Optimization of digital radiography system using in-house phantom: preliminary study

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Abstract. The purpose of this study was to obtain information on optimum exposure parameter combination on simulated thorax and abdomen examinations using Direct-Digital Radiography (DR) and Computed Radiography (CR) systems. An in-house phantom dedicated for quick QC was utilized as an image quality quantification tool in term of contrast. The optimization was performed on Philips Essenta DR, CR Fuji Profect CS, and CR Agfa 10-X. Exposures were performed using corresponding clinical setting with combinations of kVp, mAs, filters, and a variation of simulated patient thicknesses. The Figure of Merit (FOM) was employed as optimization parameter, calculated as ratio of squared Signal Difference to Noise Ratio (SDNR) and surface dose for every measurement. The image quality was evaluated using Modulation Transfer Function (MTF) and Contrast Consistency (CV).

Based on FOM, MTF, and CV calculations, acquisitions optimization for thorax examination using DR was obtained on 55-63 kVp, 5-8 mAs, with additional filter 1 mm Al + 0.1 mm Cu. For abdomen examination, the optimized results were 81-102 kVp, 8-12.5 mAs, with additional filters 1 mm Al+0.1 mm Cu and 1 mm Al+0.2 mm Cu. On the other hand, the optimized results using CR on thorax examination were on the range of 55-63 kV, 4-8 mAs, also with the same additional filters with DR. The results of optimization of abdomen examination were on the range of 85-102 kV, 8-20 mAs, and again with the same additional filters. This gave information that different receptors used on the same x-ray unit produced almost similar optimization conditions.

1. Introduction

Technology utilization of x-rays had grown rapidly from analogue image receptor into a digital receptor, such as digital radiography. There are fundamental differences in terms of the sensitivity response of the image and radiation dose of patients between screen film (analogue) and digital radiography systems [1,2]. The optimization of digital system is required to ensure optimum exposure parameter combination to produce adequate image quality with effective surface dose in adherence with ALARA (As Low as Reasonably Achievable) principle. To achieve the optimization goal, image quality quantification tool is used. This study introduces the use of an in-house phantom constructed for quick QC for optimization purpose.

The Figure of Merit (FOM) was employed as optimization parameter, calculated as ratio between squared Signal Difference to Noise Ratio (SDNR) and surface dose [3–7]. Additional image quality parameters are required to support the FOM in determining the optimum conditions. The Contrast is defined as the ratio of the different signals to average signal, it depends on the subject and the
characteristics of the image detector, where the contrast object size can be represented through contrast consistency (CV). Meanwhile, the spatial resolution characteristics of image is represented by Modulation Transfer Function (MTF).

2. Materials and methods
The study was performed on multiple devices and multiple simulated anatomy to investigate the feasibility of the in-house phantom for optimization. It was performed on Philips Essenta DR Compact x-ray unit with three different image receptors, i.e., Philips Essenta DR (on-board), CR Fuji Profect CS, and CR Agfa 10-X. They were operated in Department of Radiology, Regional General Hospital of Cibinong, Bogor, Indonesia. The Philips Essenta on-board DR device had a Digital Diagnost flat detector of amorphous silicon with a size 43 cm x 43 cm. The maximum tube voltage was 150 kV with inherent filter of <0.3 mm Al at 100 kV and a selection carousel of additional filters of 0 mm Al (no filter), 1 mm Al + 0.1 mm Cu, 1 mm Al + 0.2 mm Cu, and 2 mm Al. The second detector was CR Fuji Profect CS with imaging plate detector type ST-VI size 24 cm x 30 cm and IP Cassette type CC. It had processing speed of 120 IPs/hr and time required for IP Feed/Load was 54 second. The third detector was CR Agfa 10-X read imaging plate at the high resolution of 10 pixels/mm, the dedicated cassettes were inserted horizontally.

2.1. General setup and phantom
The exposure was performed on simulated thorax and abdomen examinations. Thorax examination was simulated by stacks of cork sandwiched between two 2 cm Polymethyl Methacrylate (PMMA) slabs, the variation of thickness on thorax measurement were 15 cm, 20 cm, and 24 cm. While, abdomen examination was simulated by various thickness of PMMA, i.e., 20 cm, 25 cm, and 30 cm. Thorax examination used SID 150 cm, while abdomen examination used SID 100 cm.

The in-house phantom dedicated for quick QC is utilized as an image quality quantification tool in term of contrast, it was placed just above the image detector. The main part of in-house phantom was made of PMMA material with a density of 1.18 g/cm³ and size 250 mm x 250 m x 8 mm. The in-house phantom consist of 4 modules as show in Figure 1. The first module was collimation field suitability, second was contrast linearity module, there is four circular trenches with a diameter of 15 mm with each depth 0.5 mm, 1.0 mm, 1.5 mm, and 2 mm. The third module was contrast consistency, consist of 4 circle trenches as deep as 1.5 mm with sizes of 15 mm, 10 mm, 5 mm, and 2 mm respectively. And the last was Modulation Transfer Function (MTF) module, consists of a Cu plate (copper) size 20 mm x 30 mm with a thickness 0.5 mm, where plate was tilted at 3° on in-house phantom.

