Designing phantom in-house for quick check computed radiography (CR) and digital radiography (DR) system

R Muharam1*, I Lestariningsih2, Nurlely1, D S Soejoko1
1Department of physics, Faculty of Mathematics, University of Indonesia, Depok, West Java, 16424, Indonesia;
2Department of Radiology, RSUD Cibinong, Bogor, West Java, 16914, Indonesia
*riyan.muharam@sci.ui.ac.id

Abstract. Computed Radiography (CR) and Digital Radiography (DR) are digitalized radiography systems which have connection between image quality and dynamic-characteristic dose that quality control becomes important for a patient. Phantom quick check with CR and DR system are designed to observe parameter of image quality, spatial resolution, signal nose to ratio (SNR) and detectability. The preparation phantom was designed with acrylic 25 cm x 25 cm x 1 cm that has well objects with the diameters from 5 mm to 25 mm and depth 1 mm to 8 mm also Aluminium with 15 mm x 15 mm and thickness of 0.4 mm, 0.6 mm, 0.8 mm, 1 mm, 1.2 mm, 1.4 mm, 1.6 mm. Radiation quality beam or ROA 5 has found to measurement standard in general radiography. The result is SNR graphic versus object for each depth and give information to select objects. From graphic, contrast linier object and detectability is selected for a phantom design. The image from quadrant I could be used to analyse linearity pixel value. Quadrant II could be used to analyse detectability object size. Quadrant III and IV could be used to analyse the resolution spatial. Meanwhile, the point object was used to evaluate the spatial resolution with MTF measurement and Line pair bar. Based on the conducted trial test on the in-house phantom and the image result from each quadrant, further study will be performed to ensure that this in-house phantom will be usable for quick check at hospitals.

1. Introduction
The development of imaging diagnostic radiology using x-rays is very fast recently. Many hospitals in Indonesia radiography commonly use Computed Radiography (CR) or Digital Radiography (DR) system for replacing film-screen, but it is not equipped with the availability of quality control (QC) equipment like dosimetry and the quality of imaging in hospitals in Indonesia. Because of this, to speed up the checking process of a tool, it needs a component which can ensure the quality of that tool or quality assurance (QA). One thing that needs to do is to control the quality of QC of that tool. The QA as a planned and systematic activity must be done in a qualified system so the quality of a product or service are fulfilled, while QC represent a technique and activity of observation which is used to fulfil the quality requirement [1]. In computed radiography (CR) the result of the image can be reconstructed by using computerized system to give an optimal image so the information of diagnostic image is more accurate. The imaging process of CR
is no longer using a dark chamber but using dry processing method resulting film laser imaging, usage of PSP enables IP to be reused [2]. The advantage of CR and DR are the output in digital images or Digital Imaging and Communication in Medicine (DICOM) format that can be reprocess to get contrast had better. The difference between CR and DR is the process of image result where the result of DR can be displayed on monitor as in CR. Digital radiography system is also known as Digital Direct Radiography (DDR) [3]. The image is also in DICOM format to make it possible to reprocess to get a good image contrast [4]. Quality control of X-rays unit and these systems is necessary to maintain produced images are always in high quality. So far almost all hospitals are not provided with QC devices for radiography units and these CR and DR systems.

The purpose of this research is to design phantom for that can be used for quick check of CR and DR system. Several parameters by using phantom measurements influencing image quality can be performed, particularly detectability, pixel value linearity, and spatial resolution.

2. Material and Method

For preparation phantom objects a slice of polymethyl methacrylate (PMMA) or acrylic with size of 25 cm x 25 cm x 1 cm provided with various size and depth of small wells as objects, diameter size 5 mm, 10 mm, 20 mm with depth from 1 mm to 8 mm. Other objects are aluminium with size of 15 mm x 15 mm and thickness of 0.4 mm, 0.6 mm, 0.8 mm, 1 mm, 1.2 mm, 1.4 mm, 1.6 mm, 1.8 mm. Radiography of this phantom was made by using Phillips Essenta DR unit belong to RSUD Cibinong. Image acquisition using beam quality RQA 5. Optimum size and depth small well objects, and aluminium thickness were selected for designing QC phantom.

