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Radiation dose and image quality optimization in lumbar spine digital radiography for overweight and obese patients: Phantom study

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ABSTRACT

Background: Lumbar spine radiography plays an important role in routine use for clinical practice in overweight and obese patients. The radiographer is responsible for setting suitable exposure factors for the tradeoffs between radiation dose and image quality (IQ).

Objective: To investigate the effect of different kVp values combined with AEC used on radiation dose and IQ for routine lumbar spine radiography in overweight and obese patients.

Materials and methods: A 1.5 and 3 cm thickness of frozen pork lard was placed on a pelvis phantom to simulate an overweight and obese patient, respectively. The phantom was imaged at 10 kVp intervals in combination with AEC used. For IQ evaluation, CNR and SNR were calculated, and the observer study was determined using visual grading scores (VGS) with a 5-point Likert scale. The radiation dose was measured using a DAP meter, and then the figure of merit (FOM) was calculated.

Results: SNR and CNR for both AP and lateral projection showed a slightly decreasing trend when kVp increased in all groups. The DAP values decreased when the higher kVp was selected with AEC used in each group. The VGS by five radiographers showed good image quality in all groups, while the FOM at 100 and 109 kVp was the highest score for both AP and lateral projections.

Conclusion: The optimal kVp setting in this study ranged from 100 to 109 kVp in combination with AEC used, indicating minimal radiation dose, while maintaining diagnostic IQ.

Introduction

The number of overweight and obese people has increased dramatically in recent years. The World Health Organization (WHO) stated that 13% of the world's adult population was obese, with the global prevalence of obesity increasing 3-fold between 1975 and 2016.[1] Obesity is categorized as one of the most serious public health issues, impacting the increased risk of numerous diseases and reducing life expectancy.[2] Medical examinations and procedures, including radiography, play a significant role in the diagnosis, treatment, and care of obese patients.[3] Radiographic imaging procedures in overweight and obese patients present practical challenges because of the increased radiation dose required, as well as reduced image quality.[4] The attenuation of the X-ray beam, scatter radiation, and long exposure times result in motion artifacts

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during radiographic examination.[5,6] More adipose tissue in overweight and obese patients leads to poor photon penetration, resulting in high quantum noise.[7] Therefore, it becomes critical to optimize exposure parameters within the framework to be as low as reasonably achievable (ALARA), while the compromise between radiation dose and image quality needs to remain consistent with the diagnostic purpose.

Lumbar spine radiography plays a vital role in routine clinical practice, and it can assist the doctor to assess damage to the lumbar bone. However, lumbar spine radiography is conducted at the highest collective dose, with higher radiation-induced cancer risk compared with other X-ray examinations. Using high-exposure parameters (i.e., tube voltage and tube current) delivers increased radiation doses in lumbar spine radiography, with many X-ray photons penetrating the human body.[8] Therefore, it is necessary to understand and optimize the exposure parameters for lumbar spine radiography by keeping the radiation dose as low as possible while not diminishing the image quality.

In this study, we aimed to optimize the exposure parameter of lumbar spine radiography in the DR imaging system for overweight and obese patients by increasing the X-ray tube voltage in combination with the use of automatic exposure control (AEC).

Materials and methods

Experimental Setup, Imaging Acquisition, and Phantom

A general radiographic unit (SIEMENS Multix TOP, München, Germany) and a gadolinium oxysulfide (GADOX) based DR detector (VIVIX-S, Vieworks Co., Ltd., Gyeonggi-do, Korea) were used for image processing. Quality assurance tests for the X-ray units and the detector were conducted routinely including the consistency of AEC.

In this experimental study, we set up the phantom into 3 groups: normal, overweight, and obese group. In the normal group, an anthropomorphic pelvis phantom (RS-113T, Radiology Support Devices, Inc., CA, USA) was used to image radiographs. The phantom was positioned in supine and lateral positions with 20x43 cm for the AP view and 25x43 cm for the lateral view of beam collimation sizes with 12:1 grid ratio. The central ray was centered at a point at the level of the 3rd lumbar vertebral body and the SID was set at 100 cm for all images. For the lateral projections, the phantom was turned to its left side until the midcoronal plane of the phantom was at 90 degrees to the image receptor. Experimental images were taken across a range of kVp settings in combination with the use of a central AEC chamber, starting with the 70 kVp and increasing to 109 kVp at approximately 10 kVp intervals.