Figure 1. Modules of in-house phantom, (1) collimation, (2) contrast linearity, (3) contrast consistency, and (4) MTF
2.2. Optimization variations and steps
The study was performed on simulated thorax and abdomen with exposure combination of kVp, mAs, and filter settings based on clinical use. Three steps of optimization methods were performed, first the value of kVp was varied from 55 kVp to 66 kVp for thorax examination and from 81 kVp to 102 kVp for abdomen examination. Secondly the obtained optimum kVp was used with mAs variations, 4-10 mAs for thorax examination and 8-20 mAs for abdomen examination. The last, the optimization results from these two steps was used for final optimization with using 4 types of added filtration provided by manufacturer, i.e., 0 mm Al, 1 mm Al + 0.1 mm Cu, 1 mm Al + 0.2 mm Cu, and 2 mm Al. All steps of optimization were performed for each thorax measurements (15 cm, 20 cm, and 24 cm thickness) and for abdomen measurements (20 cm, 25 cm, and 30 cm thickness).

2.3. Dose measurement and quantitative image quality evaluation
The entrance surface dose (ESD) was measured using a RadCal® 10X6-6 ionization chamber (IC) (Radcal Corporation, California, USA) dosimeter. Ionization chamber was places just above the surface of the phantom for each exposure condition, where the dose obtained had included the backscattered radiation. The images of each measurement were record in the form of raw data with DICOM format and it will be processed used Image-J software (NIH, Maryland, U.S.) to get pixel value that will be used to calculate SDNR, MTF, and CV.

The image processing to find the value of SDNR used module number 3 in the in-house phantom, by doing circular region of interest (ROI) on a large circle on object and background of image (Figure 3.). The SDNR value will be calculated based on equation (1), as ratio between the average pixel value and standard deviation of circular regions of interest (ROI). N_L was the pixel value of background and N_o,i was the pixel value of selected object, with STD was standard deviation of ROI. The SDNR and ESD will be used to calculated FOM based on equation (2), where FOM as ratio between squared SDNR and surface dose (ESD).

\[ SDNR = \frac{[N_L - N_{o,i}]}{\sqrt{(STD_{o,i}^2 + STD_L^2)}} \]  \hspace{1cm} (1)

\[ FOM = \frac{SDNR^2}{ESD} \]  \hspace{1cm} (2)

MTF calculation used image of module number 4 in in-house phantom. Data processing used ImageJ software was done with Generate MTF in the SE MTF 2xNyquist plugin. The values were obtained on
the MTF graph were interpolated to determine the MTF 10%. Coefficient of Variation (CV) was the last image quality parameter used in supporting the FOM to determine the optimum exposure parameter combination. The CV value was obtained by image of module number 3 in in-house phantom and data processing also used Image-J software and will be calculated based on equation (3). SDNR was obtained by circular ROI on the object and background of the four circles. This study was done at least three repetitions for dose and image quality measurement, with FOM, MTF, and CV being calculated as means from all repetitions.

Figure 3. Region of Interest (ROI) on the image

3. Results

3.1. Optimization on CR systems
The optimization of CR system consists two manufacturers, i.e., CR Fuji Profect CS and CR AGFA 10-X. The ESD and SDNR values each measurement were used to FOM calculation as Equation (2). Table 1 presents optimization results for AGFA 10-X and FUJI Profect CS on simulated thorax and abdomen examinations.

Table 1. Summary on optimized parameters on CR devices

| Examinations | Optimized parameters | ESD (µGy) | SDNR  | FOM  | MTF 10% (cycle/mm) |
|--------------|----------------------|-----------|-------|------|-------------------|
| **Fuji Profect CS** | | | | | |
| Abdomen | 102 kVp, 16 mAs, 1 mm Al + 0.2 mm Cu | 1057.9 | 2.510 | 0.006 | 0.212 |
| 20 cm | 96 kVp, 20 mAs, 1 mm Al + 0.2 mm Cu | 1065.3 | 2.310 | 0.006 | 0.124 |
| 25 cm | 102 kVp, 10 mAs, 1 mm Al + 0.2 mm Cu | 601.7 | 1.940 | 0.007 | - |
| 30 cm | 66 kVp, 4 mAs, 1 mm Al + 0.1 mm Cu | 34.5 | 3.170 | 0.298 | 1.025 |
| Thorax | 57 kVp, 4 mAs, 1 mm Al + 0.1 mm Cu | 34.6 | 2.770 | 0.226 | 1.042 |
| 15 cm | 60 kVp, 5 mAs, 1 mm Al + 0.1 mm Cu | 39.4 | 2.370 | 0.148 | 0.994 |
| 20 cm | 85 kVp, 10 mAs, 1 mm Al + 0.1 mm Cu | 563.7 | 1.514 | 0.004 | 0.272 |
| 25 cm | 96 kVp, 10 mAs, 1 mm Al + 0.1 mm Cu | 961.9 | 1.210 | 0.002 | - |
AOCMP-SEACOMP

