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Optimal exposure factors for lumbar spine AP in computed radiography examinations

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ABSTRACT

Background: In diagnostic radiography, selection of kVp and mAs to produce acceptable image quality with a minimum dose has been a challenge even for experience radiographers. The aim of this study was to determine optimal exposure factors for lumbar spine AP examinations in computed radiograph using dose-image quality analysis. ***Materials and Methods:*** A female anthropomorphic phantom was used for dose-image quality analysis to determine the optimal exposure factors (mAs and kVp) for lumbar spine AP. Indirect method was used to estimate the entrance skin dose (ESD) to the anthropomorphic phantom. kVp values of 70, 80, 90 and100 were selected while mAs values of 16, 18, 20,22,25, 28,32, 36, 40, 45 and 50 were also selected for the acquisition of all the images. Three (3) senior radiographers evaluated the image quality using image quality criteria set up by European Commission. ***Results:*** The result indicated that the image quality score increased as ESD (mGy) increased. However, there was no significant change in image quality score between ESD of 1.941 and 4.882 mGy. 70 kVp and 22 mAs were accepted as optimal exposure factors for standard body size lumbar spine AP examinations in diagnostic radiography of computed radiography (CR). ***Conclusion:*** Optimization of exposure factors (kVp and mAs) is necessary in radiographic examinations to ensure safe use of radiation in medicine. It ensures effective patient dose management because radiograph with high quality can be obtained for effective diagnostic information.

Keywords: *Optimal, radiation, protection, doses, image.*

INTRODUCTION

In diagnostic radiography, peak kilo –voltage (kVp) and milliampere seconds (mAs) are among the most important factors that control radiation dose, image quality and the exposure indicator [1, 2]. Other factors such as filtration, collimation, focus-source to detector distance, thickness of the body and positioning can influence patient radiation dose and image quality [3]. Selection of kVp and mAs to produce acceptable image quality with minimum dose has been a challenge in radiography even for experience radiographers. Small errors in the selection of kVp and mAs can lead to significant increase in patient radiation dose which may be not noticed in computed radiography systems (CR) [4]. High values of kVp will increase Compton scattering which will degrade image contrast and adversely affect image quality [5]. However, high kVp can decrease patient radiation dose [6] and therefore careful selection of this parameter is very crucial in radiographic examinations. In order to establish the optimal exposure factors for the purpose of optimization, image quality levels sufficient to acquire necessary diagnostic information must be first determined and subsequently establish the exposure factors levels at which this image quality can be achieved [7]. Image quality assessment for optimization in computed radiograph (CR) can be done by either subjective analysis or objective analysis [8]. The objective analysis employs the use of physical qualities of the image such as contrast- noise- ratio (CNR), signal-noise-ratio (SNR), modulation transfer function (MTF) and detective quantum efficiency (DQE) [9, 10]. However, the relationship between these image quality metrics and the clinical image quality is not well established [11]. The difficulty in establishing this relationship is that physical image quality metrics are not directly measured under clinical conditions [2]. The subjective analysis which is usually time consuming and expensive use receiver operating characteristics (ROC) and visual grading score (VGC) [11]. This method depends on observer visualization of anatomic structures and scores them according to clarity of their appearance. Some investigators have provided data on image quality based on CNR and SNR in Ghana [12]. However, there is scanty information on dose-image quality analysis using a subjective approach in computed radiography (CR).

The aim of this work is to use visual grading analysis (VGAS) to determine the image quality and use dose- image quality approach to establish optimal exposure factors for lumbar spine AP in computed radiography examinations for the purpose of optimization of patient radiation doses.