Simulation of overweight and obese patients was achieved by placing 1.5 cm and 3 cm thick layers of frozen pork lard on the frontal and lateral aspects of the phantom, respectively (Figure 1). The CT scan (Philips Medical Systems, Cleveland, USA) was performed to measure CT density measurements for validation of the frozen pork lard which uses as stimulating abdominal fat. Our result data of CT density of frozen pork lard was -112 HU, indicating a similar tissue density of human fat.[9]

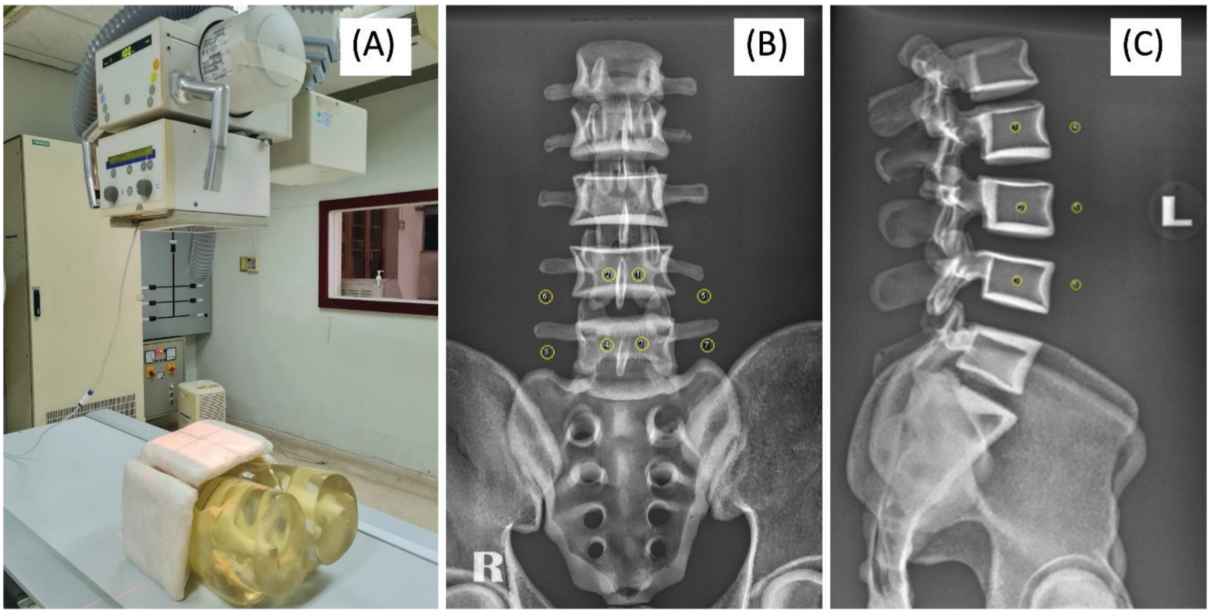

Figure 1. *The experimental set-up. A: with 3 cm slices of frozen pork lard placed on the pelvis phantom, B,C: The ROIs were drawn on the image of AP and Lateral lumbar spine, respectively*

Radiation Dose Measurement

The dose area product (DAP) was measured by attaching a DAP meter (VacuDAP™; VacuTec Meßtechnik GmbH, Dresden, Germany) to the center of the radiographic tube.

