Assessment and Optimization of Radiation Dosimetry and Image Quality in X-ray Radiographic Imaging

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Abstract—The main purpose of this study was to investigate the effect of tube potential on radiation dose and image quality; and to optimize the radiographic imaging by applying different types of parameter such as kilovoltage, types and thickness of filters. Studies were conducted to obtain the best quality radiograph of the RMI chest phantom using Toshiba Mobile Equipment. The first part of this study was to investigate the effect of kVp on radiation dose and image quality by applying different kVps. The second part of this work was to optimize the image by evaluating parameters such as tube potential, filter types (Copper and Aluminium), and filter thickness from 0 mm to 0.6 mm. The absorption dose increases as the kVp increases. The optimization of radiation dose and image quality can be obtained by using Copper filtration. Contrast to noise ratio is higher when using 0.2 mm copper thickness at 100 kVp, which denoted a better image quality. In conclusion, the optimization of x-ray radiographic imaging is needed to produce good quality image without exposing the patients with high radiation dose.

Index Terms—Radiation dose, image quality, x-ray radiographic imaging, optimization

I. INTRODUCTION

DIAGNOSTICS imaging using film has been used since many years ago [1]. During early days, the radiation dose given to the patient does not consider the side effect that will be suffered by the patient. After a number of examination performed, and results on the risk of cancer increased due to ionizing radiation exposure have arised, attention should be given to optimize the radiation dose given to the patient [2-3]. The quality of the image and the anatomic structure that appears within the image depends on the parameters of imaging used and the amount of radiation exposed.

Basically, when the radiation dose is increased, the quality of the image is increased, but it also increased the radiation dose that being absorb by the patient. Level of acceptance of image quality should be recognized before any optimization can be done [4-6]. This to ensure that any clinical diagnostic information needed is not missing out from the image produce. To obtain optimal radiation dose that suitable for producing a good image and cause less harm to the patient, there are several ways to do so.

Optimization of radiation dose technique includes the use of optimum peak kilovoltage (kVp). Basically, when the kVp increases, the energy of x-ray produce will increase. High energy of x-ray beams will penetrate denser material and produce better images. But, high energy x-ray beam will produce more photoelectric reaction that will produce secondary x-ray [2-3]. This secondary x-ray will be absorbed within tissue and increased the absorb dose of the patient. In order to produce optimal image quality and reduce the absorb dose, optimum kVp should be obtained.

When the x-ray beam penetrates into patient's body, the x-ray beam will undergo several reactions. Some of x-ray beam might penetrate through body and hit the film, some of x-ray beam will react with atom inside patient's body yield a Compton scattering reaction and photoelectric reaction and some of x-ray beam might simply being absorbed by the tissue inside the body [4-6].

Usually, soft x-ray is easily being absorbed by the tissue in the body and increase the radiation dose absorb by the patient. Soft x-ray does not contribute to production of image quality [6]. The presence of soft x-ray only increase the radiation dose absorb by the patient. Addition of filters will filter the beam coming out from the x-ray tube. All soft x-rays will be blocked by the filters and left only the x-ray beam with higher energy pass through the patient. The amount of energy blocked by the filters depends on the thickness of the filters. The thicker the filter, the more energy is blocked by the filters and optimization of radiation dose can be achieved.

The main objective of optimization of radiation dose is to ensure that the diagnostic image produces achieve its acceptance level without giving any serious harm to the patient and also the radiographer. Therefore, this study focus on the assessment and optimization of radiation dosimetry and image quality in radiographic imaging.

II. Materials and Method

A. Experimental set-up

In this study, we imaged the RMI Radiographic Chest Phantom (model 170B) using Toshiba mobile x-ray machine. The image was captured on Radiographic film MG-SR Plus Konica Film. The radiation dose was measured using PTW UNIDOS ionization chamber. Two types of filters were used in this study: Copper and Aluminium filters with thickness of 0.2 mm, 0.4 mm and 0.6 mm.

