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Evaluation of the Influence of Exposure Index on Image Quality and Radiation Dose

Soo-Foon Moey[1*], Fatin Naimah Binti Mohamad Asri[1]

1. Department of Diagnostic Imaging and Radiotherapy, Kulliyyah of Allied Health Sciences, International Islamic University Malaysia, Jln Sultan Ahmad Shah, Bandar Indera Mahkota 25200 Kuantan, Pahang, Malaysia

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ABSTRACT

Introduction: The introduction of digital radiography has led to a significant problem in terms of dose creep. To address this problem, manufacturers have established a set of exposure indicators (EI) as a feedback mechanism to safeguard against overexposure. The EI is the measure of incident exposure to the detector that is directly proportional to the signal-to-noise ratio and can be related to image quality. The aim of this study was to evaluate the influence of EI on image quality and radiation dose for the posterior anterior (PA) chest radiography.

Material and Methods: This study was conducted in three phases, namely pre-optimization, experimental, and post-optimization. A total of 60 patients that could fulfill the inclusion and exclusion criteria for the PA chest radiography were recruited. The radiographic technical parameters, dose area product, and EI were recorded. Radiographs were printed and evaluated by two recruited radiologists using the modified evaluation criteria established by the Commission of European Communities in 1996.

Results: Statistical analysis using Spearman's Rho Correlation showed an insignificant relationship between EI and image quality for the PA chest radiography ($P>0.05$). Conversely, there was a significant relationship between EI and radiation dose ($P<0.05$).

Conclusion: The EI can be used as an indirect measure of image quality and radiation dose. The EI does not directly determine image quality since the radiographic technique and parameters used can affect image quality. Although EI can be used as a measure of radiation dose, it cannot provide an accurate measurement of the radiation received by the patient.

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Introduction

The introduction of digital radiography system to medical imaging departments has resulted in its rapid replacement in conventional radiography because of its advantages. Some of the advantages of this system include post-processing capabilities of radiographic images and wide exposure latitude that enables the manipulation of contrast. However, the introduction of digital radiography imaging has created a significant problem in terms of dose creep. Dose creep can be defined as an increase in exposure over time when using the digital system with manual tube settings. It could also result in the increase of patient dose [1, 2].

Furthermore, it is an unintended patient overexposure, which is usually driven by the desire to reduce the amount of quantum mottle on a radiographic image. This is because radiologists tend to address their concern for underexposed images. In contrast, images that are overexposed often receive less focus unless saturation occurs. The potential harms of dose creep are caused by the radiation of unnecessarily high dose to patients. Thus, manufacturers have addressed this problem by developing a set of indicators called exposure index (EI). The term EI refers to the measure of the amount of the exposure that is received by the imaging plate. Hence, the exposure indicator provides useful feedback to the radiographer concerning the exposure delivered to the image receptor. However, it is uncertain whether EI is adopted by radiographers [3].

The exposure indicator is a range of manufacturer-specific values that provides the radiographer with an indication of the accuracy of their exposure settings and optimum image quality for each specific examination. Given that there are various manufacturers of digital imaging systems in the market, different names are used to indicate EI. Furthermore, the definition of exposure indicator varies between manufacturers, which makes it difficult to compare exposure values across systems. Siemens digital radiography system uses an EI value which is directly proportional to dose [4]. However, no reference EI range for a specific anatomical region has been provided by Siemens. However, for the

**Corresponding Author:* Email: moeysf@iium.edu.my

Siemens direct radiography system (Axiom Aristos), the manufacturer-recommended EI value for chest radiography ranges from 150 to 400 [5].

Posterioanterior (PA) chest radiography was used in this study for the evaluation of EI as it is one of the most common types of radiographic examinations performed in the radiology departments and also the most frequently repeated examination. Literature review suggests the importance of basic radiographic practice up to the present time. With the advent of digital radiography technologies, radiographers' competency in selecting appropriate exposure factors and knowledge pertaining to the attenuation processes has been questioned. This is due to the "erosion" of technical factors because of the capability of digital radiography in post-processing [6].

Furthermore, EIs have been reported to be higher during out of hours than within hours [6, 7]. This advocates the re-education of the workforce to prevent unnecessary radiation exposure [8]. It is the radiographers' professional obligation to know the equipment capabilities and utilize the available options in optimizing radiation dose and image quality. Effective usage of digital technology requires updating the scientific knowledge of the radiographers [9].

Education of radiographers regarding the association of EI and patient dose can assist the radiography community in reducing radiation dose. Radiographers must also be aware of technical parameter selection and its effects on patient radiation dose. The EI monitoring based on over and under the recommended range can be used as an educational tool in improving image quality in the department. Furthermore, departmental standardized EI is expected to improve radiographers' performance in optimizing image quality and dose. This will aid in eradicating the widespread use of standardized EI that causes confusion due to manufacturer terminology [10].

