IMAGE QUALITY AND RADIATION DOSE COMPARISON IN MEDIUM AND HIGH KILOVOLTAGE FOR DIGITAL PA CHEST RADIOGRAPHY

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ABSTRACT

Introduction: Various medium and high tube potentials were utilized to conduct chest x-rays. There are advantages and disadvantages with regards to image quality and radiation dose when using medium and high kilovoltage (kVp) technique. However, radiographers have misconstrued understanding pertaining to the choice of tube potential as well as grid usage when performing chest radiography. **Methods:** The experimental study was conducted using the PBU-50 phantom by exposing it with medium kVp utilizing grid and non-grid as well as high kVp with grid. All images obtained were evaluated using the modified evaluation criteria for PA chest established by the Commission of European Communities, 1996 whilst the dose area product (DAP) was determined using the Dose Area Product (DAP) meter. The value obtained from the DAP meter was converted to entrance surface dose (ESD) usingCALDOSE_X5.0 software and mathematical formula. **Results:** The Wilcoxon Signed-Rank Test indicated a significant difference in ESD when using medium and high kVp; Z= -2.666, p <0.05. Additionally, a significant difference in ESD was also indicated when using medium kVp with and without the grid; Z= -2.201, p <0.05. Further, Wilcoxon Signed-ranked Test indicated that there was a significant difference in image quality when using medium and high kVp; Z= -2.666, p< 0.05. **Conclusions:** Medium kVp should be used to demonstrate pathological conditions as well structures composed of calcium like the rib, spine or calcified lesions. Otherwise, high kVp is the preferred choice due to its low radiation dose and overall image quality acceptability.

KEYWORDS: Chest, Image Quality, Radiation, Dosage, Digital Radiography

INTRODUCTION

Chest radiography is the commonest examination and contributes to about 30% to 40% of the overall examinations conducted in the radiological arena (Nocetti et al., 2015). Chest radiographs are useful for the detection of abnormalities in the airways, blood vessels, bones, heart, and lungs (Ekpo, Hoban & Mcentee, 2014). The standard practice for chest radiography is a posteroanterior (PA) chest x-ray in the upright position. The images produced are valuable as it serves as the first line imaging technique for diagnosis, treatment and follow-up procedure. Even though radiation dose to the patient for chest radiography is low, the collective dose becomes significant as an individual undergoes this examination repeatedly (Sun, Lin, Tyan & Ng, 2012). Thus, both radiation dose and image quality in chest radiography have been the subject of research.

The development of the digital imaging system allows the minimization of radiation dose in radiography and image enhancement due to its' post-processing capability (Allisy-Roberts & Williams, 2008; Vano & Fernadez Soto, 2007). Due to the wide dynamic range in digital radiography, under or overexposure are quite unlikely to occur, thus lessening image retakes (Williams et al., 2007). This can be fulfilled since the digital system allows adjustment of the contrast in the acquired images. As a digital image has a wide dynamic range and therefore allows a wide margin of error in the exposure setting, there is also a tendency for radiographers to increase exposure factors to avoid repeats. This will then result in the phenomenon called "dose creep" which leads to an "unnoticed" increased in patient dose (Moey & Shazli, 2018).

In combating dose creep, the radiographers need to have the knowledge to select the correct technique parameters. At high kVp (>100 kVp), higher penetrable energy is provided for the photons to reach the receptor. This then contributes to a lower radiation dose as the photons pass through the patient's body tissues. However, the image contrast is low due to the presence of high scatter radiation which can be reduced by using an anti-scatter grid (Moore et al., 2015). In contrast, x-ray photons with medium kVp (60-75 kVp) undergo photoelectric absorption which then limits the amount of photon transmitted through the body from reaching the image receptor. This phenomenon resulted in a high contrast image especially for anatomical structures with different atomic number compositions (Martin, 2007). As a result, the patient radiation dose is notably higher when compared to the usage of high kVp technique.

There are advantages as well as disadvantages with regards to image quality and radiation dose when using medium and high kVp technique. However, it appears that many radiographers to date have not reflected the understanding of the usage of medium and high kVp technique, especially for chest radiography. As such this study aims to provide the knowledge so that radiographers would be better informed in the selection of appropriate technique for producing an image of diagnostic quality with the lowest radiation dose possible to the patient consistent with the As Low as Reasonably Achievable (ALARA) concept.