Image quality evaluation

The signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR)

The images were evaluated by calculating the SNR and CNR by using the ImageJ software.[10] All the ROIs must have the same size and be placed at the same location for all the images. An object and a background region of interest (ROI) were determined to obtain SNR and CNR. The object ROIs of the frontal view contained 4 individual areas, each of which covered the vertebral regions of L4 and L5 respectively. The background ROIs of the AP view contained 4 areas, covering soft tissue regions on either side (left and right) of the intervertebral joints L4/L5, and L5/S1 but excluded areas of the transverse processes (Figure 1B). For the lateral view, the object ROIs of the frontal view contained 3 individual areas, each of which covered the vertebral regions of L3, L4, and L5 and the background ROI contained 3 areas that covered soft tissue regions and anterior to the vertebral body (Figure 1C). The SNR and CNR were calculated using the following Equation 1 and 2.[11]

$$\text{SNR} = \frac{\textit{Average pixel value of object}}{\sigma_{object}} \quad (1)$$

$$\text{CNR} = \frac{\textit{Pixel value object - Pixel value background}}{\sigma} \quad (2)$$

furthermore, σ is calculated as $\sqrt{\frac{SD_1^2 + SD_2^2}{2}}$ where SD_1 is the standard deviation for the ROI_{Object} and SD_2 is the standard deviation of the $ROI_{Background.}$[11]

Observer study: Visual Grading Score (VGS)

The images were assessed by 5 radiographers, each which a range of 3-10 years of experience. Observers were blinded to the exposure parameter used for each image, which were displayed in randomized order. Thirty images of the lumbar spine in each group were created, including 15 radiographs of AP projection and 15 radiographs of lateral projection. The images were evaluated on the same diagnostic monitor using INFINITT software (distributed by THAI GL CO., LTD., Bangkok, Thailand). All radiographs were assessed on a five-point Likert scale according to the criteria listed in the European guidelines.[12] The image quality criteria and the rating on the scale were demonstrated in Table 1.

Table 1. Anatomical criteria of lumbar spine and scoring scale

Part and Projection		
AP (anteroposterior) Lumbar Spine	*Visually sharp reproduction of the:* • *Upper and lower-end plate surfaces.* • *Pedicles.* • *Cortex/trabecular patterns.* *Reproduction of the:* • *Intervertebral joints.* • *Spinous and transverse processes.* • *Sacro-iliac joints*	
Lateral Lumbar Spine	*Visually sharp reproduction of the:* • *Upper and lower-end plate surfaces.* • *Cortex/trabecular patterns.* *Reproduction of the:* • *Pedicles and intervertebral foramina* • *Spinous processes* *Full superimposition of the posterior vertebral edges*	
Visual grading scale	*1 = Not visible* *3 = Acceptable visibility* *5 = Very good visibility*	*2 = Probably not visible* *4 = Good visibility*

Optimization: Figure of Merit (FOM)

In this study, the FOM was calculated to correlate our finding of DAP and CNR. With CNR and DAP, it can calculate the FOM, which is described as follows: [13]

$$FOM = \frac{CNR^2}{DAP} \quad (3)$$

Statistical Analysis

The results were compared using an ANOVA-like test by using the GraphPad Prism software (GraphPad, La Jolla, CA, USA) for statistical analyses. A *P* value less than 0.05 was considered to indicate a statistically significant difference. The degrees of the agreement were assessed using the intraclass correlation coefficient (ICC) and the results were considered significant at the 95% confidence level by using SPSS Software Version 17.00 (SPSS, Inc., Chicago, IL, USA). According to criteria to evaluate the ICC, the value of less than 0.4 represents poor interobserver agreement, 0.40-0.59 represents fair agreement, 0.6-0.74 represents good agreement and 0.75-1.00 indicates excellent agreement.[14]

Results

SNR and CNR

The resulting SNR and CNR for AP and lateral view of the lumbar spine are shown in Figure 2 with the corresponding values for the normal, overweight, and obese groups. The SNR and CNR, in both AP and lateral projection, were slightly decreased in all groups when higher kVp was applied. The SNR of the obese group was significantly lower when compared with the normal group *(P<0.001).* Furthermore, there were no significant differences in the CNR among the three groups at the same tube voltage in the AP projection. For comparisons of CNR between the obese and normal group in lateral projection, CNRs were significantly superior when increasing tube voltage in lateral projection (*p*<0.001).