Various studies have reported different findings; for instance, a relationship was found between radiation dose and EI [11] but an association between EI and entrance surface dose is projection dependent [12]. Furthermore, [13] reported that EI could be used as a dose indicator for monitoring the consistency of patient exposure. Another study performed by [14] further indicated that EI can be inconsistent in computed radiography but reliable in digital radiography.

The afore-mentioned studies have highlighted the significance of EI in providing feedback for radiographers regarding the adequacy of the technical parameters selected for a projection. New standardized EI adoption is set to facilitate a greater understanding and utilization of EI. With this background in mind, this study aimed to evaluate the influence of EI on image quality and radiation dose for PA chest radiography. The findings obtained in this study can be used to provide the radiographers with the feedback mechanism and information and guide them in adopting the best practices in optimizing image quality and radiation dose.

Materials and Methods

This retrospective study was carried out from September 2017 to May 2018. The study was conducted at the Radiology Department of Hospital Sultan Haji Ahmad Shah (HOSHAS), Kuantan, Pahang Darul Makmur, Malaysia. Ethical approval (No. IIUM/305/14/11/2/IREC581) was obtained from the Research Ethics Committee of the International Islamic University of Malaysia. The X-ray unit used in the current study was Vertex Multixtop (Siemens, Germany) and image acquisition was performed using the Siemens Axiom Aristos flat panel Cesium Iodide-Amorphous silicon detector.

Dose area product (DAP) was obtained using the KermaX plus DAP meter that was placed underneath the entire collimator. The equipment was calibrated and tested to ensure that it functioned satisfactorily. This included the automatic exposure control (AEC) performance, generator check, and X-ray field alignment. This study was performed in three phases. A total of 60 patients that could fulfill the inclusion and exclusion criteria for posteroanterior (PA) chest radiography were recruited, 30 patients were employed during the pre-optimization phase, and the other 30 patients were used for the post-optimization phase.

The patients involved in the study were aged 20-60 years and had a body mass index (BMI) of 25-30 kg/m^2 without any physical, visual, or hearing disabilities. The patients who could not read or understand Bahasa Malaysia or English were excluded. During the pre- and post-optimization phases, the applied parameters and radiographic technique were recorded. For each PA chest X-ray examination conducted, the technical parameters, DAP and EI were recorded. The images were then printed, and their image quality evaluated by two recruited radiologists. Patient's demographic data and technical parameters for the pre- and post-optimization phases of the PA chest examinations are shown in Table 1.

Pre-optimization phase

During this phase, the radiographic technique and exposure parameters were left to the radiographer that was in charge of performing the examination.

Post-optimization phase

In the optimization stage, for each centimeter of anatomical thickness, a change of 2 kVp was utilized [15, 16]. Furthermore, an additional copper filtration of 0.2 mm was employed, together with tight collimation. Before the implementation of the optimization phase, the radiographers in the radiology department were given continuous medical education. This education was performed to convey the common faults when carrying

Table 1. Patients' demographic data and technique parameters

Variables	Pre-optimization	Post-optimization
	Mean (range)	Mean (range)
Age (year)	46.3 (21-60)	42.13 (23-60)
Weight (kg)	65.6 (57-80)	68.5 (60-80)
KVp	121.5 (121-129)	112.7 (102-129)
mAs	1.57 (0.97-2.59)	2.32 (1.0-23.72)
Total filtration	2.5 mm Al	2.5 mm Al+0.2 mm Cu
Collimation size (m)	0.11 (0.09-0.12)	0.104 (0.08-0.19)
System	FFDR (direct)	FFDR (direct)
Types of patient	Ambulatory patient	Ambulatory patient
AEC	Side chambers	Side chambers
FFD (cm)	180	180
EI-value	177 (137.8-216.2)	181.47 (144.67-218.27)

FFDR: full-field digital radiography, AEC: automatic exposure control, FFD: film-focus distance

out the PA chest radiography and suggest corrective actions to be adopted in the post-optimization phase. The importance of accurate and proper anatomical positioning over the AEC detectors was also addressed in this phase. During this phase, the patients were checked for eligibility as for the pre-optimization phase. The examinations were carried out using the same X-ray unit and image acquisition device.

Image quality evaluation

Image evaluations were carried out on all chest radiographs. The images were assessed by two radiologists, who were blinded to the study. The assessment of the images was performed following the modified evaluation criteria for PA chest established by the Commission of European Communities (1996). All radiographs were evaluated using a high-contrast illuminator with a brightness of 1500 cd/m². Both the assessors were requested to evaluate the visibility of anatomical structures based on a score range of 1-4 for each criterion (appendix 1). The total score ranged from 7 to 28 for each radiograph. In this graded system, images that obtain high scores denote a high-image quality and vice versa.