Presently, various tube potentials were used to perform chest x-rays. The choice of tube potential generally depends on the radiologists' preference in providing the radiological report. The correct selection of kVp setting is crucial on image quality and radiation dose. A higher contrast radiograph can be produced using a medium kVp range but with higher radiation due to photoelectric absorption phenomenon when x-ray interacts with matter. On the other hand, high tube potential usage will result in a wide latitude (less contrast) image but with reduced radiation because of Compton scatter. As such, the radiographer must be competent enough to select the technique parameter, especially the tube potential in relation to the diagnostic information required.

Theoretically, when using medium kVp range, no grid should be utilized unless for isolated cases when the patient is big or obese. This is because there are "naturally" varied anatomical structures found in the region of the chest. This is further enhanced with the phenomenon of photoelectric absorption, resulting in a higher contrast chest image. From the observation of the researcher, radiographers appear to have misconstrued understanding pertaining to the usage of medium and high tube potential as well usage of the grid when performing chest radiography. As such this study aims to compare the image quality and radiation dose when using medium kVp with and without the grid and high kVp with the use of a grid. The information obtained from this study can aid in providing the understanding required by the radiographers in increasing their competency when undertaking PA chest radiography.

METHODS

The experimental study was performed at the Radiography Laboratory, Department of Diagnostic Imaging and Radiotherapy (DDIR), Kulliyyah of Allied Health Sciences, International Islamic University Malaysia, Kuantan, Pahang. A ceiling mounted x-ray unit; Siemens AXIOM Aristos, OPTITOP 150/40/80HC-100 (Siemens, Germany) was used to perform this experimental study with utilizing the thorax of a PBU-50 phantom (Kyotokagaku, Japan). The entrance surface dose (ESD) and image quality were acquired by using kVp settings in the medium kVp and high kVp range as well as with and without the grid. The technical parameters used for the experimental study is as in Table 1 and Table 2.

Table 1. Imaging parameters used for medium and high kVp in PA chest

Imaging parameters	Medium kVp	High kVp
Imaging plate size (cm)	35 x 43	35 x 43
Imaging plate orientation	Lengthwise	Lengthwise
Source to image distance (SID) (cm)	180	180
Central ray (CR)	Perpendicular to midsagittal plane (MSP) of the phantom at T7 level	Perpendicular to midsagittal plane (MSP) of the phantom at T7 level
Kilo-Voltage peak (kVp)	60, 70, 75	105, 113, 121
AEC (Chamber)	On (Side)	On (Side)
Focal spot	Large focal spot	Large focal spot
Grid (grid ratio)	Moving grid, 12:1	Moving grid, 12:1

Table 2. Imaging parameters used for medium kVp using the grid and non-grid in PA chest

Imaging parameters	Grid	Non-grid
Imaging plate size (cm)	35 x 43	35 x 43
Imaging plate orientation	Lengthwise	Lengthwise
Source to image distance (SID) (cm)	180	180
Central ray (CR)	Perpendicular to midsagittal plane (MSP) of the phantom at T7 level	Perpendicular to midsagittal plane (MSP) of the phantom at T7 level
Kilo-Voltage peak (kVp)	60, 70, 75	60, 70, 75
AEC (Chamber)	On (Side)	Off
Focal spot	Large focal spot	Large focal spot
Grid (grid ratio)	Moving grid, 12:1	-

The experimental set up for the experimental study is as shown in Figure 1. All the images were obtained by positioning the thorax of the PBU-50 phantom in an erect position.

Figure 1. Experimental setup for PA chest radiography

The radiation dose from the dose area product (DAP) meter (Kerma X_Plus, IBA, Germany) was placed beneath the collimator to obtain the dose of the entire collimation area during the examination.

Image Quality Evaluation

Two radiographers who were blinded to the study were invited to evaluate the images using high contrast 1500 cd/m^2 illuminator. This is to ensure illumination consistency during the evaluation process. The image quality of the nine images was evaluated using the modified criteria list adopted from the European Community, 1996. The images were scored based on the visibility of the chest anatomical structures using the grade scale of 1 to 4 for each criterion. Since there were eight criteria, the total score ranges from 8 to 32 for each radiograph. In this grading score system, a higher score indicates better image quality. The criteria used for the image evaluation is as in Table 3.