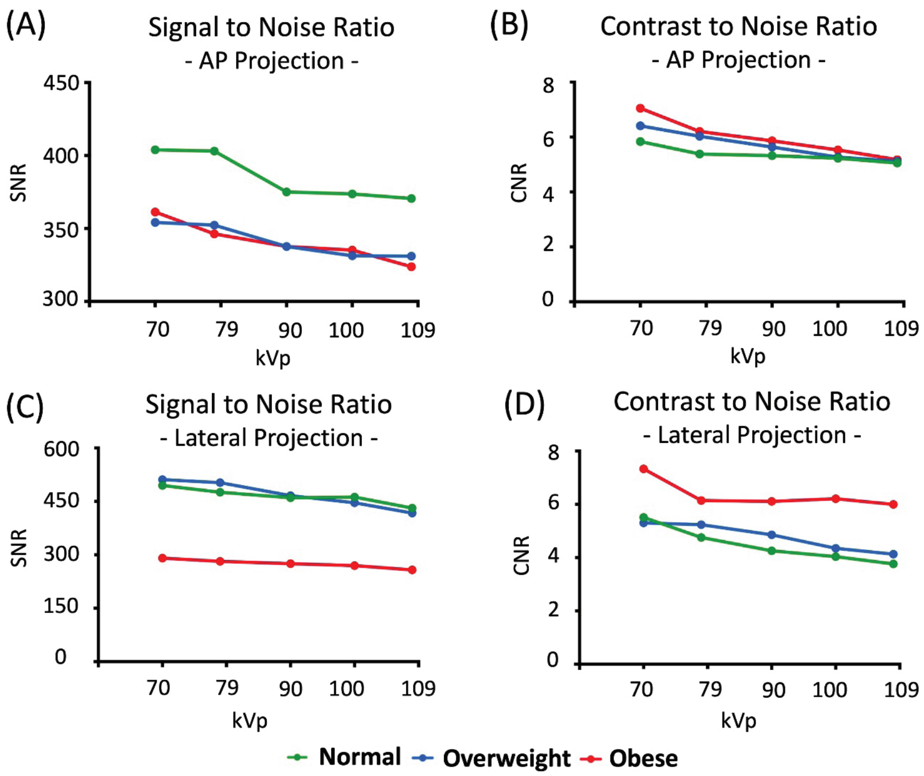

***Figure 2**. SNR and CNR of lumbar spine radiography. A,B: AP projection, C,D: lateral projection.*

DAP and Image Quality Score

The results of DAP values are shown in Figure 3(A,C). For AP projection, the DAP ranged from 62 to 119 µGym^2 in the normal group, 75 to 146 µGym^2 in the overweight group, and 85 to 163 µGym^2 in the obese group. For lateral projection, the DAP ranged from 117 to 231 µGym^2 in the normal group, 144 to 279 µGym^2 in the overweight group, and 259 to 500 µGym^2 in the obese group. Overall, for both projections, the DAP values gradually decreased, indicating a decrease in radiation doses, when the higher kVp values were used.

The average of the VGS of the AP and lateral lumbar spine in various kVp used is shown in detail in Figure 3(B,D). The mean image score of the lumbar spine in each group and in various kVp ranged from 3.6 to 4.5 and no observer scored the images as less than 3 on the 5-point rating scale, indicating that all of them agreed to accept image visibility. Moreover, the result demonstrated there was no significant difference in an overall subjective image quality when using the higher kVp values (*p*>0.05).

Moreover, the ICC values were below 0.4 in both AP and lateral projections. It can be noted that there was no correlation in the results, indicating poor agreement.

