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The Practice of Chest Radiography Using Different Digital Imaging Systems: Dose and Image Quality

Soo-Foon Moey [1*], Zubir Ahmad Shazli[1], Inayatullah Shah Sayed[1]

1. Department of Diagnostic Imaging and Radiotherapy, Kulliyyah (Faculty) of Allied Health Sciences, International Islamic University Malaysia, Kuantan Campus, 25200 Kuantan, Pahang, Malaysia

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ABSTRACT

Introduction: The study was undertaken to evaluate the practice of chest radiography using different digital imaging systems and its influence on dose and image quality.
Materials and Methods: The study was carried out in two hospitals from March 2016 to June 2016. Sixty ambulatory patients aged 21 to 60 years who were able to cooperate without difficulty and weighed between 60 to 80 kg were selected randomly. The active matrix flat panel imagers technology was employed in the direct radiography (DR) system for Hospital A, whilst Hospital B used the single read out computed radiography (CR) system. The dose area product (DAP) meter was utilized in measuring the entrance surface air kerma. The chest radiographs were evaluated by two radiologists.
Results: The mean entrance surface doses (ESDs) for posteroanterior chest in Hospital A (0.098 mGy) was lower than that obtained in Hospital B (0.161 mGy). However, the ESDs at both centres were lower than the recommended value by the International Atomic Energy Agency (IAEA; 0.3 mGy). The quality of the images for chest radiography in both hospitals was adequate to make a diagnosis with ESDs and effective doses lower than those recommended by IAEA and United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).
Conclusion: The study serves to highlight the practice of chest radiography with two different systems and its influence on image quality and dose. It can be concluded that there were significant differences in image quality and radiation dose for chest radiography practice using CR and DR.

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Introduction

Despite the advancements in radiological technology, particularly cross-sectional techniques, chest radiography remains the first-line chest imaging technique. Amongst the benefits of chest radiography is the speed of image acquisition and interpretation, low radiation dose, and low costs [1]. So far, chest radiography has made a vital contribution to excluding chest diseases and cardiac conditions, as well as to ascertaining treatment responses. In the radiological arena, digital radiographic examinations account for about 50% of the total dose arising from radiation [2] and chest X-rays account for about 25% [3] and 30-40% [4] of all the radiological examinations performed.

The proposition surrounding digital radiography (DR) for reducing dose besides high dynamic range is dose efficiency. As density and image contrast can be optimized in digital radiography, radiographers can easily vary them. Due to this, variability in density and image contrast can easily be unobserved which can result in dose increase, known as “dose creep” [1, 5]. Dose creep may not be a major issue in low-dose radiography such as chest radiography. However, when considering dose optimization, the multiplicity of subsequent chest radiographies conducted on the hospital population, and in particular, the young population, remains a major concern [2]. As digital systems have wide latitude in dose level settings, radiographers tend to increase radiographic exposure to ensure an image of acceptable quality is produced, which can result in unintentional increase of radiation dose to the patient. It is therefore important to evaluate the practice of radiographers in the clinical setting utilizing two different digital imaging systems and its influence on image quality and radiation dose to the patients, ultimately, eliminating radiation doses that do not contribute to the diagnosis.

In clinical practice, different digital technologies for chest radiographic examinations are available. Detector development in direct radiography (DR) and computed radiography (CR) constitutes the greatest technological improvement in radiology [6]. The abilities and explicit characteristics of the digital

**Corresponding Author:* Department of Diagnostic Imaging and Radiotherapy, Kulliyyah (Faculty) of Allied Health Sciences, International Islamic University Malaysia, Kuantan Campus, 25200 Kuantan, Pahang, Malaysia. Tel: +609-5713346; Fax: +609-5716776; Email: moeysf@iium.edu.my

detector affect radiographic technique preference, the image quality produced, and the radiation dose received by the patient. In DR, the caesium iodide material is packed into slender columnar structures parallel to one another for the incident X-ray photons to be along the length of this columnar arrangement. This phosphor arrangement limits the spread of light photons in the proximity of the X-ray absorption region during the X-ray light conversion and on to charge collecting system. Further, this approach allows increased absorption efficiency via the columnar arrangement in creating thicker X-ray absorbers with less degradation of spatial resolution as compared to converters that are unstructured with equivalent thickness [7]. In CR, the degradation of spatial resolution is mainly caused by laser light beam scattering during image readout as the laser light scattering de-excites regions of the phosphor in the imaging plate. This then results in "blurring" outside the size of the pixel.

