Iranian Journal of Medical Physics

ijmp.mums.ac.ir

Effects of Kilovoltage on Image Quality and Entrance Surface Dose in Lumbar Spine Digital Radiography

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ARTICLE INFO

Article type:
Original Article

Article history:
Received: Sep 04, 2018
Accepted: Nov 27, 2018

Keywords:
Digital Radiography
Image Quality
Radiation Dosage
Lumbar Spine

ABSTRACT

Introduction: Digital radiography possesses a wide dynamic range and has a major advantage in producing an acceptable image of diagnostic value even though overexposure occurs. Lumbar spine (LS) radiography is the most common examinations that gives high radiation dose to patients and accounts for the highest collective population dose of any conventional radiographic examinations. As such, this study was carried out to ascertain the impact of image quality and entrance surface dose (ESD) with different exposure settings in the anteroposterior (AP) and lateral LS.

Material and Methods: The torso of the PBU-50 phantom was exposed to medium and high kilovoltage peak (kVp). A total of 14 images for LS were obtained. Relative image quality was assessed using Leeds Test Objects TOR CDR whilst the ESD was ascertained using an optically stimulated luminescence dosimeter.

Results: The results of Friedman test indicated a significant difference in image quality when using medium and high kVp. Wilcoxon signed-rank test also reflected a significant difference in ESD between the use of medium and high kVp for both AP and lateral LS.

Conclusion: Significant differences in image quality and ESD were obtained using medium and high kVp with medium kVp resulting in high contrast but low contrast sensitivity and vice versa. The findings of the present study indicated that the recommended kVp for AP LS was from 75kVp to 81kVp whilst for lateral LS the recommended kVp was from 85kVp to 90kVp for an average adult patient.

► *Please cite this article as:*
Ramli H.A.**,** Moey S.F. Effects of Kilovoltage on Image Quality and Entrance Surface Dose in Lumbar Spine Digital Radiography. Iran J Med Phys 2019; 16: 368-371. 10.22038/ijmp.2018.34167.1431.

Introduction

The lumbar spine (LS) examination is one of the radiographic examinations that accounts for the highest collective population dose amongst conventional radiographic examinations [1, 2]. As the gonads lie in close proximity to the region of interest during a lumbar X-ray examination, it is therefore very vital to keep the dose "as low as reasonably achievable" (ALARA). In order to achieve this, the International Commission on Radiological Protection recommends that all exposures must be justified, optimized, and limited [3, 4].

In order to optimize the radiation dose to the gonads, the Commission of European Communities recommends guidelines on optimal exposure parameters, such as tube potential, source to image distance, and total filtration [4, 5]. Although keeping the dose "as low as reasonably practicable" (ALARP) in LS X-ray examinations is crucial, the quality of produced LS image is equally important.

Digital radiography (DR) was first introduced in medicine in the early 80s by Fujifilm Medical Systems [6]. One of the advantages in DR is that it has a wide dynamic range. This allows radiographers to manipulate contrast in ensuring an acceptable image quality due to "errors" in exposure factor selection. As such, without adequate training in DR, there is a possibility of radiographers increasing the radiation dose to avoid "repeats" when underexposure occurs. Then this leads to a phenomenon called dose creep, which is an "unwanted" increase in exposure factors resulting in an "unnoticed" increased radiation dose to the patients [2, 7].

However, the extent in which kilovoltage peak (kVp) can be manipulated without affecting image quality with an increasing radiation dose to the patients is still unclear. This study sought to explore the aforementioned phenomena. The information acquired can then provide a better understanding for radiographers in selecting the optimum kVp for future dose reduction while maintaining good image quality in conducting anteroposterior (AP) and lateral LS radiography.

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Materials and Methods

This experimental study was conducted in the Radiography Laboratory of the Department of Diagnostic Imaging and Radiotherapy, Kulliyyah of Allied Health Sciences, International Islamic University Malaysia, Kuantan campus, Pahang Darul Makmur, Malaysia. The X-ray unit used was the AXIOM (Siemens, Germany). The images were acquired using 14”x17” FCR standard cassette type CC (Fujifilm, Japan) and then read using FCR CAPSULA XL II (Fujifilm, Japan). The images were then printed out using the Medical Dry Laser Imager DRYPIX Plus model 4000 (Fujifilm, Japan) that has a 14-bit grayscale resolution. The torso of the anthropomorphic phantom PBU-50 (Kyoto Kagaku, Japan) was utilized in this study.

