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Optimum tube voltage for pelvic direct radiography: a phantom study

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Abstract

Pelvic radiography is a frequently performed radiological examination. Its average effective dose (E) is 0.53 mSv which is comparable to the annual per caput dose from diagnostic radiology, 0.6 mSv. However, existing studies on optimum tube potential for pelvic X-rays tend to be limited to screen-film and computed radiography. The purpose of this study was to determine the tube voltage for dose-image optimisation in pelvic direct radiography (DR). Fifty-four pelvic phantom images were acquired using 50-135 kV at 5 kV increments (three images taken at each kV level) and milliampere seconds determined by automatic exposure control. The signal-to-noise ratio (SNR) and dose were measured for each image. Figure of merit (FOM) defined as the ratio of SNR^2 to E was used to determine the optimum tube potential. The FOM indicates 135 kV is the optimum setting for pelvic DR. Using the European Commission tube voltage recommendation (75-90 kV) as a reference point, there was only a slight (5.56%) decrease of image quality in the femoral neck region at 135 kV. However, its E was 0.054 mSv. This appreciable dose reduction potential could be attributed to the improvement of detective quantum efficiency and image processing technology of the recent DR system.

Keywords

Direct radiography, flat panel detector, dose-image optimisation

Introduction

Dose-image optimisation in X-ray examinations is not a new idea. A range of techniques has been suggested by The International Commission on Radiological Protection (ICRP) including optimisation of tube voltage, voltage waveform, filtration, source-to-image distance (SID), shielding, collimation, scatter control, image receptor and processing, x-ray table top, exposure recording, repeat examination reduction and quality assurance.[1] These techniques have been studied extensively over decades.[2-8] Optimum radiographic techniques have been established, for example, European Guidelines on Quality Criteria for Diagnostic Radiographic Images published by European Commission (EC) in 1996.[9] Although some of the techniques are still appropriate for current practices, others such as tube voltage settings may need to be reviewed because of the advent of new digital imaging systems, for example, flat panel detector (FPD) with caesium iodide (CsI) scintillator.[6, 10-16]

Studies showed that acceptable image quality and dose saving could be achieved in chest radiography with CsI FPD when using a tube potential higher than those for other image receptor technologies such as computed radiography (CR) and selenium-based FPD.[11, 13-16] However, a lower tube voltage might be necessary in some situations depending on diagnostic requirements.[13, 17] Optimum tube potential should be determined for each X-ray examination type. Chest X-rays is the most common type of radiological examination.[15] A number of studies reported the use of high tube voltage technique for dose reduction in direct radiography (DR).[13-16] Although pelvic X-rays is also frequently performed[18] and it is the second common X-ray examination type in Australia,[19] existing studies on optimum tube potential for pelvic X-rays tend to be limited to screen-film radiography and CR.[20-22] Recent studies on dose optimisation for pelvic DR have only covered the areas of SID, patient orientation and automatic exposure control (AEC) chamber selection.[18, 23, 24]

Since pelvic X-ray examination frequency[18, 19] and average effective dose (E) (0.53 mSv[25] - comparable to the annual per caput dose from diagnostic radiology, 0.6 mSv[26]) are relatively high and there is a paucity of literature on this area, the purpose of this study was to determine the tube voltage for dose-image optimisation in pelvic DR.

Materials and methods

A Shimadzu RADspeed general radiography unit with a built-in dose-area product (DAP) meter and a Canon CXDI-70C wireless CsI FPD system was used in this study. Regular quality assurance was handled by the manufacturer. At 80 kV, the measured half-value layer and total filtration were 3.5 mm of aluminium (mm Al) and 3.96 mm Al respectively. The imaging area of the CsI FPD is 35 x 43 cm with a pixel matrix of 2800 x 3408 and a pitch of 125 μm. Pelvic X-ray images were obtained through the use of an anthropomorphic pelvic phantom (STT/1163, Supertech, Inc., USA).

Fifty-four pelvic anteroposterior images were acquired using the phantom, tube voltages between 50 and 135 kV at 5 kV increments (three images were taken at each kV level), milliampere seconds (mAs) determined by AEC (with two lateral chambers activated and covered by iliac crests), a SID of 100 cm, a centring point as midsagittal plane at a level midway between anterior superior iliac spine and symphysis pubis, a collimation of 35 x 43 cm, and a moving grid (ratio: 10:1; frequency: 52 lines cm^{-1}; and focal distance: 100 cm).[18, 24] The measured DAP was stored within each image in Digital Imaging and Communication in Medicine (DICOM) format which was exported to a computer workstation for data analysis.