Detectors used in both CR and DR are dominated by quantum and electronic noise. However, fixed pattern noise such as light collection efficiency exists in the reader employed for CR, and pre-amplification utilized in DR can be eliminated through digital post-processing. Digitization of the analogue data contributes to quantization noise in both CR and DR. Detectors used in digital radiography typically use 10 to 14 bits in creating the output image to minimize quantification noise. However, some systems employ logarithmic pre-amplification to minimize quantification mistakes for low-signal output detectors [7]. However, noise in CR systems was basically more than that in DR systems, hence better image quality attainment using DR compared to CR [8]. In addition, scatter radiation, a form of noise, contributed to the degradation of image quality in digital radiography due to the reduction of the dynamic range of intensities. Primarily, scatter affects radiographic contrast, and signal-to-noise ratio (SNR) is decreased due to the reduction of signal and the introduction of Poisson quantum noise [7].

Comparative studies carried out on various detectors suggested that differences in results can be attributed to the system used (CR, screen film [SF], or DR), the dose level, the statistical analysis method, the nature of lesions delineated, and whether it is a clinical or phantom study [1]. Most studies in the past assessed the likelihood of reducing radiation dose in chest radiography by comparing CR with SF or DR with CR [5, 8, 9]. However, some interest amongst researchers has been generated in studying the performance of numerous digital systems [8-12], with the majority of the studies using either objective measures or human observer phantom studies [1]. So far, few studies have compared the practice of chest radiography using different digital imaging systems and its influence on radiation dose and image quality in clinical settings. As such, this study sought to evaluate the effects of chest radiography using CR and DR systems on radiation dose and image quality in hospitals A and B using the modified evaluation criteria lists derived from the European Commission (EC) image quality criteria [13]. The results from this research could enhance the knowledge and awareness pertaining to the influence of two different digital systems in chest radiography on image quality and radiation dose.

Materials and Methods

The research protocol was carried out after obtaining ethical approval from the Ethics Committee of the International Islamic University of Malaysia (ethics approval No.: IIUM/305/14/11/2/IREC581). Sixty ambulatory patients with body mass index (BMI) within the range of 25-30 kg/m^2 were recruited, 30 of whom were from Hospital A and 30 patients from Hospital B; all the patients presented to the hospital for posteroanterior (PA) chest X-ray. All the subjects consented to participate in this prospective study. The study at Hospital A was performed from March to May 2016, while in Hospital B, it was carried out during June-July 2016. Recruitment of patients for the study was stopped once 30 patients from each hospital had been chosen. Patient data such as height, weight, and AP thickness were taken, and technical factors such as tube potential (kVp), tube current-time (mAs), focus to film distance (FFD), and collimation size were recorded.

Hospital A utilized the Axiom Aristos unit (Siemens, Germany) and a flat panel caesium iodide-amorphous silicon detector. However, both hospitals used the same type of viewing monitor (EIZO Flex Scan L557 and Konica Minolta Dry Pro 873 printer (Japan). The X-ray unit employed in Hospital B was the Vertex Multitop system (Siemens, Germany) and image acquisition was performed via using a barium fluorobromide plate activated with europium. Quality control checks for the viewing monitor and printer for Hospital A were on 28th February 2016 and 17th February 2016, respectively. While quality control check for the viewing monitor in Hospital B was performed on 17th May 2016 and for the printer on 6th June 2016. All the images were printed by the radiographers that carried out the examinations.

Dose Area Product

The entrance surface air kerma (ESAK) from each exposure was measured using a dose area product (DAP) meter (KermaX plus IDP, Germany). The DAP meter's ionization chamber was inserted below the collimators of the X-ray tube to intercept the field of irradiation, which is proportional to exposure area product (EAP). The relationship of these quantities can be explained using the equations below:

$$DAP = a \times b\,(air) = c\,(air) \times d \quad (1)$$

$$DAP = \frac{e}{f} \times d = \frac{e}{f} \times g \times \left(\frac{h}{j}\right)^2 \quad (2)$$

where a is the irradiated area at the DAP position (collimator), b (air) denotes the entrance surface air kerma (ESAK), c (air) indicates entrance surface skin dose, d exhibits the irradiated area at the focus to skin distance, e is the entrance surface dose, f shows the back scatter factor, g demonstrates the irradiated area at the focus to film distance, h is the focus to skin distance, and j denotes the focus to film distance.