Table 3. Criteria used to evaluate image quality

Image criteria		Score			
		1	2	3	4
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				

Entrance Surface Dose

The radiation dose is read by a dose area product (DAP) meter Kerma X-plus. The ESD was obtained by using the CALDOSE_X5.0 version software. The entrance surface dose (ESD) was then estimated using the DAP values obtained and the irradiated area when acquiring the images using equation 1 and 2.

$$ESD = \frac{DAP}{Area\ (ESD)} \times BSF \qquad \text{Equation 1}$$

$$Area\ (FSD) = Area\ (FFD) \times (FSD / FFD)^2 \qquad \text{Equation 2}$$

(FFD= focal-film distance, FSD=focal-skin distance, ESD= entrance surface dose, DAP= dose area product)

RESULTS

Entrance Surface Dose

Estimated ESAK, INAK values, tube output and backscatter factor using Caldose_X5.0 software for digital PA chest radiography with the range of kVp are as shown in Table 4. The highest and lowest dose area product (DAP) values obtained for the examinations with the grid were 16.48 μGym2 and 7.55 μGym2 respectively. For the examination without the grid, the highest and lowest DAP values were 2.64 μGym2 and 1.93 μGym2 respectively. The ESD were then estimated using Caldose_X5.0 software by insertion of the exposure factors used (kVp and mAs). The estimated ESD values are as in Table 5.

Table 4. Estimated tube output, INAK, ESAK values and backscatter factor using Caldose_X5.0Software.

Imaging parameter				Caldose_X5.0 Software			
Grid status	kVp	mAs	DAP meter (µGy m²)	TUBE OUTPUT (µGy/mAs at 1m)	INAK (mGy)	ESAK (mGy)	BSF
Moving Grid	60	15.4	16.48	60.93	0.38	0.5	1.32
	70	8.9	13.15	80.98	0.29	0.38	1.33
	75	7.2	12.03	102.42	0.26	0.35	1.35
Moving Grid	105	2.88	8.28	148.85	0.19	0.27	1.41
	113	2.46	7.85	173.32	0.18	0.26	1.42
	121	2.22	7.55	198.46	0.19	0.26	1.39
Non-grid	60	2.80	2.64	60.93	0.07	0.09	1.32
	70	1.60	2.14	80.98	0.05	0.07	1.33
	75	1.25	1.93	102.42	0.05	0.06	1.35

Table 5. Conversion of DAP values to estimated ESD for the technical parameters used

Imaging parameter			Entrance Surface Dose (ESD)		
Grid status	kVp	mAs	DAP meter (µGy m²)	BSF (mGy)	ESD (mGy)
Moving Grid	60	15.4	16.48	1.32	0.0014
	70	8.9	13.15	1.33	0.0011
	75	7.2	12.03	1.35	0.0010
Moving Grid	105	2.88	8.28	1.41	0.00075
	113	2.46	7.85	1.42	0.00072
	121	2.22	7.55	1.39	0.00067
Non-grid	60	2.80	2.64	1.32	0.00023
	70	1.60	2.14	1.33	0.00019
	75	1.25	1.93	1.35	0.00017

For chest radiography using the grid (Figure 2), at the lowest kVp (60 kVp), the estimated ESD was 0.0014 mGy and at the highest kVp (121 kVp) the estimated ESD value was 0.00067 mGy with the focus to skin distance (FSD) fixed at 162 cm. Meanwhile, for chest radiography without the grid (Figure 3), at the lowest kVp (60 kVp), the estimated ESD was 0.00023 mGy and at the highest kVp (75 kVp), the estimated ESD value was 0.00017 mGy with the FSD for the examination at 160 cm.