MATERIALS AND METHODS

A female anthropomorphic phantom (The Phantom Laboratory, Salem, New York, RAN 100) was used in this work for dose- image quality analysis to determine the optimal exposure factors (mAs and kVp) for lumbar spine AP. A female anthropomorphic phantom represents an average patient size with 163 cm in height and 54 kg in weight. The CR equipment was manufactured by Shimadzu Medical Systems (Kyoto, Japan) in 2012 and installed in 2016. The maximum and minimum kVp of the CR equipment were 150 and 40 respectively. The model number was UD150L-40E. The entrance skin dose to the phantom was calculated with the same mathematical method as described previously [13].

kVp values of 70, 80, 90 and100 were selected while mAs values of 16, 18, 20,22,25, 28,32, 36, 40, 45 and 50 were also selected for the acquisition of all the images. Each of the kVp values was set on all the values of mAs. Three radiographs were obtained for each of the exposure factors. Random numbers were assigned to each image for easy identification.

For acquisition of lumbar spine AP images, the phantom was placed in supine position on the patient couch and the X-ray beam was directed perpendicularly. The CR detector and the X-ray beam were centred at the iliac crests joint of the phantom to include all the vertebrae of the lumbar region. Detector size of 43 cm × 35 cm was used but the X-ray beam was collimated to cover only the region of interest. Focus to detector distance of 100 cm was used for all the images acquired. The detectors were then readout and the images stored on CR review monitor where the images were later assessed by three senior radiographers. The images acquired were not subjected to post-processing since it was difficult to guarantee the same level of post-processing. A reference image was acquired using 74 kVp and 28 mAs which was recorded as an average exposure parameters for lumbar spine AP at the study centre. The study was conducted in Sunyani regional hospital in the Bono region of Ghana where many cases are referred for radiological examinations.

Clinical assessment of image quality using phantom images

Three senior radiographers were selected to evaluate the image quality for all the images. One hundred and thirty-two (132) test and one reference images were assessed by the observers using image quality criteria set up by European Commission [14]. The image quality assessment was based on visualization of the anatomical structures criteria and scored as shown in table 1 [15]. The reference image obtained was only used for comparison on the dose and image quality with the test images not for the purpose of relative visual grading.

The overall image quality was estimated using absolute visual grading analysis score (VGAs) (equation 1) [2, 11, 16].

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$$\text{VGAS} = \frac{\sum_{i=1}^{I}\sum_{s=1}^{S}\sum_{o=1}^{O} G_{i,s,o}}{I \times S \times O} \quad (1)$$

Where Gi, s, o is the grading (1, 2,3,4, 5) given by observer O for image I and structures S, I is the number of images, S is the number of anatomical structures graded, and O is the number of evaluators.

The senior radiographers were educated on the process of visual grading analysis before the assessment. The observers were blinded from the exposure factors to avoid bias. To avoid influence of fatigue on the results of the assessment, the observers were given the freedom to evaluate the images at their own convince. The soft images were assessed on the CR review monitor because the study center has no picture archiving and communication system (PAC). Six anatomical structures were evaluated for lumbar spine AP in each of 132 images.

Data analysis

Microsoft Excel (2013) was used for data analysis. The significance difference between ESD and VGAS was determined using single factor t-test Analysis of variance (ANOVA).

Table 1. Anatomical criteria of lumbar spine AP used for visual grading score.

	Anatomical criteria for lumbar spine AP	Clearly confident that the criterion is fulfilled (5)	Somewhat confident that the criterion is fulfilled (4)	Indecisive whether the criterion is fulfilled or not (3)	Somewhat confident that criterion is not fulfilled (2)	Clearly confident that the criterion is not fulfilled (1)
1	Reproduction of the sacro-iliac joints					
2	Visually sharp reproduction of the pedicles					
3	Reproduction of the transverse process					
4	Reproduction of the spinous process					
5	Reproduction of the intervertebral spaces					
6	Reproduction of the adjacent soft tissue					

RESULTS

The study was carried out to establish optimal exposure factors and compare it with study center's average exposure factors to improve patient radiation protection for lumbar spine AP examinations. The phantom entrance skin dose (mGy), image quality analysis score (VGAS) and exposure parameters for lumbar spine AP radiographs are presented in table 2.