Assessment of Image Quality

Qualitative assessment via observer performance rating of visibility acceptance of anatomical features provided an adequate method of assessing radiographic diagnostic acceptability. As the image quality criteria are related to the subjective interpretation of visual data, the difference in the inter-radiologist agreement could be due to whether the interpretation is based on appropriateness of the image for its intended purpose or the radiologists' perceptions or abilities [8]. The two centres' chest radiographs were rated by two radiologists using high contrast 1500 cd/m^2 illuminator. The modified evaluation criteria derived from the EC, 1996 [13] formed the radiologists' performance assessment in this study as shown in Table 1.

The two invited radiologists who were blinded to the study evaluated the image quality using the modified evaluation criteria list. Each radiologist was required to rate the visibility of the anatomical structures based on a grade scale of 1 to 4 for each criterion. Each criterion was rated on a scale of 1 to 4 and as there were eight criteria, the total score ranged from 8 to 32 for each radiograph with higher scores indicating better image quality in this graded score system (Appendix 1). Consistency in the rating of the radiographs' image quality was maintained by employing the same radiologists. Table 1 summarizes the statement criteria found in the score sheet.

Statistical Analysis

The scored data in the study were analysed using SPSS. The patients' demographic factors and technical parameters were summarized using descriptive statistics such as mean and range to provide an overview of the collected data. As the data were not normally distributed, Spearman's rank order correlation (rho) was used to evaluate the correlation of both ESD with mAs and kVp with weight. Linear regression was utilized to assess the contribution of variance of mAs to ESD, while inter-rater agreement was evaluated by using Cohen Kappa statistics [14].

Results

Sixty patients consisting of 30 women and 30 men from the two hospitals with the mean age of 46.3 years (age range: 21 to 60 years) for Hospital A and the mean age of 23.8 years (age range: 18 to 30 years) for Hospital B were included in the survey. The patients' mean weight in Hospital A was 65.6 kg, while the mean weight of patients from Hospital B was 68.3 kg. The mode tube potential for Hospital A was 121 kVp, while that of Hospital B was 125 kVp.

Density, contrast, and resolution were subjectively evaluated by the two radiologists using the modified Commission of European Communities (CEC) score sheet [13]. The mean ESD for PA chest radiographic examinations for Hospital A was 0.098 mGy (range: 0.038 to 0.158 mGy), while that of Hospital B was 0.161 mGy (range: 0.069 to 0.198 mGy). Table 2 summarized the patient and technical parameters and the mean ESD for PA chest examinations accrued in the study for the two hospitals, as well as those obtained from other studies. The mean S value obtained for Hospital A was 177.8 (range: 138.6 to 217) and for Hospital B it was 383.6 (range: 188.6 to 578.6). Table 3 presents the estimated ESDs, and Table 4 provides the effective doses derived for PA chest radiography in this study and obtained from the literature.

A significant Spearman correlation coefficient of 0.89 ($P<0.05$) was obtained between mAs and ESD for Hospital A, while in Hospital B, this correlation was non-significant ($P=0.29$). The survey also reflected that mAs contributed to 22.3% of the variance for Hospital B and 56% of the variance for Hospital A, which is explained by the linear model on the ESD. A moderate significant correlation of 0.37 ($P<0.05$) was indicated between kVp and weight for Hospital A, and a non-significant correlation was indicated for the same variables for Hospital B.

Table 1. Criteria used to evaluate image quality

	Image Criteria
A	Performed at full inspiration
B	Symmetrical reproduction of the thorax
C	Visualization of the vascular pattern of the lungs
D	Visualization of the trachea, bronchi, heart borders, diaphragm, and costophrenic angles
E	Appropriate density
F	Appropriate contrast
G	Sharpness
H	Appropriate collimation

Adopted from CEC, 1996[12]

Table 2. Summary of patients' characteristics, technical parameters used for posteroanterior chest in the two hospitals and other studies