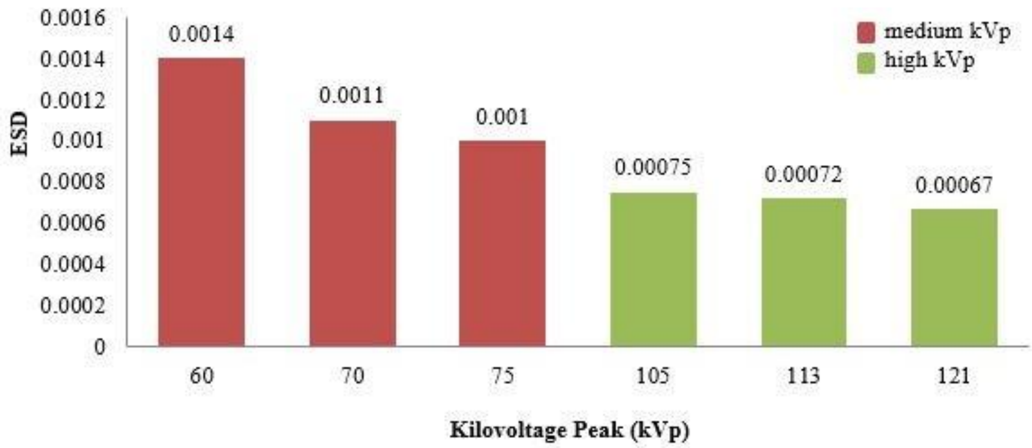

Figure 2. The effect of medium and high kVp on ESD for PA chest

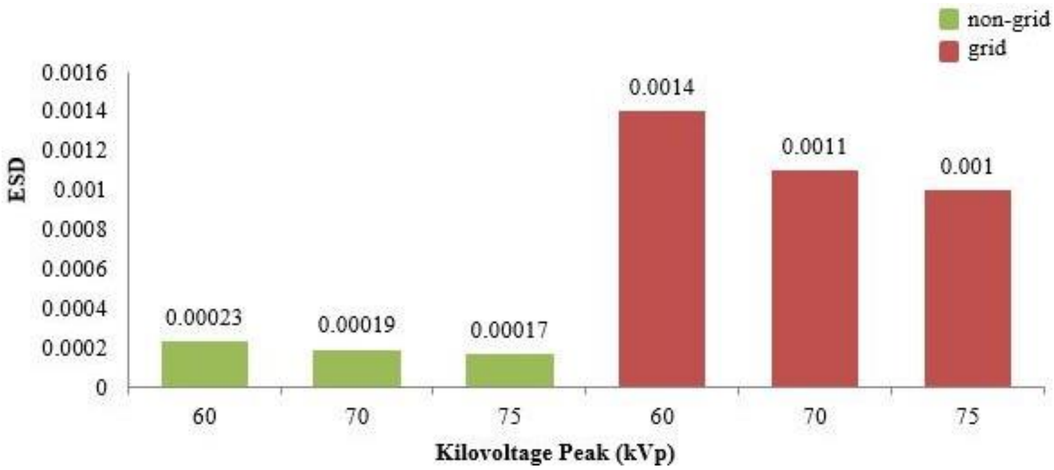

Figure 3. The effect of medium kVp using the grid and non-grid on ESD in PA chest

Image Quality

The score of image quality by the evaluators when using medium and high kVp range are shown in Table 6. The mean score for image quality when using medium kVp with the grid is higher compared to the score attained when using high kVp. For PA chest using medium kVp with and without the grid, the image quality with the grid is slightly higher compared to when without using the grid. This can be deduced that, the higher the kVp, the poorer the image quality. The effect of kVp on image quality is summarized in Figure 4 and Figure 5.

Table 6. Image quality score obtained from the two raters

Imaging parameter			Quality Score		
Grid status	kVp	mAs	Rater 1	Rater 2	Mean score
Moving Grid	60	15.4	23	23	23
	70	8.9	23	23	23
	75	7.2	24	24	24
Moving Grid	105	2.88	21	21	21
	113	2.46	22	22	22
	121	2.22	22	23	22.5
Non-grid	60	2.80	23	23	23
	70	1.60	23	23	23
	75	1.25	22	22	22

