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A Phantom Study for the Optimization of Image Quality and Radiation Dose for Common Radiographic Examinations in Digital Radiography

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ABSTRACT

Introduction: Phantom studies facilitate the implementation of radiation dose surveillance as a function of radiographic technical parameters for minimizing patient radiation dose. The evidence of such investigations can then be used to evaluate technical parameters used in the radiographic procedures to reduce radiation dose without compromising the image quality.

Material and Methods: This experimental study was carried out using an anthropomorphic phantom and the Leeds test object. Computed radiographic system was utilized and the images were printed for objective evaluation. Dose-area-product (DAP) readings were obtained using a DAP meter for the technical parameters employed for the radiographic procedures.

Results: The use of 0.2 mm additional copper filtration resulted in the lowest radiation doses for all four radiographic procedures (i.e. posteroanterior chest, anteroposterior abdomen and lumbar sacral spine projections). The highest tube potential appropriate to the body part being imaged, patient size, image receptor response and required information resulted in the minimum radiation dose to the patient without compromising the image quality. The focus to film distance utilized for the radiographic procedure must be in accordance with the focus to grid distance specified by the manufacturer when using the bucky to eliminate grid "cut-off."

Conclusion: The optimization of image quality and radiation dose can be accomplished by using a phantom and selecting the imaging parameters that yield an acceptable image quality with the lowest entrance surface dose while considering the adjustment for patient size.

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Introduction

The highly rapid and competitive development of new technology in digital radiography have propelled the manufacturers to strive for producing a more user-friendly technology with higher image quality and lower radiation dose. Even though the new technology of digital radiography can bring about lower radiation dose, there is a tendency to increase the radiation dose among radiographers, which is commonly called "dose creep." This phenomenon occurs due to radiographers' attempt to omit repeats caused by underexposure which results in the delivery of higher radiation to patients unknowingly [1].

Therefore, the reduction of radiation dose requires the control of dose creep and adoption of best practices in digital radiography while maintaining the image quality as outlined in the Radiological Protection and Safety in Medicine [2]. More than 80% of all clinical radiological examinations are routine X-ray examinations including posteroanterior (PA) chest, anteroposterior (AP) abdomen and lumbar sacral spine projections [3].

Given the deleterious effects of X-rays, it is pertinent to protect the patients undergoing diagnostic radiological procedures. Patient dose measurement is an important approach facilitating the optimization of radiation protection during radiological examinations and revealing the significance of radiation dose survey [4]. The estimation of radiation dose to patients using radiographic technical parameters is a useful technique in keeping patients' radiation dose to a minimum level [5]. This approach renders results providing the evidence to reassess the radiological procedures in order to reduce the radiation dose without compromising the image quality.

The achievement of an image of acceptable quality can be attained by using the minimum radiation dose as a reference [6]. Regarding this, the present study was carried out using a phantom to evaluate the radiographic technical parameters that can result in

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the lowest radiation dose and an acceptable image quality. The findings of this study can be utilized for the optimization of common radiographic examinations, namely PA chest, AP abdomen as well as AP and lateral lumbosacral spine radiography.

Materials and Methods

This experimental study was conducted at the Radiography Laboratory, Department of Diagnostic Imaging and Radiotherapy, Kulliyyah of Allied Health Sciences, International Islamic University Malaysia, Kuantan, Pahang, Malaysia. The X-ray unit used in this study was a Multixtop unit (Siemens, Germany). The image acquisition was accomplished using a 43×35-cm barium fluoro-bromide imaging plate activated with europium. The acquired images were then read using a single image read out reader; FCR Capsula XLII [CR-IR 359] (Fuji, Japan). The images were printed out using the Fuji Medical Dry Laser DRYPIX Plus (Model 4000, Japan) to be scored objectively.

An anthropomorphic phantom (PBU-50) was utilized for the study. The Leeds test object TOR CDR (Leeds Test Objects Ltd., United Kingdom) was used to relatively compare the quality of the obtained images using the technical parameters (tables 1-4). A dose-area-product (DAP) meter (Kerma X_plus, Germany) was placed below the X-ray tube collimator to measure the DAP. Image acquisitions were obtained for the PA erect chest, AP abdomen, as well as AP and lateral lumbosacral spine using the imaging parameters presented in tables 1-4.