An open-source image processing program (ImageJ 1.48c, National Institutes of Health, USA) was used to measure mean and standard deviation of pixel values of three regions of interest (ROIs) including femoral neck, pubic ramus and sacrum adapted from European Guidelines on Quality Criteria for Diagnostic Radiographic Images.[9] The signal-to-noise ratio (SNR), i.e. the ratio of mean pixel value to standard deviation of pixel value[27] was calculated for each ROI to indicate the image quality.[4, 13, 15, 28] The measured DAP, X-ray tube potential, anode angle, filtration material and thickness were entered into a Monte Carlo program (PCXMC V.2.0.1.4, STUK - Radiation and Nuclear Safety Authority, Finland) to estimate the E of each exposure.[16, 25, 29] Although more accurate dose measurement could be achieved through the use of thermoluminescent dosimeter,[5, 30] the DAP is commonly used in the dose optimisation studies for E calculation because of its efficiency.[16, 28, 30, 31] An objective figure of merit (FOM) defined as the ratio of squared SNR to E was used to determine the optimum tube potential that could maintain a balance between image quality (SNR) and E.[13, 16, 32]

An IBM SPSS Statistics Version 21 program was employed in statistical analysis. Factorial analysis of variance was used to determine whether the effects of tube potential on image quality (SNR) and FOM were influenced by ROIs. A p-value less than 0.05 obtained from inferential statistics was considered statistically significant.

Results

Statistically significant interactions were found between the tube voltage and ROIs on SNR (p=.000) and FOM (p=.000) and the interactions are shown in Figures 1 and 2 respectively. There were slight changes of SNR of femoral neck and sacrum, and an appreciable increase of SNR of pubic ramus when the tube potential increased from 50 to 135 kV. The FOM of all ROIs increased with the tube potential. Tables 1 and 2 highlight the SNR and FOM values at specific points (75, 90 and 135 kV, and kV yielding the lowest and highest values). Seventy-five and 90 kV are the lower and upper limits of the tube voltage range for pelvic radiography suggested by EC,[9] and 135 kV was the highest tube potential used in this study. At 135 kV, the SNR value of the pubic ramus region was the highest (11.25) and its sacrum SNR value (14.5) was 12.58% and 17.12% higher than those at 75 (12.88) and 90 kV (12.38) respectively although there was a 5.56% decrease of its femoral neck SNR value (12.75) when comparing to that at 75-90 kV (13.5).

Figure 3 shows the effect of tube potential on radiation doses. When the tube voltage increased, there were remarkable decreases of E and DAP especially in the low kV range (50-75 kV). The E and DAP at specific tube voltages are given in Table 3. At 135 kV, the E was 0.054 mSv which is around one third and half of the values at 75 (0.158 mSv) and 90 kV (0.103 mSv) respectively.

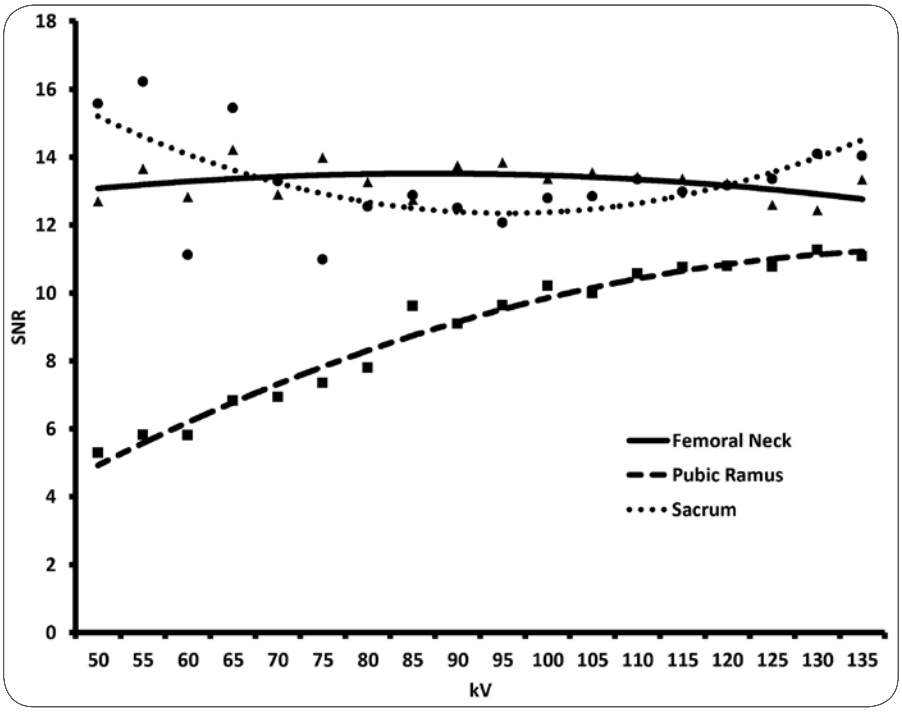

Figure 1. Interaction between tube voltage and regions of interest on signal-to-noise ratio (SNR).