Statistical Analysis

The data were analyzed using SPSS, version 21.0. As the data violated the stringent assumption, Spearman's Rho correlation was performed to determine the relationship between EI and image quality and between EI and radiation dose. In this regard, this correlation coefficient facilitated the rejection or acceptance of the null hypothesis stating that there is no significant relationship between EI and image quality and between EI and radiation dose. Scatter plot was adopted using Microsoft Excel (version 14.0) to depict the linearity, direction, and strength of the relationship between the variables. Cohen's kappa coefficient was utilized to indicate inter-observer agreement amongst the two radiologists for overall scores pertaining to image quality for both pre- and post-optimization phases.

Results

In the pre-optimization phase, the mean age of the patients was 46 years (age range: 21-60 years). In the post-optimization phase, the mean age of the patients was 42 years (age range: 23-60 years). The mean weight for the patients in the pre- and post-optimization phases were almost similar. A slightly lower tube potential was used for the post-optimization, compared to that adopted for the pre-optimization phase. The pre-optimization phase involved the use of an inherent filtration of 2.5 mm aluminum, while the post-optimization phase involved the adoption of an additional filtration of 0.2 mm copper based on the results of the experimental study indicating a significant decrease in radiation dose after the addition of this filtration.

Inter-Observer Agreement

A high inter-observer agreement was indicated among the two radiologists for the overall scores pertaining to image quality. Cohen's kappa statistics showed high agreement values of 0.77 and 0.9 in the pre- and post-optimization phases, respectively.

It was found that the EI values ranged from 110 to 256, reflecting that none of the radiographs in the study had EI value above the recommended EI range. The relationship between the EI and image quality is shown in Figure 1. The scatterplot in Figure 1 shows a very weak but positive linear association between image quality and EI. In addition, no association was found between EI within the recommended EI range and image quality.

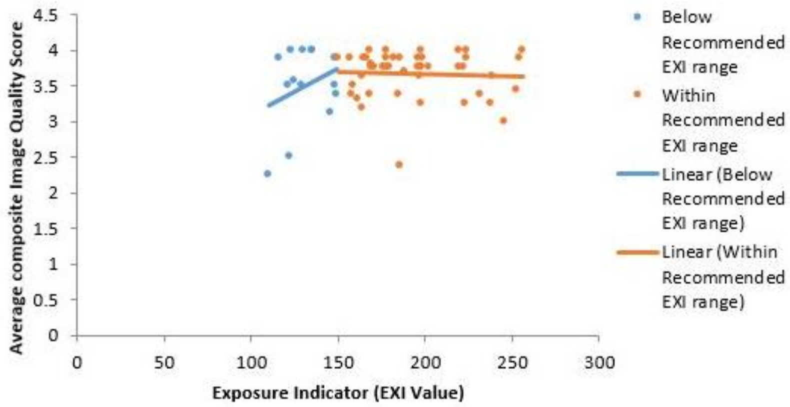

Figure 1. Scatterplot of EXI value against image quality

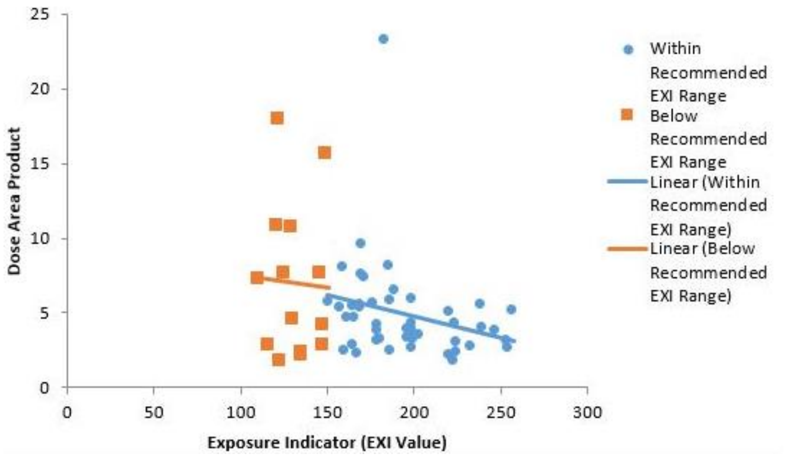

Figure 2. Scatterplot of EXI value against dose area Product

Spearman's Rho correlation was run to determine the relationship between EI within and below the recommended range and image quality. The results of Spearman's Rho correlation between EI within the recommended range and image quality was insignificant (r[46]=-0.004, P>0.05). For the EI below the recommended range and image quality, the results of Spearman's Rho correlation also showed an insignificant result (r[14]=0.140, P>0.05). Hence, the null hypothesis, stating that there is no relationship between EI and image quality for the PA chest radiography, was accepted.