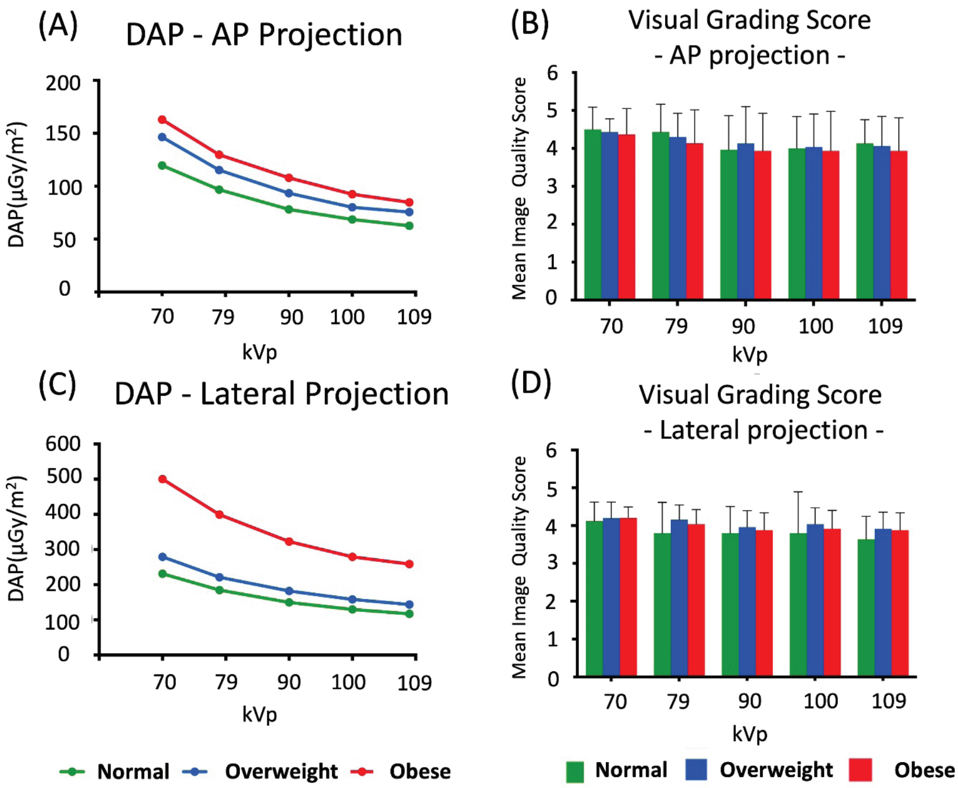

***Figure 3**. DAP values and Image Quality Score of lumbar spine radiography. A,B: AP projection, C,D: lateral projection.*

The Figure of Merit (FOM)

For the AP projection, the highest FOM was at 109 kVp for the normal and overweight groups, and 100 kVp for the obese groups (Figure 4A). However, there was no statistical difference between 100 and 109 kVp for AP projection in all groups. For the lateral projection, 90 kVp provided the highest FOM in the overweight group (Figure 4B). Moreover, 100 and 109 kVp provided the highest FOM in the obese group, while 70 kVp provided the highest FOM for the normal group. In both projections of the lumbar spine, AP and lateral, FOM values increased as kVp increased, except in the lateral projection of the normal group. However, the FOM of the lateral projection in the normal group had no statistical difference in each kVp.