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30 cm  
102 kVp, 8 mAs, 1 mm Al + 0.1 mm Cu  
818.8  
3.050  
0.002  
-

15 cm  
55 kVp, 4 mAs, 1 mm Al + 0.1 mm Cu  
27.3  
1.879  
0.129  
0.553

20 cm  
60 kVp, 8 mAs, 1 mm Al + 0.2 mm Cu  
40.7  
0.948  
0.022  
0.711

24 cm  
60 kVp, 10 mAs, 1 mm Al + 0.1 mm Cu  
90.3  
2.33  
0.060  
0.649

3.2. Direct-Digital Radiography (DR)
Similar to CR optimization, on Philips Essenta DR optimized parameters are presented on Table 2. The table shows mean FOM value with kVp, mAs, and additional filter at each thickness of abdomen and thorax as well as optimized combination of parameters.

Table 2. Summary on optimized parameters on Philips Essenta on-board DDR

| Examinations | Optimized parameters | ESD (µGy) | SDNR | FOM | MTF 10% (cycle/mm) |
|--------------|----------------------|-----------|------|-----|-------------------|
| Abdomen      |                      |           |      |     |                   |
| 20 cm        | 102 kVp, 12.5 mAs, 1 mm Al + 0.2 mm Cu | 914.7     | 2.760 | 0.008 | 0.634             |
| 25 cm        | 96 kVp, 12.5 mAs, 1 mm Al + 0.2 mm Cu | 820.9     | 1.330 | 0.002 | 0.581             |
| 30 cm        | 81 kVp, 8 mAs, 1 mm Al + 0.2 mm Cu | 318.8     | 0.490 | 0.001 | -                 |
| Thorax       |                      |           |      |     |                   |
| 15 cm        | 57 kVp, 8 mAs, 1 mm Al + 0.1 mm Cu | 54.3      | 1.500 | 0.043 | 0.606             |
| 20 cm        | 55 kVp, 6.3 mAs, 1 mm Al + 0.1 mm Cu | 40.8      | 1.377 | 0.048 | 0.415             |
| 24 cm        | 63 kVp, 5 mAs, 1 mm Al + 0.1 mm Cu | 54.3      | 1.363 | 0.034 | 0.593             |

4. Discussion
This study was aimed to obtain optimum exposure parameter combinations on digital radiography systems using in-house phantom. The results of each measurement show a fluctuating FOM value, so to determine the optimum exposure parameters using the MTF and CV values as supporting factors. However, MTF was more considered to support FOM in determining the optimum conditions compared to CV. The results of CV were not shown, because the CV results in this study were not satisfactory to represent image contrast consistency. For MTF, not all images in each abdomen thickness produce MTF value, this was caused by PMMA making-up abdomen phantom too thick. So, that making in-house phantom did not receive a lot of photon intensity, causing a lack of contrast in MTF images on in-house phantom, so when the image do ROI with Image-J software, it was not generate MTF value.

In general, FOM, MTF, and CV value run into fluctuation in each measurement. This is due to the SDNR values being fluctuated in all exposures. Besides that, the materials of abdomen and thorax phantoms also affected the results. The thorax phantom consisted of stacks of cork sandwiched between two 2 cm PMMA slabs, causing the detector to receive more noise from the low density material gap, as expected from thorax planar imaging. Meanwhile, the abdomen phantom was composed of solid
PMMA slabs, providing more interaction equilibrium. These values, however, is suggested to the hospitals for parameter selection reference.

Table 3. General the optimum exposure parameter combinations digital radiography

| Examinations | Optimized kVp | Optimized mAs | Optimized Filter                          |
|--------------|---------------|---------------|-------------------------------------------|
| Abdomen      |               |               |                                           |
| 20 cm        | 85 - 102 kVp  | 10 – 16 mAs   | 1 mm Al+0.1 mm Cu and 1 mm Al+0.2 mm Cu   |
| 25 cm        | 96 kVp        | 10 – 20 mAs   |                                           |
| 30 cm        | 81 – 102 kVp  | 8 – 10 mAs    |                                           |
| Thorax       |               |               |                                           |
| 15 cm        | 55 – 66 kVp   | 4 – 8 mAs     | 1 mm Al+0.1 mm Cu and 1 mm Al+0.2 mm Cu   |
| 20 cm        | 55 – 60 kVp   | 4 – 8 mAs     |                                           |
| 24 cm        | 60 – 63 kVp   | 5 – 10 mAs    |                                           |

5. Conclusion

From the study, the FOM shown tendency to depend on thickness, while MTF is independent to thickness. Based on FOM, MTF, and CV calculations, acquisitions optimization for thorax examination was obtained on 55-66 kVp, 4-10 mAs, with additional filter 1 mm Al + 0.1 mm Cu and 1 mm Al + 0.1 mm Cu. For abdomen examination, the optimized results were 81-102 kVp, 8-20 mAs, with additional filters 1 mm Al+0.1 mm Cu and 1 mm Al+0.2 mm Cu. Generally, different image receptors used on the same x-ray unit produced almost similar optimization recommendations when performed using the same tools.

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