B. Assessment of Image Quality

The assessment of image quality was performed at fixed tube current and exposure time of 1.0 mAs and varying the tube voltage. The RMI Radiographic Chest phantom was exposed with 56 kVp up to 100 kVp with increment of 4 kVp. The film was processed. The images were analyzed using ImageJ software. The mean and standard deviation of background and object from the film were obtained by drawing region-of-interest on the image. The CNR are then calculated using equation (1).

$$CNR= (\mu_{detail} - \mu_{background})/(\sqrt{(\sigma^2_{detail} + \sigma^2_{background})}) \qquad (1)$$

μ_{detail} and $\mu_{background}$ are mean of detail and background respectively. σ^2_{detail} and $\sigma^2_{background}$ are the standard deviations for the detail and background respectively. A graph of CNR against tube voltage is plotted.

C. Measurement of Radiation Dose

The measurement of radiation dose was done using the same parameters applied for assessment of image quality. In this study, the PTW UNIDOS ionization chamber was placed under the exposure window to get the measurement of absorbed dose. The measurements of radiation dose were recorded.

D. Measurement of Radiation Dose and Image Quality for Different Types and Thickness of Filters

The effect of different types and thickness of filters on radiation dose and image quality was investigated. The tube current and exposure time was set at 1.0 mAs and the tube voltage was increased from 80 kVp to 120 kVp. The thickness of Copper filter was added from 0.2 mm up to 0.6 mm. This procedure was repeated for Aluminium filter.

III. Result

The production of image of the body depends on several factors. It is important to understand how the image is produced, anatomical structure that we want to examined, the factors that influence the image quality and radiation dose received by the patient. The CNR are calculated to analyze the image quality. Four graphs of CNR against tube potential was plotted for different parts anatomical structure found in chest phantom: fat, vertebra, tumor and bone step wedge.

Figure 1 shows the CNR of different diameters of fat versus tube potential. The highest CNR of fat can be seen in the range of 72 kVp to 84 kVp for all diameters of fat.

Figure 2 shows the CNR of vertebra versus tube potential. Results show that the highest CNR of vertebra is achieved at 84kVp. The CNR of vertebra decreases above 85 kVp.
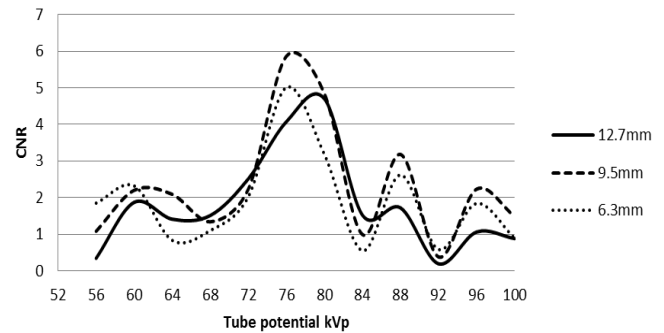

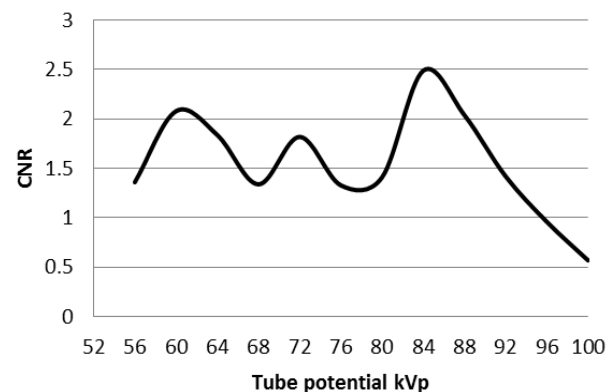Fig. 1. The CNR of fat with different diameters against tube potential

Fig. 2. The CNR of vertebra against tube potential

Figure 3 shows the CNR of all bone stepwedges versus tube potential. The CNR increases slowly as the tube potential increases. The maximum CNR of all bone step wedges is achieved at 100 kVp.
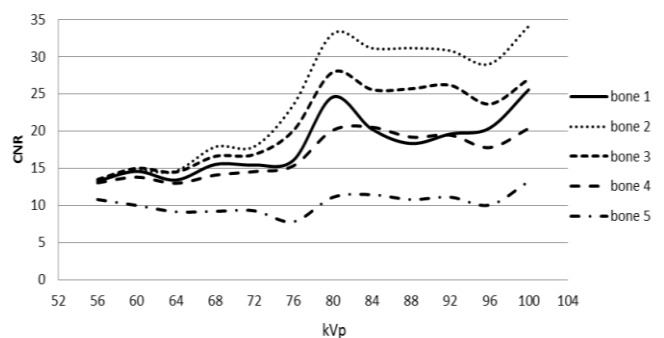

Fig. 3. The CNR of bone stepwedges against tube potential

Figure 4 shows the CNR of tumors of different diameters versus tube potential. The CNR of tumors is maximum at 76 kVp. As the tube potential increases, the radiation expose is also increase.