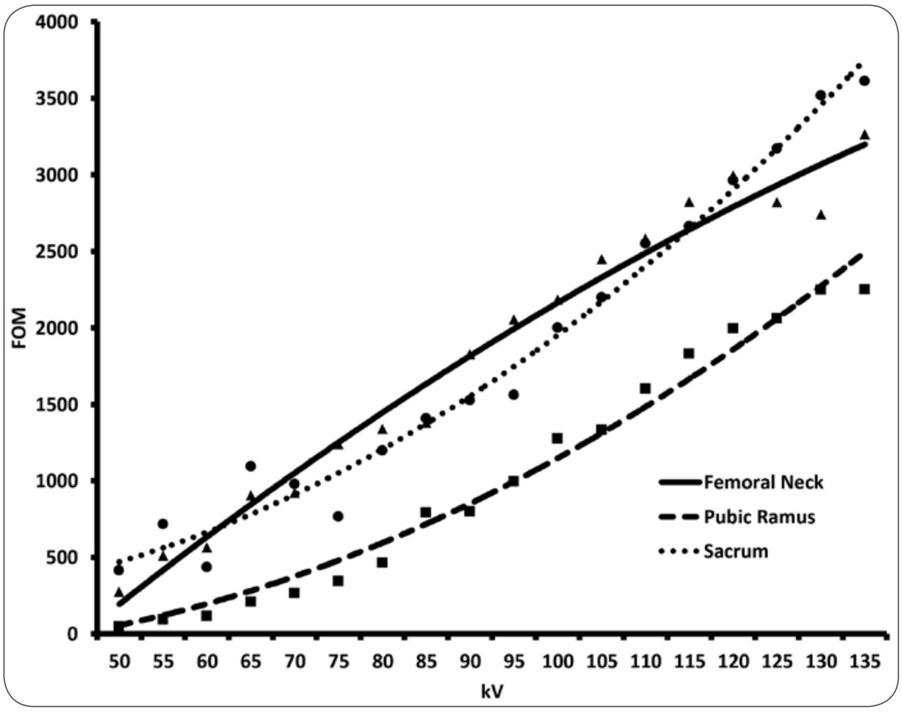

Figure 2. Interaction between tube voltage and regions of interest on figure of merit (FOM).

Discussion

Figure 2 and Table 2 show the FOM values of all ROIs were the highest at 135 kV. This indicates a good balance between image quality and radiation dose could be achieved when 135 kV is used for pelvic DR. Using the EC tube voltage rec-

Table 1. Signal-to-noise ratio (SNR) of regions of interest at different tube voltages.

REGION OF INTEREST	SNR at 75 kV (DIFFERENCE)†	SNR AT 90 KV (DIFFERENCE)†	SNR at 135 kV (DIFFERENCE)†	LOWEST SNR (DIFFERENCE)†	HIGHEST SNR
Femoral Neck	13.50 (0%)	13.50 (0%)	12.75 (-5.56%)	12.75 at 135 kV (-5.56%)	13.50 at 75-90 kV
Pubic Ramus	7.88 (-29.96%)	9.13 (-18.84%)	11.25 (0%)	4.94 at 50 kV (-56.09%)	11.25 at 135 kV
Sacrum	12.88 (-15.54%)	12.38 (-18.82%)	14.5 (-4.92%)	12.38 at 90 kV (-18.82%)	15.25 at 50 kV

†Difference between SNR and highest SNR = [(SNR – Highest SNR) / Highest SNR] x 100%.

Table 2. Figure of merit (FOM) of regions of interest at different tube voltages.

