed using ImageJ. For quantitative contrast measurement, selected ROI was mathematically compared to calculate the signal difference to noise ratio (SDNR) using equation 1[5–7].

\[
SDNR = \frac{N_L - N_O}{\sqrt{SD_O^2 + SD_L^2}}
\]  

(1)

with \(N_L\) being the background pixel value, which is the mean pixel value of the ROI with a certain area outside the object's image; \(N_O\) being the mean pixel value of the object, which is the average pixel value on ROI; \(SD_L\) being the default background standard deviation value; and \(SD_O\) being the standard deviation value on a certain area in the object image.

Objects on modules (3) are used to quantify the variance of the image contrast (SDNR) of each objects with respect to objects size (using coefficient of variance, CV). Calculation of the MTF is performed using slanted-edge method on the angulated copper plate.

2.5. **Three-steps optimization**

The in-house phantom with certain thickness groups that represents the anatomy of paediatric patients were imaged using a range of varied parameters, i.e. kVp, mAs, and added filtrations, each in every steps. On every exposure, ESAK were measured and the resulting image was quantitatively assessed. As primary parameter, the figure of merit (FOM) is defined as \(SDNR^2/ESAK[5]\), as greater FOM indicates a more desirable technical parameter combination for that corresponding thickness and anatomy. The first step was to find desirable peak tube current (kVp), followed by finding the tube loading (mAs) with greatest FOM on the second step, and finally choosing desirable added filtration. On each steps, all other parameters (especially the one parameter with greatest FOM from the previous step) are kept constant. The MTF and CV were taken into account when two or more variations yielded on statistically similar FOM values.

3. **Results**

From the measurements that have been made, FOM values are obtained for each variation of kVp, mAs, and additional filters on all thicknesses in each anatomy. Different results were obtained from different type of digital system and is presented separately.

3.1. **CR device**

The optimization of CR device was performed on Siemens Axiom Luminos TF unit with Kodak DirectView Classic CR. The results of CR optimization along with the ESD and SDNR values are shown in Table 2.
Table 2. Optimized parameter combination results on Siemens Axiom Luminos TF unit with Kodak DirectView Classic CR

| Age Groups | Examination | Optimized Parameter | ESD (μGy) | SDNR | FOM |
|------------|-------------|---------------------|-----------|------|-----|
| Cranial    |             |                     |           |      |     |
| A          | 12.5 cm     | 44 kV; 2 mAs; 0.1 mmCu | 18.3      | 1.35 | 0.099 |
| B          | 14 cm       | 47 kV; 4.5 mAs; 0.2 mmCu | 28.7      | 1.82 | 0.115 |
| C          | 14.5 cm     | 48 kV; 6.3 mAs; 0.2 mmCu | 41.2      | 2.23 | 0.120 |
| D          | 15 cm       | 48 kV; 9 mAs; 0.2 mmCu | 61.0      | 2.60 | 0.111 |
| Thorax     |             |                     |           |      |     |
| A          | 14 cm       | 43 kV; 3.2 mAs; 0.1 mmCu | 13.6      | 1.91 | 0.268 |
| B          | 17 cm       | 43 kV; 4 mAs; 0.2 mmCu | 8.9       | 1.68 | 0.318 |
| C          | 20 cm       | 46 kV; 8 mAs; 0.2 mmCu | 20.6      | 1.90 | 0.175 |
| D          | 24.4 cm     | 50 kV; 8 mAs; 0.2 mmCu | 31.1      | 2.46 | 0.195 |
| Abdomen    |             |                     |           |      |     |
| A          | 14 cm       | 48 kV; 5.6 mAs; 0.2 mmCu | 36.7      | 2.10 | 0.120 |
| B          | 16.5 cm     | 50 kV; 4.5 mAs; 0.2 mmCu | 39.0      | 2.28 | 0.134 |
| C          | 20 cm       | 53.5 kV; 9 mAs; 0.2 mmCu | 110.3     | 3.33 | 0.101 |
| D          | 23 cm       | 60 kV; 7.1 mAs; 0.2 mmCu | 148.5     | 3.93 | 0.104 |

3.2. DDR device

The optimization of DDR device was performed on Siemens Luminos Agile Max DDR. The results of DDR optimization along with the ESD and SDNR values are shown in Table 3.