Variables	Hosp. A	Hosp. B	Hart et al., 2010[15]	Asadinezhad & Toossi, 2008[16]
	Mean (Range)	Mean (Range)	Mean (Range)	Mean (Range)
Age	46.3 (21-60)	23.77 (18-30)	68 (16-97)	45 (18-80)
Weight (kg)	65.6 (57-80)	68.27 (60-80)	70 (49-93)	68 (52-88)
Height (m)	1.64 (1.53-1.78)	1.63 (1.53-1.73)	-	-
AP thickness (cm)	25.5 (21.5-29.5)	25.6 (22.2 – 29)	-	-
kVp	121.5 (121-129)	124.57 (120-125)	88 (62-104)	66 (46-83)
mAs	1.57 (0.97-2.59)	2.4 (1.9-2.5)	5 (0.3)	18 (4-90)
Collimation Size (m^2)	0.11 (0.09-0.12)	0.12 (0.08-0.14)	NA	NA
System	DR	CR	SF (400 speed)	SF(400 speed)
Types of Patient	Ambulatory Patient	Ambulatory Patient	Ambulatory Patient	Ambulatory Patient
AEC	Side Chamber	Side Chamber	Side Chamber	-
FFD (cm)	180	180	180	180
S/EXI Values	EXI Value 177.8 (138.6-217)	S Value 383.6 (188.6-578.6)	-	-

*CR: Computed radiography, DR: Digital radiography, SF: Screen-film

Table 3. Mean entrance surface dose in mSv compared with reported values in the literature

Projection	Exam	This Study (2016)		Hart et.al, 2010[15]	Malaysia, 2009[17]	Asadinezhad & Toossi, 2008[16]	IAEA (Muhugora et al, 2008)[18]
		Hosp. A	Hosp. B				
Posteroanterior	Chest	0.098	0.161	0.15	0.9	0.41	0.33

Table 4. Estimated mean effective dose in mSv compared with reported values in the literature

Projection	Exam	This Study (2016)		Wall et. al., 2011[19]	Hart et. al., 2010[15]	Asadinezhad & Toossi, 2008[16]	IAEA (Muhugora et. al., 2008)[18]
		Hosp. A	Hosp. B				
PA	Chest	0.012	0.021	0.014	0.014	0.04	0.05

Image Criteria Score

Sixty radiographs, 30 radiographs from Hospital A and 30 radiographs from Hospital B, were evaluated for image quality to investigate whether the radiographs produced with the used kVp were of optimum quality. The overall average radiologists' scores for the radiographic techniques utilized in the two hospitals are exhibited in Figure 1. Overall, the image criteria scores for both radiographic techniques and positioning for Hospital A were better than those for Hospital B, except for performance of full inspiration of the patients undergoing chest radiography (Figure 1).

Inter-Observer Agreement

Inter-observer agreement between the two radiologists was computed using Cohen's kappa coefficient, which reflected a high inter-rater kappa coefficient of 0.77 for Hospital A, while that of Hospital B was 0.89.

Discussion

Technical Factors

The findings of the study indicated that the radiographers preferred selecting 121 kVp for the examinations in Hospital A and 125 kVp in Hospital B. The study also indicated the preference of selecting the optimal kVp, which provided the anatomical structure that was being imaged with the best contrast, which is in accordance with the recommendation of the European Commission [13]. The tube current product (mAs) is normally adjusted based on patient thickness [20-21]. However, the radiographers in this study utilized visual estimation as there was no readily available chart in selecting the appropriate mAs to AP thickness. In addition, kVp was quantitatively estimated based on weight in Hospital A as there was a moderate significant correlation between kVp and weight. However, kVp selection in Hospital B was through visual estimation.

Further, Hospital A's employment of the (automatic exposure control) AEC to optimally produce the set image density provided a more accurate means for selecting radiographic exposure (mAs) to patient thickness. This then aided the reduction of misjudgement of the radiographer in setting suboptimal exposures. However, this is true if the anatomical area of interest was placed over the AEC with the correct selection of chamber/s and bucky [20]. Usage of AEC aids in alleviating the tendency of giving overexposure that would result in improved image quality with an unwarranted radiation dose increased to the patient. This phenomenon otherwise known as "dose creep" is of increased concern in digital radiography [22, 23]. This study also indicated that higher kVps were used in the two hospitals than that recommended by EC, 2008 [24], which resulted in lower mAs being used as compared to other studies.

S and EXI Values

As all the digital radiography systems have different indexes, it is difficult to make a comparison across the systems in hospitals A and B. However, the exposure index (EXI) is shown to be proportional to the square of signal to noise ratio, indicating that it is related to image quality. The S and EXI values at hospitals A and B were found to be related to collimation size with poor collimated radiographs, indicative of lower EXI values, which was consistent with the findings of Baker [25]. This was due to the inclusion of areas of air that suggests overexposure, while in fact the radiograph was underexposed. Further, female patients recorded higher S and EXI values due to body part thickness and the size of collimation utilized [25]. Additionally, large variability in S and EXI values are not indicative of large dose differences to the detectors of different systems [26] as even the range of S values was outside the recommended range of 150 to 250 [27], the radiation dose was still below that recommended by the vendors.