REGION OF INTEREST	FOM at 75 kV (DIFFERENCE)†	FOM AT 90 KV (DIFFERENCE)†	FOM at 135 kV (DIFFERENCE)†	LOWEST FOM (DIFFERENCE)†	HIGHEST FOM
Femoral Neck	1270.27 (-60.50%)	1837.84 (-42.86%)	3216.21 (0%)	189.19 at 50 kV (-94.12%)	3216.21 at 135 kV
Pubic Ramus	486.49 (-80.64%)	864.86 (-65.59%)	2513.51 (0%)	54.05 at 50 kV (-97.85%)	2513.51 at 135 kV
Sacrum	1067.57 (-71.79%)	1567.57 (-58.57%)	3783.78 (0%)	486.49 at 50 kV (-87.14%)	3783.78 at 135 kV

†Difference between FOM and highest FOM = [(FOM – Highest FOM) / Highest FOM] x 100%.

ommendation (75-90 kV) as a reference point, there was only a slight (5.56%) decrease of image quality in the femoral neck region at 135 kV. However, at the same time, 12.58-42.77% increases of image quality were noted in the sacrum and pubic ramus regions (Figure 1 and Table 1) and the E reduction was remarkable (a 47.57-65.82% decrease) (Figure 3 and Table 3). As the gains from using 135 kV outweighed the loss, the highest FOM values were obtained.

The use of higher tube voltage has been suggested by ICRP[1] as a dose reduction strategy because the penetration power of X-rays increases and fewer photons are absorbed by body parts when the tube potential is high. This leads to more photons able to reach the image receptor creating the potential to reduce the tube current as well. The E reduction noted in this study was the outcomes of tube current reduction by the AEC to achieve a constant, appropriate dose level at the FPD, and the decrease of X-ray absorption by the structures of the phantom when higher tube potentials were used. However, the main problem associated with this strategy is the reduction of subject contrast and SNR due to the decrease of differential absorption and increase of Compton scattering (noise).

Previous studies demonstrated the feasibility of using higher tube potential for dose reduction without any notable image quality degradation in pelvic screen-film radiography.[7, 30] However, conflict views on this issue were noted in pelvic CR. Findings for[20, 21] and against[22, 28] its use were found in the literature. When the detective quantum efficiency (DQE) (defined as the ratio of squared SNR at the receptor output to squared SNR at the receptor input) is considered, it appears remarkable image quality degradation would be expected in pelvic CR if tube potential greater than or similar to the one applied to screen-film radiography is used. Although the DQEs of CR and screen-film technologies at 0 cycle mm^{-1} (c mm^{-1}) are similar (approximately 26%), the DQE of CR drops rapidly at higher spatial frequencies. At 1 c mm^{-1}, the DQEs of CR and screen-film are around 18% and 25% respectively.[11, 12]

In this study, the CsI FPD was used as the image receptor. Its DQEs at 0 and 1 c mm^{-1} are approximately 66% and 55% respectively, which more than double the corresponding values of CR and screen-film, and are 89% and 67% higher than those of selenium-based FPD (about 35% at 0 c mm^{-1} and 33% at 1 c mm^{-1}).[11, 12] As

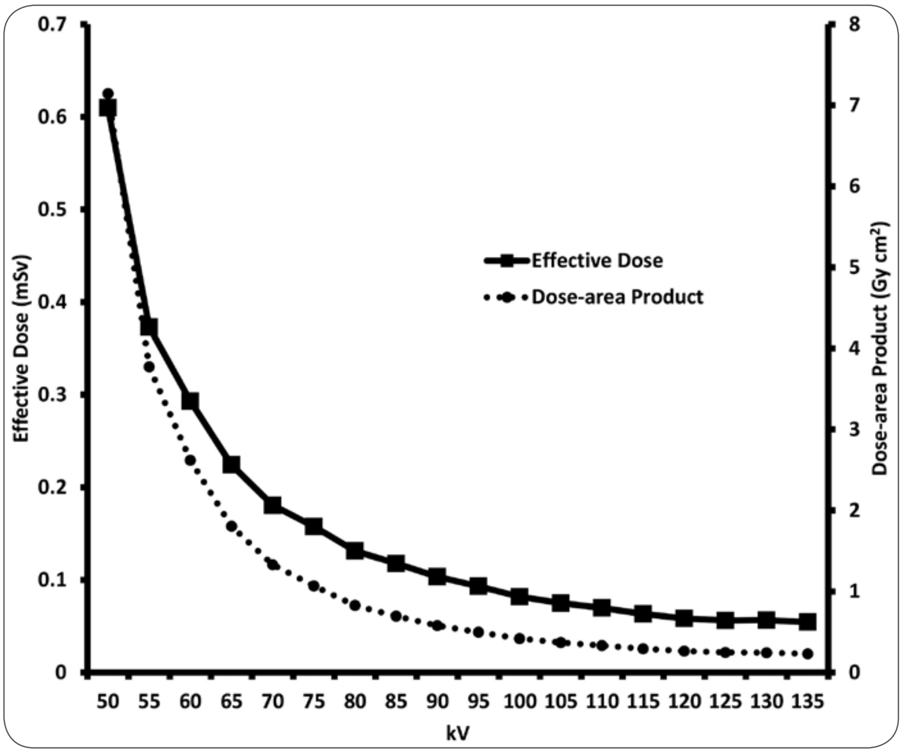

Figure 3. Effect of tube voltage on radiation doses.