In-house phantom has been designed and was made of acrylic with the size of 25 cm x 25 cm x 1 cm. This phantom was divided into 4 quadrants, first quadrant consisted of an array well objects with size of 10 mm diameter and various depth from 1 mm to 5 mm and an array aluminium objects with size of 10 mm and various thickness of 1 mm, 1.2 mm, 1.5 mm, 1.7 mm, and 2 mm. Second quadrant consisted of an array well objects with depth 5 mm and size of 5 mm, 7 mm, 10 mm, 13 mm, 15 mm and other aluminium objects array each thickness of 2 mm and the same various size with well objects. Third quadrant consisted a plate of Cu with size 20 mm x 15 mm in 3 degrees oblique position respect to x-phantom axis. Fourth quadrant consisted of bar phantom line pair leeds type 18 placed on 45° oblique respect to x-phantom axis.

2.1. Determining Radiation Beam Quality with an added filter (RQA)

Radiation quality determination for calibration in diagnostic radiography is commonly used RQA with added filter of aluminium and the measurement of the back of patient is done (in image intensifier) [5]. To determine the characteristics of the beam of radiation RQA are made based on the reference in Technical Report series No. 457 as shown at Table 1. For dosimetry Raysafe X2 has been used to measuring RQA beam.

To determine RQA-5, SID (Source Image to Detector) are set to 180 cm and placed the sensor on the crosshair collimation with added filter 21 mm Aluminium, current 10 mA and variation of voltage kV. The value of HVL is measured in every exposure until HVL 6.8 mm is resulted. Repeated for 3 times until got a consistent value, then repeated again to found RQA 2 – RQA 7 following requirement in TRS 457.

2.2. Phantom positioning

In data collection, phantom is positioned by adding stacked PMMA until 15 cm, then positioning to represent the clinical condition of a patient’s abdomen. After that, expose with exposure factor are 70 kV and 10 mAs, distance of SID are 110 cm and 30 x 30 cm of collimation field.
2.3. Image quality analysis.
Evaluation in making phantom-in-house is done by observing the image from beginning. To determine the image quality beside using qualitative method (by observing directly) the quantitative is done as well with SNR parameter from the equation 1.

\[
\text{SNR} = \frac{|N_b - N_o|}{\sqrt{\text{STD}_b^2 + \text{STD}_o^2}}
\]

The result of image processed by doing ROI (Region of Interest) using imageJ and get \(N_b\), are the mean value from background and \(N_o\) mean value from the object. Standard deviation is from object value (\(\text{STD}_o\)) and standard deviation from background (\(\text{STD}_b\)).

| Radiation Quality | X ray tube voltage (kV) | Added filtration (mm Al) | Nominal HVL (mm Al) |
|-------------------|-------------------------|--------------------------|---------------------|
| RQA 2             | 40                      | 4                        | 2.2                 |
| RQA 3             | 50                      | 10                       | 3.8                 |
| RQA 4             | 60                      | 16                       | 5.4                 |
| **RQA 5**         | **70**                  | **21**                   | **6.8**             |
| RQA 6             | 80                      | 26                       | 8.2                 |
| RQA 7             | 90                      | 30                       | 9.2                 |
| RQA 8             | 100                     | 34                       | 10.1                |
| RQA 9             | 120                     | 40                       | 11.6                |
| RQA 10            | 150                     | 45                       | 14.3                |

3. Result and Discussions

3.1. The making of phantom-In-House
The making of phantom is done in Medical physics and biomedical laboratory Department of Physics UI using Computer Numerical Control (CNC) machine. The design is made with ArtCam program and then imported to CNC machine. Then the acrylic or PMMA is placed on CNC machine until the process is finished.