Discussion

Technique parameters have a great influence on determining radiation dose and image quality. Based on the descriptive results, a greater number of EI values were found to fall within the manufacturer-recommended EI range. All these values were mainly obtained in the post-optimization phase. Appropriate kVp was used in the post-optimization phase, which resulted in the use of a lower mAs, and therefore a lower detector exposure. Although a high EI is associated with a high signal-to-noise ratio (SNR), the use of incorrect exposure techniques can result in a high radiation dose to the patient. This is supported by [17, 18] who found that high SNR is associated with good image quality, but high patient dose.

Furthermore, the incorrect exposure "settings" can result in low exposure to the detector, which results in a noisy image. Noisy images do not contribute to good image quality as quality is mainly based on SNR. This further affirmed that low EI indicates underexposure, leading to low SNR, thereby affecting image quality [18, 19]. Furthermore, beam collimation can contribute to reduced exposure to the detector. Collimation limits scatter radiation; hence, smaller collimation will ultimately reduce the exposure to the detector. This can be seen in the post-optimization phase, in which a smaller collimation size was utilized, and a lower radiation dose was obtained.

The use of a copper filter in the post-optimization phase further aided in reducing the low-energy radiation, which probably resulted in the reduction of radiation dose to the patient [16, 20]. The correct use of a properly calibrated AEC further aided the EI to fall within the recommended range [21]. This is probably due to the decrease in exposure setting error by the radiographers as the AEC only requires the selection of kilovoltage, chamber, and density. Furthermore, adherence to the optimization protocols and exposure techniques in the post-optimization phase probably resulted in consistent exposure to the detector, which resulted in radiographs of diagnostic quality [22, 16]. All aforementioned factors could have possibly contributed to images with EI values within the range suggested by the manufacturer.

Based on the results obtained in this study, radiographs that fell within the recommended EI range resulted in better image quality than those having EI below the manufacturer's recommended range. This result is supported by [23], who found that EI within the range recommended by the manufacturer resulted in a radiograph of an optimum quality. In addition, the results of this study showed that there was no correlation between EI values within the recommended EI range and image quality. This is also confirmed by [24] who indicated no direct correlation between EI and image quality.

According to the results obtained in this study, there was a weak but positive correlation between EI below the recommended range and image quality as the EI can indirectly determine image quality. However, it is debatable how manufacturers establish their recommended EI range because of the variation of EI between manufacturers. In the present study, EI was not based on the minimum exposure necessary to produce images of acceptable diagnostic quality [10]. The range recommended by the manufacturer is not definitive; thus, changes can be made depending on the radiation dose perceived by the radiographers to fall within the 'As Low As Reasonably Achievable' (ALARA) principle [1].

The EI is an indicator of detector exposure [25]. Hence, it does not indicate the radiation dose to the patient [5, 17]. According to the results obtained in this study, it was found that radiographs within the recommended EI range had lower DAP values than those below the recommended EI range. In addition, the results of the study indicated a weak negative correlation between radiation dose and EI. This result can be supported by [26] who observed a correlation between entrance surface dose and EI. However, inconsistent with our results, [19] reported that EI and patient radiation dose had a strong correlation. In the mentioned study, a high EI resulted in a high patient radiation dose. Conversely, [4] reported no association between EI and radiation dose.

Findings of this study indicated a negative correlation between radiation dose and EI, which contrasts with the results reported in the literature suggesting that EI value is directly proportional to radiation dose [18, 27]. As reported by [3], a good correlation between patient dose and EI cannot be determined because of the variation in the usage of tube potential, which influences the amount of radiation absorbed by the patient, and thus the detector. Although our results are in contrast to that mentioned in the literature, the negative relationship may or may not represent causation between the two variables, but it describes an existing relationship pattern between EI and radiation dose which is dependent on the projection [12].

Conclusion

The EI can be used as an indirect measure of image quality and radiation dose. The EI does not directly determine image quality because the adopted radiographic technique and parameters can affect image quality. It can be used as an indicator of radiation dose, but it cannot provide an accurate measurement of the radiation dose received by the patient in which a low EI value is reflective of low exposure to the image receptor, thereby resulting in a low SNR. This would result in the achievement of a noisy image with poor image quality. Conversely, an EI within the targeted or recommended range is indicative of an acceptable SNR and acceptable image quality. Thus, EI can be established in the department as a guideline to indicate whether the image produced is of acceptable quality and low radiation dose in accordance with the ALARA concept.

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