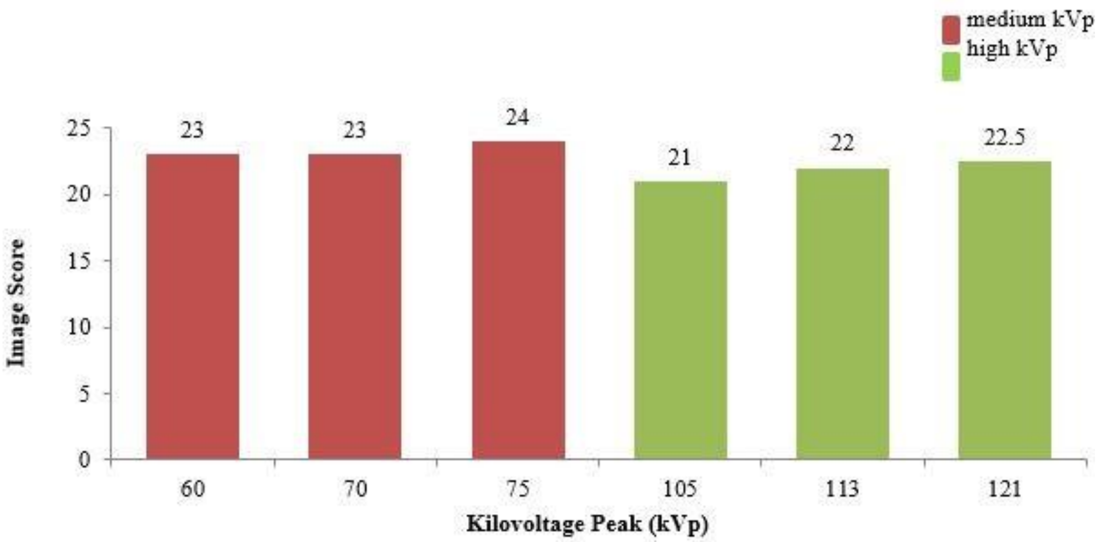

Figure 4. Effect of medium and high kVp on image quality for PA chest

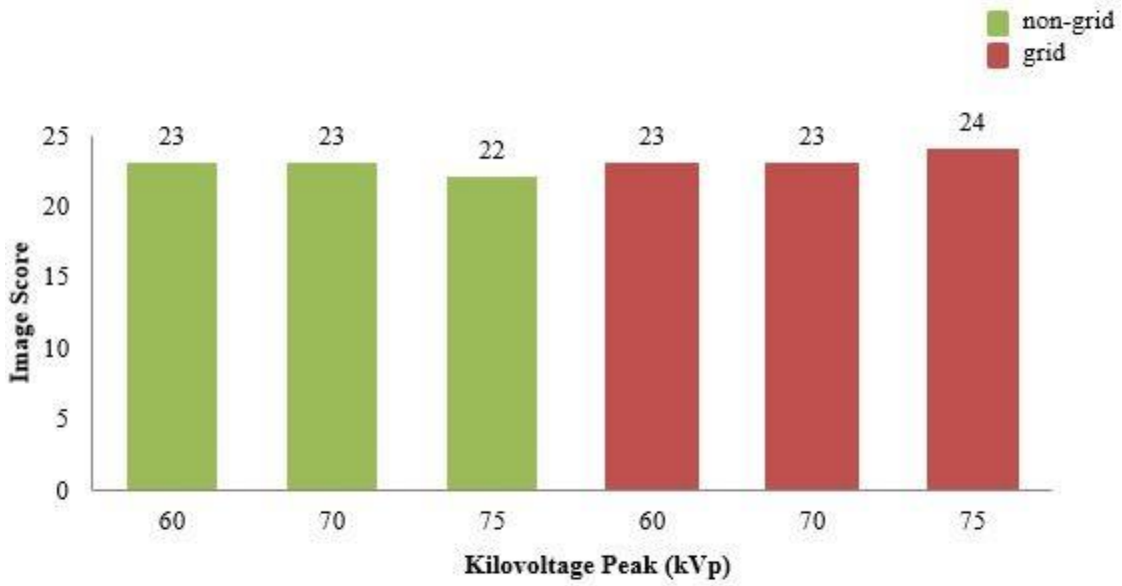

Figure 5. Effect of medium kVp using the grid and non-grid on image quality for PA chest

Inter-Observer Agreement

The result of the inter-rater agreement between the radiographers using Kappa statistics was 0.83. As a rule of thumb, any value that lies from 0.81 to 1.00 is considered an almost perfect agreement.

Effect of Using Medium and High kVp on ESD

The Wilcoxon Signed-Rank Test indicated a significant difference in ESD when using medium and high kVp for PA chest radiography; Z= -2.666, p <0.05. A higher ESD is obtained when using medium kVp with the grid.

Effect of Using the Grid and Non-grid for Medium kVp on ESD

Additionally, a significant difference in ESD is also indicated when using medium kVp with the grid and medium kVp without the grid; Z= -2.201, p <0.05. A higher ESD is obtained when using medium kVp with the grid as compared to the medium kVp without the grid.

Effect of Using Medium and High kVp on Image Quality

Wilcoxon Signed-ranked Test indicated that there is a significant difference in image quality when using medium and high kVp for PA chest examination; Z= -2.666, p< 0.05. A better image quality is acquired when using medium kVp with the grid.