Table 3. Radiation doses at different tube voltages.

RADIATION DOSE	At 75 kV (DIFFERENCE)†	AT 90 KV (DIFFERENCE)†	At 135 kV (DIFFERENCE)†	LOWEST DOSE (DIFFERENCE)†	HIGHEST DOSE
Effective Dose (mSv)	0.158 (-74.10%)	0.103 (-83.11%)	0.054 (-91.15%)	0.054 at 135 kV (-91.15%)	0.610 at 50 kV
Dose-area Product (Gy cm^2)	1.069 (-85.04%)	0.579 (-91.90%)	0.230 (-96.78%)	0.230 at 135 kV (-96.78%)	7.145 at 50 kV

†Difference between dose and highest dose = [(Dose – Highest Dose) / Highest Dose] x 100%.

the main controlling factor of DQE is the absorption property of the image receptor, the CsI FPD would be more capable to absorb X-ray photons with higher energies and yield acceptable SNR (image quality) when higher tube voltage is used. It was suggested that the CsI FPD could have effective X-ray absorption in the range of 45-120 kV.[11]

A literature review of dose-image optimisation published in 2009 recommended that 120 kV should be used for chest radiography with the CsI FPD.[15] However, a lower tube potential range, 90-110 kV was reported as the optimum setting for the CsI FPD in earlier studies using FOM to determine optimum tube voltage for chest radiography by Doyle et al.[13, 16] This implies apart from physical characteristics of image receptors, digital image processing technology could also play an important part in dose-image optimisation. At the time when Doyle et al.[13] published their findings in 2005, they commented that image quality improvement could be applied to individual ROIs by image processing software in the future. The image quality of each ROI would be optimised even in a high tube voltage setting and hence a higher kV would be appropriate. This image processing technique is known as the multi-frequency processing which has been widely used in the recent CR and DR systems for some years[10] including the system employed in this study.[33] Acceptable image quality of pelvic radiograph was obtained at 135 kV in this study.

The radiation doses found in this study were similar to those reported in other studies on pelvic radiography with the CsI FPD.[24, 34] For example, the median E of 52 patients undergoing pelvic DR examinations at a fixed tube voltage of 75 kV was around 0.157 mSv[24] while the mean E at 75 kV in this study was 0.158 mSv. Also, the median DAP of pelvic X-rays noted in a local diagnostic reference levels (DRLs) study was 0.983 Gy cm^2,[34] which is within the range of mean DAP at 75-90 kV of this study, 0.579-1.069 Gy cm^2. This would indicate the amount of potential dose reduction when using higher tube potential found in this study could also be expected in clinical situations. The E and DAP of this study at 135 kV were 0.054 mSv (one tenth of average E of pelvic radiography, 0.53 mSv[25]) and 0.23 Gy cm^2 (89.05-96.71% lower than the pelvis DRLs of United Kingdom[35] - 2.1 Gy cm^2, Switzerland[36] - 2.5 Gy cm^2, Germany[37] - 3 Gy cm^2, Sweden[38] and EC[39] - 4 Gy cm^2 and France[40] - 7 Gy cm^2) respectively.

This study only used the objective approaches, SNR and FOM to determine the optimum tube potential for pelvic radiography with the CsI FPD.[13, 16, 32] Although a previous study of the effect of tube potential on image quality of chest X-rays also employed the same method,[13] a better way would be to apply other approaches such as contrast-to-noise ratio[16] and visual grading analysis[28] to study this area as well. However, the findings of this study suggest it should be feasible to apply a tube voltage of 135 kV for pelvic DR in clinical settings. A clinical study on this aspect is warranted. Although the FOMs at 135 kV were the highest, the trends shown in Figure 2 indicate a tube voltage greater than 135 kV might be feasible. A future study should be conducted to confirm this.

Conclusion

The optimum tube voltage for pelvic radiography with the CsI FPD was determined in this phantom study. The findings indicate a good balance between image quality and radiation dose could be achieved at 135 kV. Using the EC tube voltage recommendation (75-90 kV) as a reference point, there was only a slight (5.56%) decrease of image quality in the femoral neck region. However, the E in this setting was 0.054 mSv which is one tenth of average E of pelvic radiography (0.53 mSv). This appreciable dose reduction potential could be attributed to the improvement of DQE and image processing technology of the recent CsI FPD system.

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