The average exposure factors for lumbar spine AP from the study center were 74 kVp, and 28 mAs which resulted in an ESD of 2.794 mGy with visual grading score of 0.846. The highest VGAS was 0.857 which corresponds to ESD of 4.735 mGy with exposure factors of 80 kVp and 40 mAs. Again, the lowest VGAS was 0.601 which corresponds to ESD of 1.411 mGy with exposure factors of 70 kVp and 16 mAs.

The VGAS were plotted against the ESDs (mGy) as shown in Figures 1 – 4 with standard error bars. Figures 1 – 4 indicate that the image quality score has a linear relationship with ESD.

In figure 1, the image quality increases with ESD up to 1.941 mGy and remains almost constant afterwards. There was significant difference between ESD and image quality for all the exposure factors ($P=5.43\times10^{-6}$). The diagnostic information obtained from the image quality of 0.847 with ESD of 1.941 mGy was the same for the image quality of 0.852 with ESD of 4.406 mGy. This means that the image quality of

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0.847 could provide diagnostic information needed by clinicians for diagnosis with an acceptable ESD of 1.941 mGy. Therefore, the exposure factors (70 kVp, 22 mAs) that produced this image quality could be accepted as optimal exposure factors for lumbar spine AP examinations. Patients would be overexposed whenever radiographs are produced with exposure factors that would result in ESD greater than 1.941 mGy.

Table 2. Exposure parameters and their corresponding ESD and VGAS for lumbar spine AP examination.

kVp	mAs	VGAS	ESD [mGy]	kVp	mAs	VGAS	ESD [mGy]
70	16	0.601	1.411	90	16	0.846	2.441
70	18	0.634	1.586	90	18	0.848	2.746
70	20	0.745	1.762	90	20	0.850	3.051
70	22	0.847	1.941	90	22	0.851	3.356
70	25	0.846	2.203	90	25	0.852	3.814
70	28	0.846	2.467	90	28	0.852	4.271
70	32	0.848	2.819	90	32	0.852	4.882
70	36	0.848	3.172	90	36	0.736	5.492
70	40	0.845	3.524	90	40	0.736	6.102
70	45	0.849	3.965	90	45	0.658	6.865
70	50	0.852	4.406	90	50	0.658	7.628
80	16	0.845	1.894	100	16	0.846	3.052
80	18	0.845	2.131	100	18	0.845	3.433
80	20	0.846	2.367	100	20	0.845	3.815
80	22	0.848	2.604	100	22	0.846	4.196
80	25	0.850	2.959	100	25	0.846	4.768
80	28	0.853	3.314	100	28	0.736	5.341
80	32	0.855	3.788	100	32	0.736	6.104
80	36	0.856	4.262	100	36	0.658	6.867
80	40	0.857	4.735	100	40	0.658	7.630
80	45	0.855	5.327	100	45	0.658	8.583
80	50	0.855	5.919	100	50	0.658	9.537

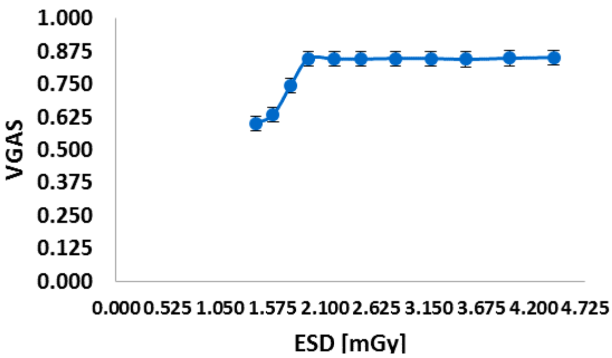

Figure 1. Relationship between image quality and ESD [mGy] for lumbar spine AP radiographs produced with exposure factors of 70 kVp and 16 – 50 mAs. The Error bar is showing standard error (SE).