Effect of Using the Grid and Non-grid for Medium kVp on Image Quality

Additionally, there is also a significant difference in image quality when using medium kVp with and without the grid; Z= -2.201, p <0.05. The image quality is better when using medium kVp with the grid as compared to the medium kVp without the grid. Radiographs obtained using medium kVp using the grid and non-grid and high grid and high kVp using the grid is as shown in Figure 6.

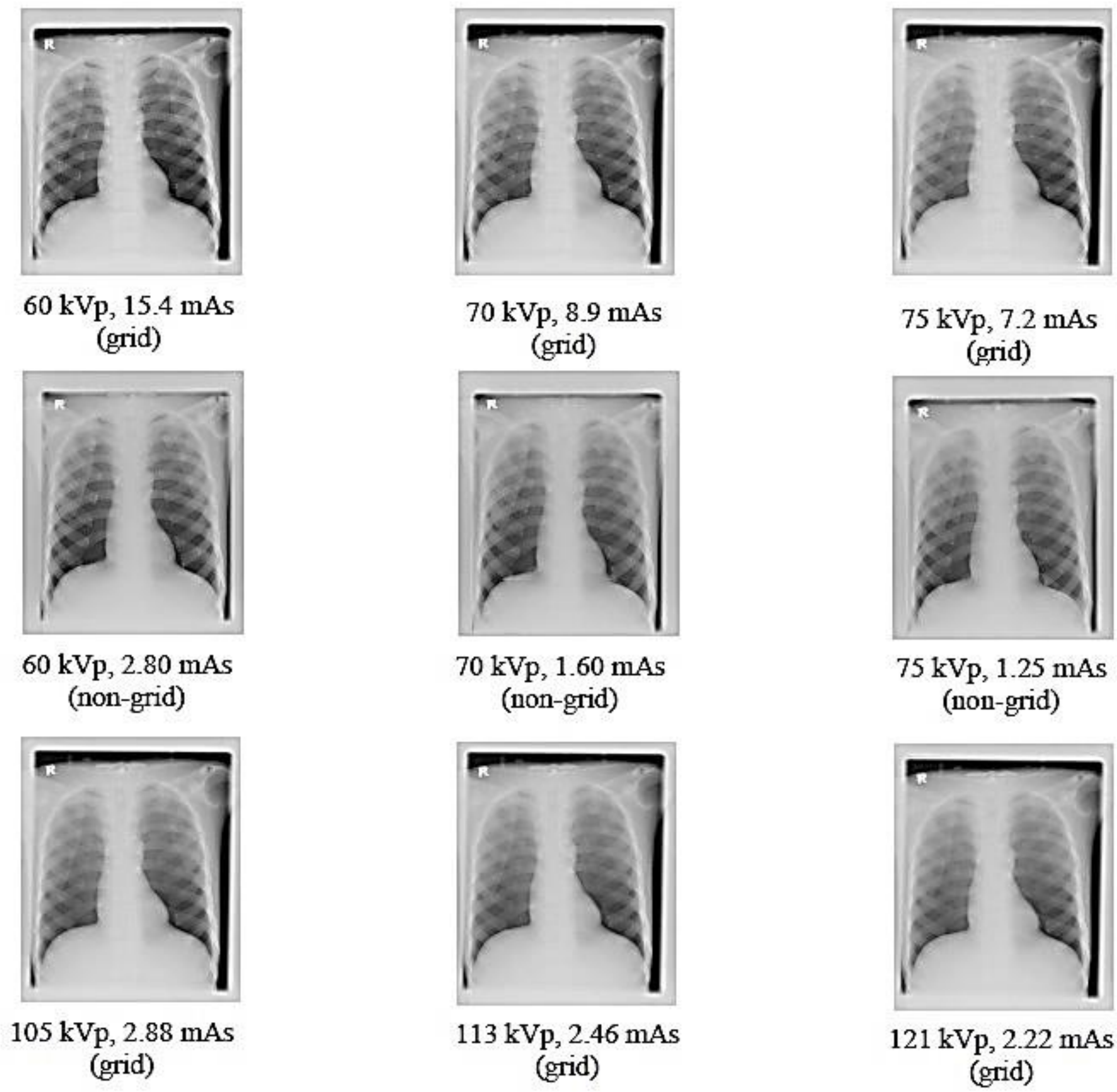

Figure 6. Radiographs obtained using the stated technical parameters

DISCUSSION

Entrance Surface Dose

The result from this study indicated that usage of high kVp with low mAs reduced the ESD for chest radiography. This is because the x-ray photons with higher energy are produced when high kVp is used. As the photons are energetic, it can then penetrate through the tissues in the body. Rather than being absorbed, the photons exit the patient's body resulting in a lower patient radiation dose. In contrast, medium kVp usage contributed to higher ESD as the x-ray photons underwent photoelectric absorption and were absorbed in the body tissues resulting in increased ESD (Bushong, 2015). Photoelectric absorption phenomenon is more likely to occur with low energy photons of 25 keV or below (corresponding to 75 kVp usage) when it interacts with the K- shell electron in the tissue atom. Consequently, the low energy photons are absorbed. At the same time, the ejected electrons experience photoelectric absorption when they travel within a short distance in the absorber (the patient body tissues). Thus, all the energy is deposited in the body tissues, thereby increasing patient's radiation dose.

Further, the usage of the grid increased the ESD when compared to the non-grid technique for medium kVp. The grid besides removing scatter radiation also partly removes the primary x-ray photons. As such, the amount of x-ray photons reaching the image receptor was reduced. Thus, usage of the grid requires an increased in exposure factors to counterbalance the primary beam that has been absorbed by the grid to produce a diagnostically accepted image (Carlton & Adler, 2006).

Image Quality

The image quality for PA chest radiography decreased with an increased in kVp usage. A high kVp resulted in more Compton scattering that will deteriorate the radiographic contrast as a greater proportion of scatter radiation reduces the image contrast (Johnston, 2019; Delrue et al., 2010). As such high kVp selection for a hypersthenic patient resulted in more scattered radiation that degrades the image quality due to a large volume of tissue being irradiated. In general, the selection of kV should provide enough penetration from the hila region to the lungs periphery which is governed by the patient's thickness, body habitus and the type of abnormality to display. In addition, the kilovoltage acts as the controlling factor