Using in-house quick-QC phantom to characterize computed and direct digital radiography: a preliminary study

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Abstract. In this study, two CR receptors (Agfa CR-85X and Agfa CR-10X) and two DDR receptors (Brivo DR-F and Essenta) were characterized in terms of detector sensitivity and image quality. An in-house phantom was specially designed to accommodate image quality assessment for quick QC and is tested as a purpose of this study. The reference quantitative aspect that were used to characterize the imaging units are the correlation between Pixel Value and image receptor dose, whereas evaluation of image quality based on the modules on the in-house phantom uses new proposed metrics (coefficient of linearity, CL, and coefficient of variance, CV). Each system’s unique Pixel Value-dose characteristics are also expressed in the results of the in-house phantom’s metrics (i.e. CL and CV). In addition, the constancy of measured modulation transfer function suggests potential use for system quality judgment. As all characterizations (Pixel Value-dose characteristics, MTF, and new metrics) indicated on unique result for each systems, the study implies that the designed in-house phantom as well as its proposed metric can be promising to be used to characterize digital radiography systems during quick QC.

1. Introduction

Digital radiography systems are replacing films over a broad range of examination. Historically, the introduction of phosphor storage is the first step toward digital imaging. To this days, computed radiography and direct digital radiography are widely used to acquire radiographic examination [1,2]. The advantage of digital radiography is that they are cost effective since they allow reutilization.

Every digital radiography system has its own characteristics and they need to be quantified during quality assurance program. Since the tool for this purpose is currently limited in Indonesia, an in-house phantom has been proposed to quickly demonstrate the state of the system during quality control to indicate if further investigation is required. The aim of this paper is to define if the produced in-house phantom is able to quickly differentiate different systems in which it is put into use. This study is a preliminary study to serve as a basis for further study in which recommended use of the in-house phantom for computed radiography (CR) and direct-digital radiography (DDR) is described.
2. Materials and methods

The four systems used in this paper are two CR systems and two DDR systems, namely, Agfa CR-85X, Agfa CR-10X, (Agfa, Mortsel, Belgium) GE Brivo DR-F (GE, Illinois, USA), and Phillips Essenta DR (Philips, Amsterdam, Netherlands). For image quality assessment, an In-house phantom (Figure 1) was specially designed to accommodate image quality evaluation during quick QC. The phantom includes circular pits with four different sizes and four different depths, as well as 1 mm of copper sheet for MTF measurement. Dose-pixel value characterization were performed on these four devices with standard RQA-5 beam condition, with dose measurements performed using Radcal 10x6-6 ionization chamber (Radcal Corporation, California, USA).

In this study, the in-house phantom were positioned under a simulated abdomen phantom, which is based on American Association of Physicists in Medicine (AAPM) Report No. 31 [3]. The abdomen phantom is essentially a stack of 17.5 cm of PMMA slabs as shown in Figure 2.

2.1. Image receptor response

The standard condition of RQA-5 beam was obtained using methods described in IAEA Technical Report Series and IPEM Report No. 91 [4,5]. To define the general characteristic of each detector, the imaging plates were exposed with RQA-5 beam under tube current variation. The characteristic was described as the correlation between mean pixel value and air kerma on the imaging plates. The mean pixel value in selected ROI of each resulting images were obtained from the DICOM file using ImageJ, while the image receptor dose was obtained using distance-corrected in-air measurement.

2.2. Phantom, setup, and positioning

To find RQA-5 standard beam, the positioning is described in Figure 3. At a constant tube current, exposures were performed with varied tube voltage. HVLs were measured at each exposure until a tube voltage that yields 6.8 mm Al HVL was identified. The in-house phantom and simulated abdomen PMMA were positioned as shown in Figure 2. For all studies, the beam was collimated according to the PMMA size with a fixed SID of 100 cm (Figure 4). Exposure parameters were determined based on clinical practice.

2.3. Image quality evaluation

New and simple metrics were introduced for quick QC using the in-house phantom, namely; coefficient of variance (CV), being the ratio of standard deviation and mean of SDNR from objects with different size, and coefficient of linearity (CL), as defined in Eq. 2. Additionally, modulation transfer function (MTF) were evaluated using angulated copper plate and was recorded as technical quality parameter.

To calculate the CL, CV and MTF, ImageJ was used. Firstly, the SDNR [6] must be selected to calculate CL and CV. The SDNR value was obtained by doing a Region of Interest (ROI) on the circular objects and the background of each objects (Figure 5). The SDNR value will be calculated based on equation (1), where \(N_{i}\) is the pixel value of the background, \(N_{o,i}\) is the pixel value of each objects, with STD\(_{o}\) is a standard deviation of the background and STD\(_{o,i}\) is a standard deviation of each objects.

\[
SDNR = \frac{[N_{i} - N_{o,i}]}{\sqrt{[STD_{o,i}^2 + STD_{o}^2]}}
\]

The resulting SDNR were used to calculate CL and CV using equations (2) and (3), respectively. For the MTF, the image from module 4 was processed using SE_MTF plugin on ImageJ. The MTF value was interpolated to find the MTF 10% value which is described as the cut-off spatial frequency for radiographic imaging [1].
Figure 1. Modules of in-house phantom; (1) collimation, (2) contrast linearity (CL), (3) contrast consistency (CV), and (4) modulation transfer function.