Entrance Surface Dose and Effective Dose

The higher ESD attained by Hospital B could be in a minor part due to visual estimation of radiographic exposure parameters in accordance with patient thickness. Even though higher kVp was utilized, higher mAs was used. This might be the cause of misjudgement of the radiographer as manual exposure settings were used for the radiographic examinations. This was indicated statistically as there was a significant correlation between mAs and ESD in Hospital A and a non-significant correlation of between mAs and ESD in Hospital B. The results of this study also reflected the contribution of mAs to the variance of ESD; the linear regression model was 56% for Hospital A and 22.3% for Hospital B.

Further, the higher ESD in Hospital B as compared to Hospital A could possibly due to the lower detective quantum efficiency (DQE) of CR system (single read out) used in Hospital B as compared to the active-matrix flat panel imagers technology employed in the DR system in Hospital A [28]. Due to a lower DQE, higher exposure factors had to be employed when using the CR system, and therefore, a higher radiation dose to achieve a given SNR [29]. It was reported that in the DR system DQE exceeded CR system by as much as 20-35% [6]. This in part is dependent on the detector type and electrodes used for collecting charge utilized for light detection that were placed on the upper stratum of the AMFPI [30]. However, doses were below the recommended value by the International Atomic Energy Agency (IAEA; 0.3 mGy) [18] for adult PA chest. Further, it was also below the recommended diagnostic reference level of 0.25-0.3 mGy for chest radiography [5]. These lower doses were possibly due to the use of high kVp among radiographers in the two hospitals, thereby giving rise to the use of a lower mAs, and ultimately, a lower ESD received by the patients. Moreover, the mean estimated effective doses obtained in Hospital A (0.012 mGy) and in Hospital B (0.021 mGy) were lower compared to the study conducted in Iran and that recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR; 0.05 mGy) [31]. This could be in part due to the SF technology utilized and a lower kVp used (Table 2).

Image Quality

The inter-radiologist agreement was high, hence subjectivity in the rating of the image quality was very low. The results of this survey indicated that images of consistent exposure level were attainable utilizing high kVps with the help of an AEC, resulting in subjective value acceptability of the radiographic image quality with decreased ESD. Numerous factors such as spatial resolution, contrast, and noise affect image quality in CR and DR just as with screen film (SF) radiography. As such, the comparison in performance of CR with single read out utilized by Hospital B and that of the AMFPI technology using structured converter material and caesium iodide (CsI) employed in the DR system in Hospital A in relation to the image quality will be the focus of the discussion.

Spatial Resolution

We compared the median value scores for sharpness in the A and B hospitals. Its value was 4 for Hospital A and 3.25 for Hospital B. The higher median value for Hospital A can be because of AMFPI technology used in the DR detector. Further, thicker phosphor material used in a single side scan in CR system such as that used in Hospital B resulted in more scattering, and therefore, degraded spatial resolution [28]; thus, DR images are considered superior to CR images in spatial resolution.

Noise and Contrast

We compared the contrast and collimation data between the two hospitals. They were found to be 2.9 and 3.4, respectively, for Hospital A and respectively 2.5 and 2.6 for Hospital B. Clearly, these values are lower for Hospital B. This may be due to less effective collimation in Hospital B compared to Hospital A that affected the radiographic contrast due to more scatter reaching the detector (Table 2). This was further affirmed statistically, as there was a significant correlation between contrast and collimation in Hospital A.

Conclusion

Digital radiography is able to address the challenges encountered when undertaking chest radiography, as the wide dynamic range is able to ensure sufficient visualization of the lungs and mediastinum region. Image quality of chest radiographs from the two hospitals were diagnostically acceptable with the ESDs and effective doses below those recommended by IAEA and UNSCEAR. This study serves to highlight the practice of chest radiography in two different hospitals with two different digital systems and its influence on image quality and dose. It can be concluded that there is a significant difference in image quality and dose for chest radiography practice using CR and DR systems. This could be partly due to the differences in detector technology with DR being superior to CR in both ESD and image quality.

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