The radiographs produced with exposure factors of 80 kVp and 16 mAs have lower image quality values (figure 2) and limited in diagnostic information. However, the radiographs that were produced with higher values of mAs (18 – 50 mAs) had higher values of image quality that could be used for diagnostic purposes but the corresponding ESDs were greater than 1.941 mGy.

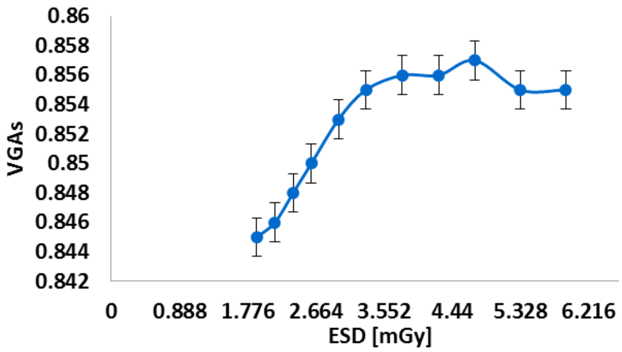

Figure 2. Relationship between image quality and ESD [mGy] for lumbar spine AP radiographs produced with exposure factors of 80 kVp and 16 – 50 mAs. The Error bar is showing standard error (SE).

In figure 2, the image quality increases with ESD until reaching 0.857 when the image quality begins to degrade as the ESD increases. There was significant difference between the image quality and ESD for all the exposure factors (P-value $=1.64\times10^{-6}$).

In figure 3 there was no change in image quality score between ESD of 3.052 mGy and ESD of 4.768 mGy. The image quality score decreased from 0.846 to 0.658 as ESD increased from 4.768 to 7.628 mGy. There was significant difference (P-value $= 5.02\times10^{-7}$) between image quality and ESD for all the exposure factors. The highest image quality score (0.846) in figure 3 produced same diagnostic information as the highest image quality score in figure 1 but with different ESDs.

In figure 4 image quality score gradually increased from 0.846 until reaching the highest- quality score of 0.852 at 4.882 mGy. The image quality score then decreased from 0.852 to 0.658 as ESD increases up to 9.537 mGy. There was significant difference (P-value $= 2.43\times10^{-7}$) between image quality and ESD for all the exposure factors. The decrease in image quality

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may be as a result of more forward scatter radiation reaching the detector due to high ESD and high values of kVp.

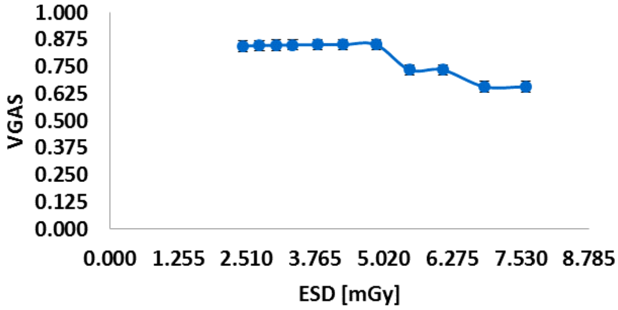

Figure 3. Relationship between image quality and ESD [mGy] for lumbar spine AP radiographs produced with exposure factors of 90 kVp and 16 – 50 mAs. The Error bar is showing standard error (SE).

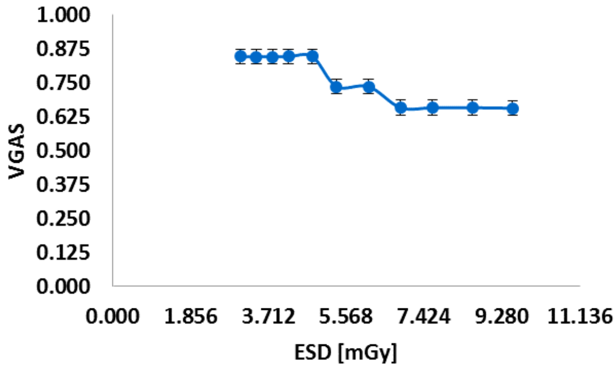

Figure 4. Relationship between image quality and ESD [mGy] for lumbar spine AP radiographs produced with exposure factors of 100 kVp and 16 – 50 mAs. The Error bar is showing standard error (SE).