(a) (b)

Figure 1. Phantom in-house (a) early phantom. (b) The design of quick check phantom
3.2. Result of RQA 5
The result of the measurement of the RQA beam radiation quality for Philips Essenta DR is shown in Table 2. Based on the measurement of RQA, the value of RQA 5 for Philips Essenta DR on 73 kV with HVL value 6.803 mm aluminium. According the result Philips Essenta DR, it was complied to recommendation of TRS 457. Then for other RQA, RQA 2 on 40 kV with HVL value 2.23 mm aluminium, RQA 3 on 52 kV with HVL value 3.95 mm aluminium, RQA 4 on 60 kV with HVL value 5.41 mm aluminium, RQA 6 on 85 kV with HVL value 8.28 mm aluminium, and RQA 7 on 96 kV with HVL value 9.28 aluminium. Figure 2 shows that an increase in voltage results in a measurable increase in the HVL value. That is because the increase in the tube voltage will accelerate the electrons that hit the target, so the X-rays produced have higher energy. Higher X-ray energy increases penetration and therefore, the HVL value also increases [8]. The comparison of RQA graphic according to TRS 457 vs measurement shows that the increase in HVL value is relatively linear with the equation y = 0.1264x – 2.5478.

| Radiation Quality | X ray tube voltage TRS 457 (kV) | X ray tube voltage (kV) | Added filtration (mm aluminium) | Nominal HVL TRS 457 (mm aluminium) | Nominal HVL (mm aluminium) | Deviation (%) |
|-------------------|---------------------------------|-------------------------|-------------------------------|-------------------------------------|----------------------------|---------------|
| RQA 2             | 40                              | 40                      | 4                             | 2.2                                 | 2.23                       | 1.36           |
| RQA 3             | 50                              | 52                      | 10                            | 3.8                                 | 3.95                       | 3.94           |
| RQA 4             | 60                              | 60                      | 16                            | 5.4                                 | 5.41                       | 0.24           |
| RQA 5*            | 70                              | 73                      | 21                            | 6.8                                 | 6.87                       | 1.02           |
| RQA 6             | 80                              | 85                      | 26                            | 8.2                                 | 8.28                       | 1.02           |
| RQA 7             | 90                              | 96                      | 30                            | 9.2                                 | 9.28                       | 0.94           |

Figure 2. The graphic of RQA comparison according to TRS 457 vs measurement
3.3. **Evaluation of In-House phantom**

To evaluate the result of phantom image, *imageJ* is used by doing ROI on the objects and backgrounds. Then measurement is done to get SNR value which is suited with equation 1. In figure 3 (a) illustrated images of preparation phantom that have been made by using RQA 5 beam. Well objects that have been selected match with SNR requirements [7], match with well object diameter more than 5 mm and depth more than 5 mm. Figure 3 (b) shows the SNR object with aluminium that give information to select object for thickness more than 1.8 mm have SNR around 5.

![Figure 3. Chart the result SNR (a) well objects of each depth (b) objects with aluminium](image)

First trial that was conducted on the in-house phantom was shown on figure 4. Each quadrant had their own functions to analyse the image quality on CR and DR systems. The image from quadrant I could be used to analyse linearity pixel value. Quadrant II could be used to analyse detectability object size. Quadrant III and IV could be used to analyse the resolution spatial. Meanwhile, the point object was used to evaluate the spatial resolution with MTF measurement and Line pair bar. Based on the conducted trial test on the in-house phantom and the image result from each quadrant, further study will be performed to ensure that this in-house phantom will be usable for quick check at hospitals.

![Figure 4. Result image of phantom quick check](image)
4. Conclusion
This research has made a preparation phantom to design phantom quick check on digital radiography systems X-ray. This research also gives RQA data on Philips Essenta DR with the RQA 2 value on 40 kV, RQA 3 on 52 kV, RQA 4 on 60 kV, RQA 5 on 73 kV, RQA 6 on 85 kV, and RQA 7 on 96 kV. The quality of standard radiation beam in general radiography determine by RQA 5. Philips Essenta DR comply recommendation by TRS 457 on 73 kV. While for selecting object phantom observed by SNR value where SNR ≥ 5 can be detected with visual eyes. Then the objects phantom quick check for quadrant 1 is the hole with 10 mm and depht from 1 mm to 5 mm for air, and for aluminium deepth of 1 mm, 1.2 mm, 1.5 mm, 1.7 mm, 2 mm. For the detectability in quadrant II, object with diameter 5 mm, 7 mm, 10 mm, 13 mm, 15 mm and 2 mm depth for aluminium and 5 mm for air. While for MTF in quadrant III will be using Cu with thickness 1 mm and quadrant IV will be filled with Bar Phantom Leeds type 18.

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