Figure 2. Simulated abdomen which consist of 17.5 cm of PMMA slabs

Figure 3. Preparation phase, finding the tube voltage that produced a 6.8 mm HVL

Figure 4. The set-up of image quality evaluation using in-house phantom

Figure 5. Region of Interest to find the SDNR value ($N_o$ for ROIs 1-4 and $N_i$ for ROIs 5-8).
\[ CL = \frac{\ln(\text{SDNR}_{\text{max}}) - \ln(\text{SDNR}_{\text{min}})}{\ln(\text{SDNR}_{\text{max}}) + \ln(\text{SDNR}_{\text{min}})} \]  \hspace{1cm} (2)

\[ CV = \frac{s(\text{SDNR})}{\text{SDNR}} \]  \hspace{1cm} (3)

3. Results and discussion

3.1. RQA-5 Beam

The tube voltage that produced beams of 6.8 mmAl HVL (RQA-5) are reported in Table 1. Philips Essenta and Philips MobileDiagnost wDR produced a 6.8 mmAl HVL with a tube voltage above value recommended by IAEA TRS 457 (66-77 kVp to get 6.8 mmAl HVL) [5]. Meanwhile, GE Brivo DR-F and Philips Practix 300 produced 6.8 mmAl HVL with tube voltage within the recommended values. These values will attribute the different image response characteristics evaluated using the in-house phantom.

| X-ray device                | Image receptor | Tube voltage (kVp) | HVL (mmAl) |
|-----------------------------|----------------|-------------------|------------|
| Philips Essenta             | Built-in DDR   | 81                | 6.8        |
| GE Brivo DR-F               | Built-in DDR   | 72                | 6.8        |
| Philips MobileDiagnost wDR  | AGFA CR-10 X   | 82                | 6.8        |
| Philips Practix 300         | AGFA CR-85 X   | 72                | 6.8        |

3.2. Image receptor response

The response curve of the four systems are reported in Figure 6. Each system presented a unique yet generally negative correlation between pixel value and the imaging plate dose, except for GE Brivo DR-F which shown an inversed curve with a positive linear correlation between pixel value and image receptor dose. The system manufactured by AGFA present a slightly different curve. Whereas the CR 10-X has a slightly linear response. The GE Brivo DR-F shown an inversed curve because this system provides its raw data in an inversed scale. This resulted on a higher pixel value of dark objects and lower pixel value on bright objects. These responses indicated the diverse nature of digital detectors character.

3.3. Image quality evaluation using in-house phantom

The image quality characterization of each systems are reported on Figure 7 whereas MTF results are given on Figure 8. Different results were yielded from different type of image receptors, indicating the ability of the in-house phantom to differentiate characters. This encouraged the idea that the produced phantom can be used for quick QC for indicating if a system pertains its respective character across time. For CL measurement, results indicating that this metric tend to be constant across different number of signal (i.e. tube current), with the exception for Agfa CR 10X. This further suggests that the metric might be useful as a quick quality metric. As for the CV, this also present on each one CR and DDR system (Agfa CR 85X and Philips Essenta DDR).

Being not an individual image quality metric, but rather a system quality metric, MTF measurement is not expected to present tendency or trend against any exposure parameters—and this is demonstrated in Figure 8. Apart from the measurement results from GE Brivo DR-F, MTF tend to be constant with varying tube current. Though rather promising, these results suggest that further study is required to confirm that CL and CV can serve as definitive metric for quick judgement as well as system quality judgment tool for MTF.
Figure 6. The response curve of the four systems. (A) The correlation between pixel value and image detector dose of CR-10X detector, (B) The correlation between pixel value and image detector dose of CR 85-X detector, (C) The correlation between pixel value and image detector dose of Phillips Essenta detector, (D) The correlation between pixel value and image detector dose of GE Brivo DR-F detector.

Figure 7. Image quality characterization of each systems, i.e. on coefficient of linearity, CL (left), and coefficient of variance, CV (right).
Figure 8. Results on MTF measurement.

4. Conclusion
The study provides preliminary indication on the ability of the in-house phantom to provide brief information on the imaging system state using a newly-defined metrics of CL, CV as well as MTF. As these metrics may reflect general quality for quick judgement, it is confirmed that further studies are required to demonstrate the robustness of the proposed metrics as well as to indicate the recommended use of the in-house phantom itself.

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