Table 3. Optimized parameter combination results Siemens Luminos Agile Max DDR

| Age groups | Examinations | Optimized Parameter | ESD (μGy) | SDNR | FOM |
|------------|--------------|---------------------|-----------|------|-----|
| Cranial    |              |                     |           |      |     |
| A          | 12.5 cm      | 44 kV, 3.2 mAs, 0 mmCu | 84.2      | 1.10 | 0.0145 |
| B          | 14 cm        | 46 kV, 5.6 mAs, 0.1 mmCu | 60.9      | 0.84 | 0.0117 |
| C          | 14.5 cm      | 49 kV, 7.1 mAs, 0.1 mmCu | 101.0     | 1.04 | 0.0108 |
| D          | 15 cm        | 50 kV, 9 mAs, 0.3 mmCu | 39.4      | 0.61 | 0.0094 |
| Thorax     |              |                     |           |      |     |
| A          | 14 cm        | 45 kV, 2.5 mAs, 0.2 mmCu | 4.1       | 1.14 | 0.315 |
| B          | 17 cm        | 45 kV, 4 mAs, 0.2 mmCu | 6.9       | 1.42 | 0.297 |
| C          | 20 cm        | 46 kV, 5.6 mAs, 0.2 mmCu | 11.5      | 1.85 | 0.299 |
| D          | 24.4 cm      | 47 kV, 6.3 mAs, 0.2 mmCu | 15.5      | 1.83 | 0.219 |
| Abdomen    |              |                     |           |      |     |
| A          | 14 cm        | 48 kV, 4 mAs, 0.1 mmCu | 54.7      | 0.71 | 0.00919 |
| B          | 16.5 cm      | 50 kV, 6.3 mAs, 0.2 mmCu | 52.7      | 0.43 | 0.00364 |
| C          | 20 cm        | 53.5 kV, 8 mAs, 0 mmCu | 451.2     | 0.44 | 0.00044 |
| D          | 23 cm        | 58.5 kV, 8 mAs, 0 mmCu | 596.1     | 0.18 | 0.00006 |

4. Discussion

From the results above, it can be seen that the FOM values are not consistent with either the increase in kVp, mAs, or the addition of filters. This occurred in both CR and DDR units. The higher tube voltage and current increases the dose for each measurement, but not the SDNR. SDNR value does not depend on high or low kVp or mAs so that resulting SDNR appears to fluctuate. This results in FOM values
being inconsistent even though the doses produced are linear with increases in kVp and mAs. Basically, the FOM value depends on two aspects, namely SDNR and dose. FOM can be very low value despite having a high SDNR if the dose received is also high.

This FOM parameter is actually very useful in clinical use since in reality, radiodiagnostic examination does not only concern with image quality, but also the dose received by the patient. However, the use of FOM parameters should be combined with other parameters. In this study, we used MTF and CV parameters as comparative parameters for the ambiguous FOM. However, not all data can be processed into MTF, especially data from phantom examinations of large thicknesses. This is due to phantoms that are too thick while the angulated copper plate on the in-house phantom is too thin, so it could not be properly detected by the software. The use of CV as a comparison parameter also finally did not show satisfactory results. Many CV values are inconsistent as well, which makes it difficult to determine the optimum combination of parameters as a comparison of FOM values. Because of these, MTF and CV were not used as comparative parameters in this study. The results of this study are all based on FOM values and is generalized in Table 4.

Table 4. General parameter combination results for groups B (1-5 years), C (5-10 years), and D (10-15 years)

| Examination | Optimum kVp | Optimum mAs | Optimum additional filter (+ 0.1 mmAl) |
|-------------|-------------|-------------|--------------------------------------|
| Cranial     | 46-48 kVp   | 4.5-9 mAs   | 0.1-0.3 mmCu                         |
| Thorax      | 45-50 kVp   | 4-8 mAs     | 0.2 mmCu                            |
| Abdomen     | 50-60 kVp   | 4.5-8 mAs   | 0-0.2 mmCu                          |

With the use of phantoms with greater thickness, a higher parameter combination is needed to produce a balanced dose and image quality. The use of kVp and mAs in each phantom thickness is adjusted to the age of paediatric patients. Patients with greater age certainly need a parameter combination that are higher so that the exposure given is sufficient to produce an image of adequate quality. With a higher parameter combination, it will certainly increase the dose received by the patients. Therefore, radiology department should have a reference parameter combination that can be used in clinical cases. However, this optimization results cannot be used as a reference parameter combination yet. Further research is required, especially with the combination of other parameters, to produce reference parameter combination. Results also indicates that CR and DDR devices require a slightly different parameter combination to achieve desirable image quality on reasonably low dose.

5. Conclusions
From this study, it can be concluded that this optimum conditions on simulated cranial, thorax, and abdomen examination using Siemens Axiom Luminos TF with Kodak DirectView Classic CR and Siemens Luminos Agile Max DDR vary on paediatric ages. In general, slightly different parameter combinations were produced in the group B, C, and D. The use of filters is highly recommended in obtaining the highest FOM. In-house phantom can be used for determining optimized parameter of image acquisition.

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