Evaluation of Radiation Dose Reduction and its Effect on Image Quality for Different Flat-Panel Detectors

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Abstract

Purpose: To evaluate the image quality of semi-anatomical chest radiographs acquired using low radiation doses from seven different flat-panel detector (FPD) systems. Materials and Methods: Radiographs of a semi-anatomical chest phantom were acquired at 70 and 110 kVp using 7 different FPDs from 5 vendors. Radiation doses were measured using a dose-area-product (DAP) meter. To standardize measurements across all FPDs, DAP value of 51.05 μGy² obtained at 70 kVp and 9.43 μGy² at 110 kVp was used as reference in this study. Radiation doses were reduced by manually adjusting mAs for both tube potentials in all FPD systems to achieve acceptable image quality. Contrast-to-noise ratio, signal-to-noise ratio and figure of merit (FOM) in lung, heart, and diaphragm for all images were analyzed. Results: In comparison with set standard protocol, radiation dose reduction of 20%, 21%, 21.6%, 59.5%, 60.7%, 62.2%, and 67.6% with optimal image quality was observed in Prognosys Prorad, GE Definium 8000, Siemens Fusion, Fujifilm FGX, Fujifilm FGXR, Philips Digital Diagnost and Siemens Aristos at 70 kVp. At 110 kVp, dose reduction of 15.7% and 34.8% was possible only for Philips Digital Diagnost and Siemens Aristos. FOM was high at 110 kVp even when radiation doses were reduced by a factor 2 when compared to 70 kVp in all digital radiography systems. Conclusion: This study demonstrates the feasibility of using a semi-anatomical chest phantom in the optimization of radiation dose and image quality. The FOM was a good indicator in assessing image quality between different detectors.

Keywords: Digital radiography, image quality, radiation dose

INTRODUCTION

Ever since the discovery of X-rays in 1895, film-screen radiography played an important role in medical imaging. However, this imaging technique was cumbersome and was replaced by digital radiography (DR) after several decades in the form of computed radiography in 1980[1-4] followed by flat-panel detectors (FPD) in the 1990s.[5,6-8] The wide dynamic range, varied postprocessing algorithms, long-term archival, digital display, and ease of use enable DR systems to provide efficient workflow in medical imaging.[5,9-11] Images acquired using conventional film-screen radiography yielded direct feedback to the operator based on whether the image acquired was over or underexposed due to the exposure factors used. The wide dynamic range in DR systems permits high variation of radiation doses and often, high radiation doses are inadvertently imparted to patients.[9,12] Health-care facilities often encounter challenges in optimizing exposure parameters to balance image quality due to changes in hardware and software functionalities of FPDs from multiple manufacturers.[13,14] Hence, normalization of exposure parameters for various radiological examinations is essential. The criteria for a reliable diagnosis are based on images of optimal quality acquired using optimized radiation doses.[15,16] According to the International Commission of Radiological Protection (103, 2007), radiation dose to the patient should be as low as reasonably achievable.[17] Radiation dose is primarily influenced by factors such as tube potential, tube current-time product, beam collimation, beam filtration, exposure (speed) class, use of grids, type of detectors, source to image distance, and patient thickness.[13,18,19] Image quality in FPDs can be quantified using parameters such as detector FOM.
Materials and Methods

Digital radiography systems

The study involved image quality assessment for seven different DR systems (caesium iodide)-based FPDs from 5 different vendors, namely Siemens, GE, Philips, Fujifilm, and Prognosys [Table 1]. Before the study, all DR systems underwent periodic quality assurance (QA) tests using a calibrated Multiparametric QA meter (Unfors Raysafe Xi, Unfors Instruments, AB, Billdal, Sweden). The FPDs were calibrated according to the manufacturer’s quality specifications.

Description of the phantom

A semi-anatomical chest phantom (Model 07-646, Nuclear Associates, Carle Place, NY, USA) was used to simulate chest radiographs and to assess the image quality of FPDs. The phantom is constructed from sheets of 0.5 mm thick copper and 6 mm aluminum cut into shapes that resembled a human heart, diaphragm, spine, and ribs. A cut-out made from the copper sheet is used to resemble the shape of the lung field. To provide additional attenuation, the entire phantom is sandwiched between 2.5 cm thick acrylic sheets. Test objects located in the lung, heart, and diaphragm regions are used to evaluate contrast and spatial resolution. The contrast detail test objects are made from copper discs of thickness ranging from 0.006 to 0.076 mm in the lung; 0.013–0.127 mm in the heart and 0.051–0.406 mm in the diaphragm region respectively aligned in a row of the matrix. This variation in the thickness of the copper disc in the matrix is to provide radiographic contrast in a perceptible range. The diameter of the copper discs ranged from 0.5 to 6 mm. High contrast resolution (spatial resolution) was evaluated by a line pair test object present in the lung region. This high contrast resolution test object best describes the ability of an imaging system to resolve objects that are close together. The test object consisted of nine-line pair groups ranging from 2.3 to 5 lp/mm oriented at 45°.