for both image contrast and scatter radiation production. As the kVp is increased, the scatter radiation also increases causing the image contrast degradation due to the additional noise produced. Nevertheless, higher kVp is essential to penetrate the denser part of the chest such as the mediastinum and the heart to visualize the lung tissue structures behind them as well as minimizing obstruction of the pulmonary pathology by the ribs shadow.

With medium kVp selection, the photoelectric absorption is more dominant. As such, an image with higher contrast demonstrating better differentiation of soft tissue and bony structures is attained. However, the downside of medium kVp selection is that the image has fewer gray scales or has a shorter dynamic range. Moreover, the photoelectric interaction resulted in more patient radiation dose as the x-ray photons do not have adequate energy to escape from the body and thus the total photon energy absorption is increased.

Compton scattering production in high kVp technique and denser tissue composition can be reduced by the utilization of a grid. This device improves the image quality by absorbing scatter radiation before reaching the detector as the undesirable radiation is restricted from reaching the detector. Thus, the visualization of abnormalities in chest radiography is enhanced as the phenomenon results in contrast depiction between adjacent tissues (Uffman & Schaefer-prokop, 2009). As a contrary for non-grid usage, the scattered radiation creates a greater quantum of noise to the radiograph and thus reduced image contrast. This then could result in poor visibility of pathology in the chest region.

CONCLUSION(S)

In conclusion, the study found that there were significant differences in both ESD and image quality when different kVp selection were utilized for PA chest examination. The entrance surface dose and image quality were considerably higher when using medium kVp compared to high kVp. Medium kVp selection should be used to demonstrate pathological conditions that need to visualize underlying soft tissue structures as well structures composed of calcium like the rib, spine or calcified lesions. Otherwise, high kVp technique is basically the preferred choice due to the low patient radiation dose and the overall image acceptability for routine examinations as the greater beam penetration allows higher density structures to be visualized through a range of narrower beam intensities.

ACKNOWLEDMENT(S)

We wish to give acknowledgement for the help given by the clinical instructors namely Radzuan bin Mohd Noor, Maziani binti Hamzah and Fatimah binti Hussain from the Department of Diagnostic Imaging and Radiotherapy. We also wish to thank all staffs and students from the Department of Diagnostic Imaging and Radiotherapy who were involved in the study directly or indirectly.

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