Figure 5 shows the absorbed dose against tube potential. An increment of 25% an be seen from 56 kVp to 60 kVp. The increment of radiation dose is linear with the increment of tube potential.
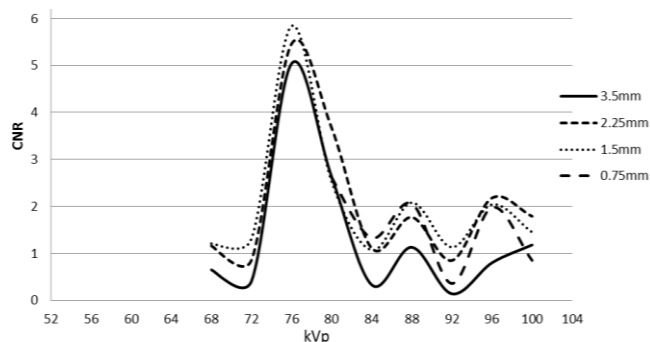
Fig. 4.   The CNR of tumors of different diameters against tube potential
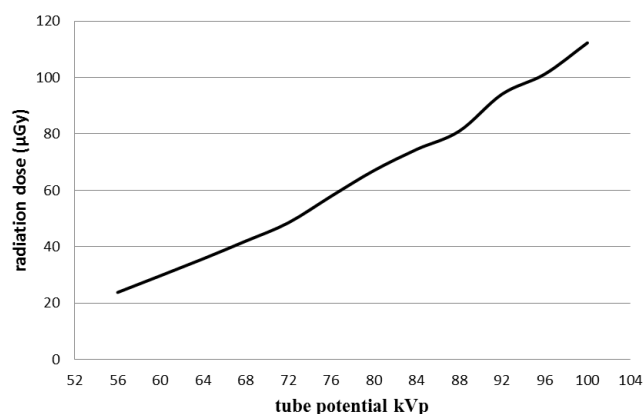

Fig. 5.   The absorbed dose versus tube potential

Results of optimization of radiation dose and image quality are presented in Figures 6 and 7. Figure 6 shows the radiation dose versus thickness of filter at different tube potential. The result shows that as the thickness of an additional filter increases, the dose gradually decreases from 80 kVp to 120 kVp.

Figure 6 illustrates that the reduction of radiation dose of 72.77% can be achieved with 0.2 mm thickness of Copper filter. With 0.4 mm thickness of Copper filter, the dose reduces about 33.34%. For 0.6 mm thick, the dose reduce over 25% compared to 0.4 mm thick.

For Aluminium filter, there is only small dose reduction compare to Copper filter. The reduction of dose only denoted 6.82%, which is ten times lesser than Copper filter. Copper filtration shows gradual decrease in dose while Aluminium filter only shows a moderate fall in dose reduction.
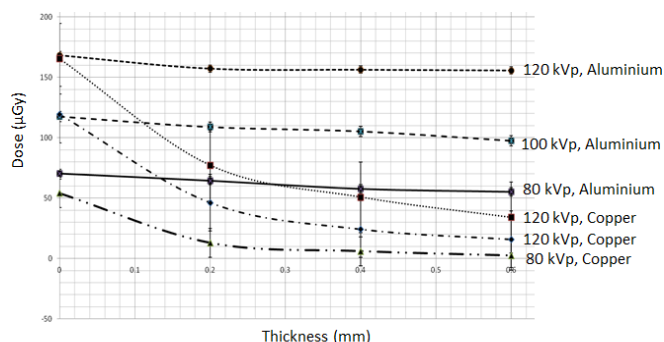

Fig. 6.   The measured radiation dose versus thickness of Copper and Aluminium filters for 80 kVp, 100 kVp and 120 kVp.

The CNR is measured to determine the image quality. Higher CNR shows that the signal of the image is better compared to background's signal, which will denote a better image quality and vice versa. Figures 7 and 8 demonstrate the CNR of bone and fat versus tube potential for different thickness of Copper and Aluminium filters.