DISCUSSION

Lumbar spine AP examinations are the second most frequently performed radiographic examinations after chest radiography [17, 18]. The doses receive by patients undergoing lumbar spine examinations are however higher than chest examinations according to published literature [18, 19]. For this reason, dose optimization in lumbar spine AP examinations is very crucial in patient radiation protection in diagnostic radiography. Dose optimization techniques for lumbar spine examinations such as air gap method, optimizing the exposure indicator, dose auditing, image quality evaluation, patient positioning have been described by some researchers [20 – 23]. However, literature on the optimal exposure factors (kVp, mAs) for optimization of lumbar spine AP examinations is scanty.

This study employs dose-image quality optimization to determine the optimal exposure parameters for lumbar spine AP examinations. Exposure parameters from 70 – 100 kVp and 16 – 50 mAs were investigated to determine which exposure parameter could produce an acceptable image quality for maximum diagnostic information in line with the principle of As Low As Reasonable Achievable (ALARA). This study shows that exposure factors of 70 kVp and 22 mAs could be used as an optimal exposure parameter. Also image quality decreases with increasing ESD (figure 4), an observation which was in agreement with Almen *et al.*, 2004. Images produced with these exposure factors had high image quality score with an acceptable ESD that could provide maximum diagnostic information for diagnosis. Selection of exposure factors for radiographic examination is very critical in ensuring patient radiation safety. Inappropriate selection of these exposure factors can adversely affect image quality and patient radiation dose [1].

Different studies have published effects of tube voltage on patient radiation dose and image quality for lumbar spine AP examinations [20, 24, 25]. These studies reported kVp ranges from 60 to 95. In a study conducted by Almen *et al.*, 2004 which evaluated visibility of lumbar spine AP images using 70 kVp and 90 kVp found out that lumbar spine AP images produced with 70 kVp had higher visibility score than those acquired with 90 kVp and therefore using higher tube voltage would not improve image quality [20]. Another study carried out by Naji *et al.*, 2017 observed that, 70 kVp has higher energy to provide more penetrability for X-ray photons and provides optimum contrast when range of kVps (50 – 110 kVp) were compared using aluminum step wedge [26]. However, these studies did not investigate the optimal factors for mAs as in the current study. The poor image quality at higher exposure factors could be due to low contrast due to increase in Compton effects at high kVp which degrade image quality and low sensitivity of CR detector at higher kVp

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[27].

The results of this study also indicate that overexposure of patients is possible in CR systems if proper optimization procedures are not instituted by radiographic facilities. The wider dynamic range of the CR detector permits higher exposure factors without an adverse effect on the image quality and therefore, it is important for each radiographic facility to determine its own optimal exposure parameters for each specific examination. Patient radiation dose reduction of 29.3% was achieved for the study center. Seibert and Morin 2011 had reported that about 5 – 10 times [28] the normal exposure can occur, but the image quality would be still acceptable because of the compensation by CR detector. Overexposure in CR systems is hardly identified since higher exposure factors reduce noise levels in CR systems.

CONCLUSION

Optimization of exposure factors (kVp and mAs) is necessary in radiographic examinations to ensure safe use of radiation in medicine. It ensures effective patient dose management because radiograph with high quality can be obtained for effective diagnostic information. This study also showed that reduction in patient radiation doses for lumbar spine AP examination was possible for the study center and therefore encourage the center to institute proper optimization protocol based on dose-image quality to protect patients.

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