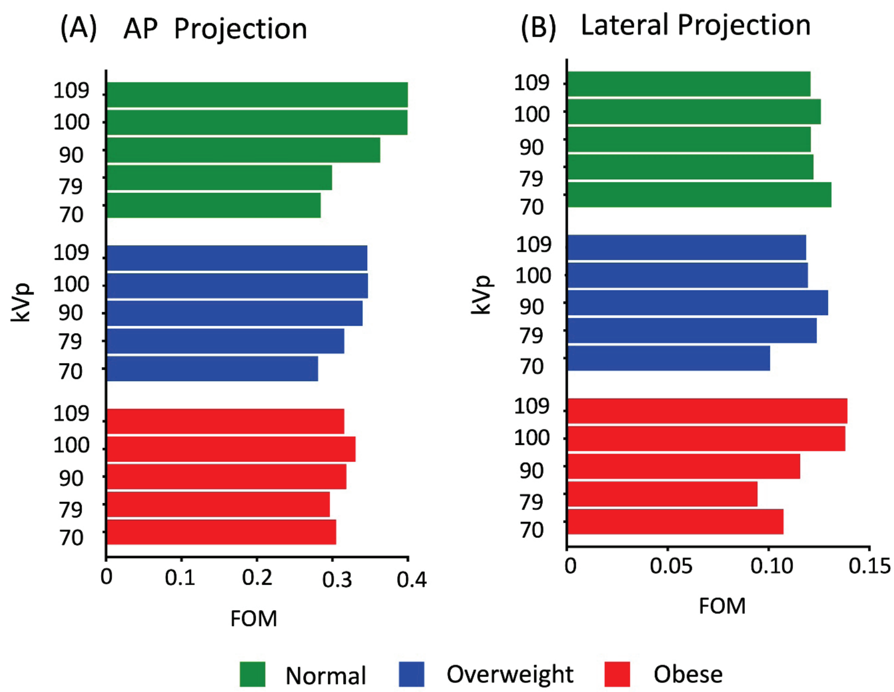

***Figure 4**. The figure of merit (FOM)*

Discussion

This study has investigated the effect of increasing the kVp values in combination with AEC used for producing routine lumbar spine radiography for overweight and obese patients using a DR imaging system.

The overweight and obese groups, in this study, were categorized by waist circumference (WC). The 1.5 and 3 cm. thickness of frozen fat lard was placed on a phantom pelvis to simulate the difference in AP abdominal diameter for the overweight and obese groups, respectively. The WC is correlated with abdominal fat,[15] and represents a valuable, convenient, and simple measurement method to quickly identify the risk factors and morbidity of obesity-related diseases.[16,17] The WC is a more suitable and simple body measurement method for obese patients than body mass index (BMI) because high WC reveals that patients have high central obesity.[18]

For dose measurement, results showed that the radiation dose delivered to patients by DAP measurement was suitable, and provided a good estimate of the total radiation energy delivered during a procedure, being directly related to the amount of radiation produced by the X-ray tube.[19] Our results showed DAP reduction when using high kVp, concurring with previous research reporting that DAP decreased at higher kV and copper filtration.[20] Further studies should be conducted to determine other factors affecting DAP such as radiographers' experience and type of X-ray machine used. Moreover, in obese patients need higher kVp to increase photon energy for passing through the patient's body resulting in more back scatter radiation occurred. Further study should consider the back scatter factor (BSF) added to the patient dose.

Tube voltage (kV) and tube current (mA) control the quantity of radiation, while the amount of radiation delivered is the product of mA and exposure time or milliampere seconds (mAs) and affects the noise. Using AEC detected mAs rather than kVp and can controlled the noise in the DR image receptor at a minimal level. In this study, AEC was used for exposures and lead to the adjustment of the mAs to obtain a constant radiation dose level. Moreover , the AEC was used as a method for the termination of radiation exposure, while AEC is also commonly used for performing routine projections in lumbar spine radiography examinations in clinical practice.[21]

This study had several limitations. Firstly, only one type of DR system was investigated, therefore the result may not be representative of other systems. Secondly, fat was simulated using frozen pork lard, which does not fully represent the distribution of human fat in overweight and obese patients. This study investigated only one parameter (kVp setting), and other parameters such as SID or additional filters should also be considered. The radiation dose used in this study (DAP) does not account for the BSF which influences on patient dose. However, DAP is an uncomplicated radiation measurement and could be used for determination as well as the calculation of the entrance skin dose.[22] Lastly, the ICC was not satisfactory for the evaluation of inter-rater reliability and demonstrated poor interobserver agreement for both AP and lateral projections (ICC<0.4). The observers had varying skill levels (experience 3-10 years) and were not trained before performing image ratings. In future studies, practice and training should be conducted for the observers before image grading.

In conclusion, this study finding suggested the potential of using high kVp combined with AEC used for lumbar spine radiography imaging in overweight and obese patients using the DR system. Our data suggested that utilization of 100-109 kVp in combination with the use of AEC gave the optimal lumbar spine image in terms of minimal radiation dose and good image quality for overweight and obese patients. The DAP decreased in both AP and lateral projections, while VGS had good visibility at higher kV values.

Conflict of interest

The authors declare no conflict of interest.

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