For the AP and lateral projections, the phantom was placed in the supine position at the center of the table bucky. The set-up of the experimental study is shown in Figure 1. The imaging parameters and techniques utilized in conducting this study are presented in Table 1. The collimation was kept constant throughout the examinations to avoid systematic errors that can be caused by scattered radiation produced [2, 4, 8]. The Leeds test objects TOR CDR (Leeds Test Objects, United Kingdom) was used as a testing tool in this study to evaluate the image quality for high contrast, low contrast, and spatial resolution when using the medium to high kVp settings (medium kVp range: 64.5 kVp to 75kVp and high kVp range: 81 kVp to 102 kVp).

Figure 1. Experimental set-up for anterior-posterior (AP) lumber spine projection

An optically stimulated luminescence dosimeter (Landauer, Japan) was placed at the level of iliac crest for both AP and lateral LS projections in determining the ESD. As the automatic exposure control (AEC) was used, kVp settings (Table 1) were selected for each examination. The checking of the AEC performance for sensitivity and linearity of the iontomat fields and limit was carried every six months under preventive maintenance by the vendor (Siemens AG Solutions, Malaysia).

Results

Image Quality

Table 2 and Table 3 summarized the exposure factors used, relative image quality and ESD for AP and lateral LS examinations respectively.

Effects of Kilovoltage Peak on Anteroposterior Lumbar Spine Image Quality

The results of Friedman test indicated that significant differences existed for image quality for AP LS between the use of medium and high kVp (X^2 [2, N=7] =13.00, $P<0.05$) with better high contrast sensitivity using high kVp, compared to medium kVp. However, the image quality for low contrast sensitivity and spatial resolution for both medium and high kVp usages were found to be similar.

Effects of Kilovoltage Peak on Lateral Lumbar Spine Image Quality

According to the results of Friedman test, it was found that significant differences existed for image quality for lateral lumbar projection between medium and high kVp usages (X^2 [2, N=7]=14.00, $P<0.05$) with better high contrast sensitivity using high kVp, compared to medium kVp. However, the image quality for spatial resolution for both high kVp and medium kVp were found to be similar.

Entrance Surface Dose

Effects of Kilovoltage Peak on Entrance Surface Dose in Anteroposterior Lumbar Spine

The findings of Wilcoxon signed-rank test indicated a significant difference in ESD for AP LS when using medium and high kVp (Z=-2.023, $P<0.05$) with higher ESD reflected when using medium kVp.

Effects of Kilovoltage Peak on Entrance Surface Dose in Lateral Lumbar Spine

The results of Wilcoxon signed-rank test reflected a significant difference in ESD for lateral lumbar projection when using medium and high kVp (Z =-2.023, $P<0.05$) with higher ESD when using medium kVp.

Table 1. Imaging parameters used for anteroposterior and lateral lumbar spine

Imaging parameters	Anteroposterior	Lateral
Imaging plate size (cm)	35 x 43	35 x 43
Collimation (cm)	16.5 x 46	18 x 43
Imaging plate orientation	Lengthwise	Lengthwise
Source to image distance (cm)	115	115
Central ray	Perpendicular to midsagittal plane of phantom at the level of iliac crest	Perpendicular to mid coronal plane of phantom at the level of iliac crest
KiloVoltage peak	64.5, 70, 75, 81, 85, 90, 96	70, 75, 81, 85, 90, 96, 102
Automatic Exposure Control (Chamber)	On (Middle)	On (Middle)
Focal spot	Large focal spot	Large focal spot
Grid (Grid ratio)	Moving grid, 12:1	Moving grid, 12:1

Table 2. Exposure factors, image quality, and entrance surface dose (ESD) obtained for anteroposterior lumbar spine

Image	kVp	mAs	Image Quality			Mean ESD (mGy)
			High Contrast Sensitivity (Number of large disc)	Low Contrast Sensitivity (Number of small disc)	Spatial Resolution (Group number)	
1	64.5	82.3	8	7	13	24.59
2	70	55.5	9	7	13	19.14
3	75	42.0	10	6	13	15.92
4	81	30.7	10	6	13	13.89
5	85	27.2	10	5	13	12.38
6	90	21.7	10	5	13	10.78
7	96	17.6	10	4	13	9.88

mAs: milliampere-second
kVp: kilovoltage peak

Table 3. Exposure factors, image quality, and entrance surface dose (ESD) obtained for lateral lumbar spine