Dosimetry and image quality assessment

Dose area product (DAP) values were measured using a dedicated DAP meter (KermaX-plus, IBA, Germany) attached to the collimator assembly. A DAP value of 51.05 μGym² at 70 kVp, 8 mAs and 9.09 μGym² at 110 kVp, 0.8 mAs obtained from Siemens Fusion unit for imaging the phantom was based on factors used clinically. This DAP value was matched across all the other FPDs by altering the mAs values to check consistency in the image acquired. Subsequently, the mAs was altered to achieve low doses with optimal image quality in all DR systems to study the efficacy of FPDs to low radiation doses. To simulate the clinical practice in chest radiography, the use of grid was restricted to 110 kVp only. All measurements were performed by placing the phantom directly on the table-top with field size of 40 cm × 40 cm and 115 cm source to image receptor distance. No added filtration was used for any FPD systems in the study.

For quantitative measurements, all images were exported to Picture Archival and Communication System (PACS) (GE Centricity, USA). Using the measurement tools in the PACS workstation, the CNR, SNR were assessed by defining three representative regions of interests (ROIs) as shown in Figure 1. The placement of the ROI was based on the study reported by Liu et al.[27] The CNR was thus computed using the formula given below

\[
\text{CNR} = \frac{\text{MPV}_R - \text{MPV}_B}{\sigma_{BG}}
\]

Where, \(\text{MPV}_R\) is the mean pixel value of the anatomical region, \(\text{MPV}_B\) is the mean pixel value of the background near the selected anatomical region, \(\sigma_{BG}\) is the standard deviation of the background. The SNR was calculated by the formula given below

\[
\text{SNR} = \frac{\text{MPV}_R}{\sigma_{BG}}
\]

Table 1: Characteristics of the flat panel detectors assessed in this study

| Digital radiography unit | Detector name | Year of installation | Pixel pitch (μm) |
|-------------------------|---------------|----------------------|------------------|
| Siemens fusion          | Trixell       | 2012                 | 149              |
| Siemens aristos         | Trixell       | 2007                 | 143              |
| GE definium 8000        | GE flashpad   | 2010                 | 200              |
| Philips digital diagnost| Trixell pixium 4600 | 2007               | 143              |
| Fujifilm FDR smart X FGXR | FDR D-EVO plus C43i | 2016           | 150              |
| Fujifilm FDR smart FGX  | FDR D-EVO plus C35 | 2019           | 150              |
| Prognosys prorad        | Canon         | 2011                 | 125              |

The phantom images acquired from all the FPDs were viewed using a calibrated monitor with a resolution of 1280 × 1440 utilized by the radiologists for reporting. Contrast and spatial

response, lag, modulation transfer function, detector quantum efficiency (DQE), noise power spectrum, and system transfer properties.[20-22] Alternatively, contrast-to-noise ratio (CNR), signal-to-noise ratio (SNR), and figure of merit (FOM) are other quantitative tools for assessing image quality in an FPD.[23,24] A semi-anatomical chest phantom can provide an information on both the quantitative and qualitative performance of an imaging detector as reported in the literature.[25] This study intends to assess the impact of radiation dose on image quality in seven different FPDs with the help of a semi-anatomical chest phantom for different imaging protocols and optimize radiation dose in low and high kVp chest radiography.

Pearlin, et al.: Optimization of radiation dose and image quality using FPD

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\[
\text{SNR} = \frac{\text{MPV}_R}{\sigma_{BG}}
\]

The phantom images acquired from all the FPDs were viewed using a calibrated monitor with a resolution of 1280 × 1440 utilized by the radiologists for reporting. Contrast and spatial
resolution patterns were rated by two radiologists and two medical physicists. The rating was based on the number of contrast (discs) and spatial details (line pairs) that were completely visualized. The image size was magnified to ×2 with preset window width and window levels. The overall rating for the contrast and spatial resolution was determined as the average rating of the number of details and the line pairs seen from the four observers. The FOM referred to as the dose-to-information efficiency was calculated by using the formula given below

\[
FOM = \frac{CNR^2}{DAP}
\]

Pearson correlation was used to evaluate the differences in the contrast details observed between the FPDs at both tube potentials.