Based on Figures 7 and 8, both bone and fat have highest CNR with 0.2 mm of Copper filter at 100 kVp. On the other hand, the CNR of bone and fat is highest with 0.2 thickness of Aluminium filter at 80 kVp and 100 kVp respectively.
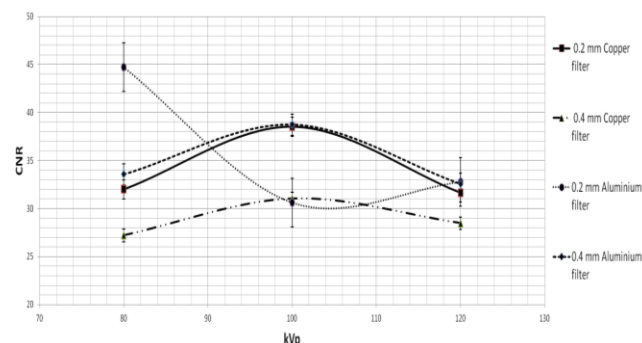

Fig. 7.   The CNR bone versus tube potential with Copper and Aluminium filters at thickness of 0.2 mm and 0.4 mm.
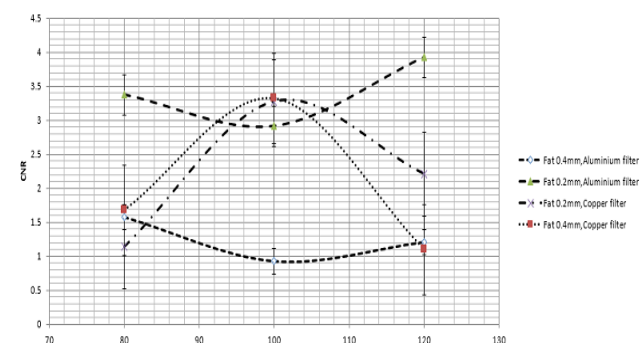

Fig. 8.   The CNR fat versus tube potential with Copper and Aluminium filters at thickness of 0.2 mm and 0.4 mm.

IV.   Discussion

This study indicates that 80 kVp to 120 kVp is the best range of tube potential for chest imaging. The highest CNR of fat, bone and tumor in the chest phantom can be observed in this range of kVp. Increasing the tube potential will increase the radiation dose. The radiation dose gradually increases when the tube potential increases.

Thus, it is not necessary to use higher kVp to obtain the best quality image. However, the tube potential selected should be appropriate for CNR required and part of the body being imaged [7-9]. Selecting low tube potential does not contribute any information on the image as the details are hardly can be seen. It only gives absorbed dose on patient but does not contribute information of image.

Variation of optimization factors should be considered in the formation of images. To attain the correct balance between patient dose and image quality it is important to know appropriate parameters selected that affect image quality and radiation dose [10-11]. Generally, added filtration such as Copper and Aluminium should absorb all low energy and transmit all high energy photons. For diagnostic radiology, Aluminium ($Z=13$) and Copper ($Z=29$) filters are usually selected for filtration [1].

Copper with an atomic number (Z=29) is a better filter for absorbing a higher proportion of lower energy photons than Aluminium for most diagnostic X-ray beams. Optimization in x-ray radiographic imaging requires best balance between the CNR in the image and the applied radiation dose in order to optimize the kVp and filter settings. The most significant dose reduction is achieved through the use of Copper filter compare to Aluminium filter. This is because Copper filter has higher atomic number than Aluminium filter.

This study shows that 0.2 mm thickness of Copper filter gives better image quality and optimal dose at 100 kVp for chest imaging. The CNR of bone is 38.52 at 100 kVp compare to 32.01 at 80 kVp and 31.65 at 120 kVp. Fat also has greater CNR at 100 kVp compare to other parameters. Higher kilovoltage is preferred for high density structures as greater penetration will give a smaller range of beam intensities transmitted through the object. Calculations of CNR and dose for different features in chest phantom using different filter thickness and tube potential produce opportunity to examine the changes in radiation quality.

V. CONCLUSION

In conclusion, reduction of dose can be achieved by varying the tube potential without changing the quality of the image. Optimization of x-ray radiographic imaging is also achievable with the use of Copper filter at 100 kVp with 0.2 mm filter thickness. For all imaging tasks, selection of suitable radiation quality is important as it will affect both radiation dose and image quality.

ACKNOWLEDGMENT

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