Image	kVp	mAs	Image Quality			Mean ESD (mGy)
			High Contrast Sensitivity (Number of large disc)	Low Contrast Sensitivity (Number of small disc)	Spatial Resolution (Group number)	
1	70	131	8	6	14	54.95
2	75	100	9	6	14	45.58
3	81	74.1	10	6	14	36.72
4	85	62.4	10	7	14	34.56
5	90	51.4	10	7	14	33.95
6	96	41.6	10	6	14	31.08
7	102	34.4	11	5	14	26.63

mAs: milliampere-second
kVp: kilovoltage peak

Discussion

Digital image quality is evaluated based on six image quality factors one of which is contrast. Contrast resolution or grayscale resolution refers to the ability to display objects at different X-ray intensities that makes them easy to be distinguished [9]. Contrast sensitivity is the relationship between image contrast and subject contrast. In low contrast sensitivity, only the objects with high contrast will be visible in the image whilst in high contrast sensitivity, the low contrast objects can also be seen in the image [10].

The results of this study indicated that the usage of medium kVp resulted in high contrast images but low contrast sensitivity. At medium kVp, the X-ray photons underwent photoelectric absorption. The reason is that most of the atoms of the body consist of elements with low atomic number with low K-shell electron binding energy [11]. Further, one of the basic rules that govern the possibility of a photoelectric interaction is when the X-ray energy and electron binding energy are near to each other [11]. Thus, a 40-keV photon is more likely to interact by the way of photoelectric effect with an atom of barium with K-shell energy of 37.4 keV, compared to a 100 keV X-ray photon.

Moreover, the relationship of the photoelectric effect is approximately proportional to the third power of the atomic number [11]. As such, the aforementioned factors resulted in a high contrast image when using medium kVp. However, Compton scattering has a more prominent effect on the image contrast as the kVp increases as a result of increased photon energy. Hence, most of the photons will scatter in a more forward direction resulting in a lower image contrast [11] when compared to medium kVp usage.

Theoretically, the best image quality should be produced at around 80 to 85 kVp [2, 12]. The reason is that in DR, the binding energy of the K-shell electron of an atom attenuates in the best way between 35 and 50 keV. Furthermore, a typical average energy produced by an exposure of 80kVp is about 35 keV [11]. Hence, at this exposure, an image with the best or optimum quality is produced. The findings of this study are not quite concurrent with fore-mentioned theory. This is probably due to the fact that this study used the Leeds Test Objects TOR which is not very sensitive in detecting the differences between the images due to the subtle change in the contrast of the images. Another possibility could be due to the subjective interpretation of the assessors. Spatial resolution was the same for both medium and high kVp settings as the group number seen for both exposure settings was 13. Theoretically, kVp does not affect resolution [2, 4]. This is concurrent with the findings of this study.

Based on the obtained findings of this study, when medium kVp was used, the milliampere-second (mAs) and ESD were higher, compared to when high kVp was utilized. The reason is that the maximum photon energy and the proportion of high-energy photons are determined by the applied tube potential (kVp) across the X-ray tube and thus penetrability of the X-ray beam [11, 12]. As such, with medium kVp usage, better image contrast is produced due to the utilization of higher mAs for increasing beam intensity [2, 4, 12]. This is in compensation for an image of diagnostic value to be produced with minimum quantum mottle [13].

However, this phenomenon will result in a reduced amount of photons being transmitted from the anatomical part being imaged [12], thereby resulting in a higher absorbed dose. On the contrary, high kVp will result in a better beam penetrability, lower ESD, but lower contrast [2, 4, 12] due to increasing forward scatter reaching the image receptor [13]. Hence, in this study when medium kVp was used, the ESD was higher due to the higher absorbed dose, compared to when high kVp was used. The reason is that kVp and mAs have an inverse relationship in maintaining the image receptor exposure in radiographic examinations [2, 4, 11]. Hence, the best practice in digital imaging is to utilize the highest appropriate kVp relevant to the anatomical part being imaged with the lowest mAs to provide adequate exposure to the image receptor [13].

Conclusion

According to the findings of this study, it was concluded that when medium kVp was used, high contrast image with low contrast sensitivity was produced. On the other hand, when high kVp was used, low contrast image with high contrast sensitivity was produced. A significant difference in the image quality was found between the use of medium and high kVp. It can be concluded that medium kVp resulted in higher mAs; as such, ESD was high. The recommended kVp obtained from this study for AP LS ranged from 75kVp to 81kVp whilst for lateral LS, the recommended kVp was from 85kVp to 90kVp for an average adult patient that is consistent with the concept of keeping the radiation dose ALARA whilst maintaining an acceptable image quality.

Acknowledgment

The authors would like to express their sincere appreciation to the staff of the Department of Diagnostic Imaging and Radiotherapy for rendering their assistance in ensuring the success of the study.

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