**RESULTS**

This study involved the evaluation of image quality using a semi-anatomical chest phantom with reference and low radiation dose for 7 FPDs from five different manufacturers as shown in Tables 2 and 3. In general, it was observed that the radiation dose and mAs decreased with increase in kVp. Table 2 represents the image quality characteristics evaluated at 70 and 110 kVp using the reference radiation dose. At both tube potentials, CNR was higher in the lung region followed by heart and diaphragm in all FPDs except in both Fujifilm systems where CNR was high in the diaphragm region, followed by heart and lung. In contrast, the SNR was higher in the lung region followed by the heart and diaphragm in both Fujifilm systems, whereas the SNR was higher in the diaphragm region followed by the heart and lung in all the other FPDs. The FOM at 110 kVp was higher than 70 kVp in all FPDs. The spatial resolution was based on the pixel size of each detector element and hence, it was 2.8 lp/mm for Siemens Fusion, GE Definium 8000, and Prognosys ProRad while the other systems had 3 lp/mm.
Table 3 represents the lowest radiation dose required to achieve optimal image quality using manual selection of exposure parameters. At 70 kVp, a dose reduction of 20%, 21%, 21.6%, 59.5%, 60.7%, 62.2%, and 67.6% was observed in Prognosys ProRad, GE Definium 8000, Siemens Fusion, Fujifilm FGX, Fujifilm FGXR, Philips Digital Diagnost, and Siemens Aristos systems, respectively, when compared to radiation dose used for reference exposure factors. At 110 kVp, the radiation dose was reduced by 15.7%, 34.8% less for Philips Digital Diagnost, Siemens Aristos, whereas the other systems had no dose reduction. The FOM for Philips Digital Diagnost at both tube potentials with low dose protocol was high in the lung and heart regions when compared to all the other FPD systems as shown in Figure 2a-c. The image quality improved when there was an increase in CNR, SNR, and FOM values. The CNR, SNR, FOM, contrast resolution, and spatial resolution observed in Table 3 were similar to findings observed in Table 2.

**DISCUSSION**

Digital radiographic imaging using FPDs has brought about significant development in the field of medical imaging, especially in enhancing workflow. Due to its wide dynamic range, the DR has the potential to impart high radiation doses to patients if exposure parameters are not optimized.[28,29] Balancing radiation dose with image quality is the goal of optimization. Achieving diagnostic image quality at low radiation doses has become feasible due to various image processing algorithms. Chest radiography is the most common imaging technique that has been widely accepted in all hospitals globally. A critical evaluation of chest radiograph is required for medical diagnosis due to a lot of contrast variations in the chest; hence it is crucial to obtain good quality images.[30]

Image quality is influenced by kVp, mAs, radiation dose to the detector, pixel size of the detector, DQE, FPD technology, and use of grid.[23] Irrespective of the radiation dose or protocols selected, all FPDs displayed high CNR values in the lung and heart regions at both tube potentials except in Fujifilm detectors as it utilizes an inverse lookup table in digital processing to produce image contrast, hence the CNR values were observed to have a negative number. In a study conducted by Liu et al.,[27] CNR was measured for both low and high tube potentials with and without the use of grids. They observed high CNR values in the lung and heart regions at 70 kVp compared to 110 kVp with and without the use of grids. However, CNR for the diaphragm was higher in 110 kVp with and without the use of grids. In our study, an increase of CNR was observed in all regions at 110 kVp compared to 70 kVp which could be attributed to the use of grid at 110 kVp. The CNR observed at 110 kVp was less than the CNR at 70 kVp for Fujifilm FGX, whereas Fujifilm FGXR exhibited higher CNR values at 110 kVp though both the detectors used the same detector technology. The reason for these differences could be due to the different software algorithms in both systems. The software algorithms used in FPD systems are vendor specific and involve the different process for noise reduction, contrast enhancement, and the type of noise reduction used in each FPD system is relatively unknown as described in the literature.[24]

Unlike CNR, SNR takes into account only the mean pixel values from the specified anatomical region and excludes the mean pixel values from the background region. The SNR was found to be high in diaphragm followed by heart and lung in all FPDs except both Fujifilm systems where the SNR was high in lung followed by heart and diaphragm. The noise levels plotted against kVp for low dose protocol is shown in Figure 3a-c. The noise levels were generally found to be higher in the lung region followed by the heart and diaphragm in two

![Figure 2: Plots of measured values of figure of merit against tube potentials (kVp) for different flat panel detectors used (a) lung, (b) heart and (c) diaphragm](image)

![Figure 3: Plots of measured values of noise against tube potentials (kVp) for different flat panel detectors used (a) lung, (b) heart and (c) diaphragm](image)
### Table 3: Image quality evaluation of different flat panel detector systems while using low radiation dose

| kVp | Lung | Heart | Diaphragm | FOM | SNR | DAP (µGy mAs⁻¹) | Spatial resolution (Lp/mm) |
|-----|------|-------|-----------|-----|-----|------------------|--------------------------|
| 70  | Siemens Aristos | 6.3  | 4.002 | 3.59 | 3.17 | 0.3 | 3.15 |
| 110 | Prognosys ProRad | 0.5 | 11.02 | 3.7 | 0.6 | 0.997 | 16.72 |
| 110 | Fujifilm FGX | 0.5 | 11.02 | 3.7 | 0.6 | 0.997 | 16.72 |
| 110 | Philips Digital Diagnost | 0.5 | 11.02 | 3.7 | 0.6 | 0.997 | 16.72 |
| 110 | Siemens Fusion | 0.5 | 11.02 | 3.7 | 0.6 | 0.997 | 16.72 |
| 110 | GE Definium 8000 | 0.5 | 11.02 | 3.7 | 0.6 | 0.997 | 16.72 |

The FOM is a factor which determines the efficiency of FPDs as it includes both CNR and radiation dose and is a good indicator in assessing image quality. The FOM was high in all three regions at 110 kVp when a grid was used irrespective of the protocols selected. The FOM in the lung region was high for Siemens Aristos followed by Philips Digital Diagnost, Fujifilm FGX, GE Definium 8000, Siemens Fusion, Prognosys ProRad, Fujifilm FGXR, and in the heart region, FOM was high for Siemens Aristos, Fujifilm FGX, Philips Digital Diagnost, GE Definium 8000, Siemens Fusion, Prognosys ProRad, Fujifilm FGXR and in the diaphragm region, FOM was high for Siemens Aristos, GE Definium 8000, Fujifilm FGX, Philips Digital Diagnost, Siemens Fusion, Prognosys ProRad, Fujifilm FGXR when 110 kVp was selected. When low dose settings were selected at 70 kVp, the Philips Digital Diagnost system had higher FOM for lung and heart followed by Siemens Aristos, both Fujifilm, Siemens Fusion, Prognosys ProRad and GE Definium 8000; however, for the diaphragm region, the FOM was higher for GE Definium 8000 followed by Siemens Aristos, Siemens Fusion, Philips Digital Diagnost, both Fujifilm systems, and Prognosys ProRad. The FOM of Siemens Aristos was higher than Siemens Fusion detector though the Siemens Aristos detector was 5 years older than Siemens Fusion indicating the age of the detector did not affect the FOM. The reduction of FOM in Siemens Fusion is probably due to the difference in detector and postprocessing algorithms.

Apart from the quantitative assessment of image quality, contrast, and spatial resolution from the test object in the phantom as assessed by different observers. The contrast details were found to be acceptable for diagnosis irrespective of the tube potential and protocol. The contrast details visualized in the diaphragm region at 70 kVp were less than those observed at 110 kVp irrespective of the protocols and FPDs used. However, the contrast details for lung and heart were similar in both tube potentials, protocols and FPDs used. The contrast details reported by the observers for the two tube potentials at low dose protocol was not significant (lung \( P = 0.174 \); heart, \( P = 0.38 \); diaphragm, \( P = 0.702 \)).

As reported in the literature, our study also suggests the use of high kVp technique for chest radiography to provide better penetration of mediastinum and increase visualization of soft structures in lungs by the suppression of visibility of ribs. \(^{[31]}\) In addition, wide dynamic range of FPDs offers manipulation different protocols used. This reason could be attributed to the imaging of the semi-anatomical phantom. From the graphs, it was observed that the noise levels for Philips Digital Diagnost were higher than the rest of the FPD systems in all three regions at both tube potentials. Multiple vendors have manufactured FPDs with different pixel sizes and as the pixel size decreases, image noise tends to increase. Although detector pixel size influences image noise, various algorithms are introduced to reduce image noise, however, due to the diversity of noise reduction algorithms between vendors, it is uncertain to quantitatively assess the image quality of different FPDs.\(^{[24]}\)
of image contrast with the use of postprocessing algorithms irrespective of the tube potentials used. The spatial resolution for Siemens Fusion, GE Definium 8000, and Prognosys ProRad are 2.8 lp/mm while it was 3 lp/mm for the rest of the FPDs throughout the study indicating that the spatial resolution is dependent on the size of the detector elements, focal spot size, and detector type. Although the phantom has shown to be an effective and reliable quality control tool for optimizing radiation dose and its effect on image quality of different FPDs, the images acquired using this phantom cannot be compared with the clinical radiographs.

**Conclusion**

This study demonstrates the feasibility of using a semi-anatomical chest phantom in the evaluation of image quality for different FPD systems at both low and high kVp chest radiography techniques. The figure of merit was a good indicator in assessing image quality between different detectors. It was possible to optimize radiation dose without compromising image quality in five different DR systems.

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**Conflicts of interest**

There are no conflicts of interest.

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