Table 1. Imaging parameters used for erect posteroanterior chest

Imaging parameters	Details
Kilo-voltage peak (kVp)	99, 105, 109, 117, 121, 125
Imaging plate size (cm)	35 x 43, lengthwise
Central ray	Perpendicular to the center of IR, mid-sagittal plane at the level of T7
Source to image distance (cm)	180
Additional filtration	No filter, 1 mm Al, 2 mm Al, 0.1 mm Cu, 0.2 mm Cu
Focal spot	Large focal spot (1.0 mm)
Grid (grid ratio)	Moving grid, 12:1
AEC	On (0)
Chamber	Side chambers

Adopted from [7]

A total of 288 images were acquired using the given technical parameters. The acquired images were assessed for quality acceptability by determining the number of large disks (low-contrast detectability), small disks (high-contrast detectability), and resolution test pattern visualized when using each of the imaging parameter. The fine balance of dose and image quality was ascertained for each projection by choosing the imaging parameter with an acceptable image quality and the lowest ESD [7]

Table 2. Imaging parameters used for anteroposterior abdomen

Imaging parameters	Details
Kilo-voltage peak (kVp)	70, 75, 81, 85, 90
Imaging plate size (cm)	35 x 43, lengthwise
Central ray	Perpendicular to the center of IR at the level of the upper border of the iliac crest
Source to image distance (cm)	100, 110, 120
Additional filtration	No filter, 1 mm Al, 2 mm Al, 0.1 mm Cu, 0.2 mm Cu
Focal spot	Large focal spot (1.0 mm)
Grid (grid ratio)	Moving grid, 12:1
AEC	On (0)
Chamber	Side chambers

Adopted from [7]

Table 3. Imaging parameters used for anteroposterior lumbosacral spine

Imaging parameters	Details
Kilo-Voltage peak (kVp)	70, 75, 81, 85, 90
Imaging plate size (cm)	35 x 43, lengthwise
Central ray	Perpendicular to the center of IR, mid-sagittal plane level of L3
Source to image distance (cm)	100, 110, 120
Additional filtration	No filter, 1 mm Al, 2 mm Al, 0.1 mm Cu, 0.2 mm Cu
Focal spot	Large focal spot (1.0 mm)
Grid (grid ratio)	Moving grid, 12:1
AEC	On (0)
Chamber	Middle chamber

Adopted from [7]

Table 4. Imaging parameters used for lateral lumbosacral spine

Imaging parameters	Details
Kilo-voltage peak (kVp)	81, 85, 90, 96, 102
Imaging plate size (cm)	35 x 43, lengthwise
Central ray	Perpendicular to the center of IR, coronal plane, level of L3
Source to image distance (cm)	100, 110, 120
Additional filtration	No filter, 1 mm Al, 2 mm Al, 0.1 mm Cu, 0.2 mm Cu
Focal spot	Large focal spot (1.0 mm)
Grid (grid ratio)	Moving grid, 12:1
AEC	On (0)
Chamber	Middle chamber

Adopted from [7]

Results

The results of the experimental study are summarized in tables 5-8. According to the results, the use of 0.2 mm copper additional filtration resulted in the lowest DAP readings. The summary of the technical parameters selected from the experimental study to be used in the optimization process is presented in Table 9. Figures 1-4 depicts the radiographs obtained from the PA chest, AP abdomen, as well as AP and lateral lumbosacral spine using the selected technical parameters with the lowest radiation dose and an acceptable image quality.

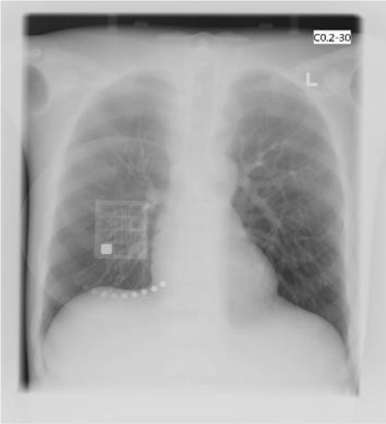

Figure 1. Chest radiograph obtained using the phantom with the selected technical parameter in table 5

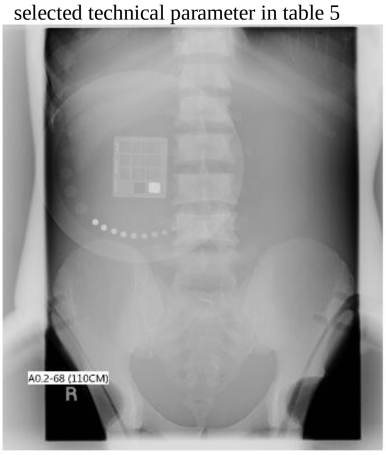

Figure 2. Abdomen radiograph using the phantom with the selected parameter in table 6

Figure 3. AP lumbosacral spine radiograph obtained using the phantom with the selected technical parameter in table 7

Figure 4. Lateral lumbosacral radiograph obtained using the phantom with the selected technical parameter in table 8

Table 5. Technical parameters used for posteroanterior chest using copper filter together with the DAP values and image quality obtained from the experimental study

Technical parameter				Dose	Image quality		
FILTER	FFD (cm)	kVp	mAs	DAP (mGy.m^{-2})	High contrast	Low contrast	Resolution
0.2 mm Cu	180	99	4.98	5.41	15	0	19
		105	4.25	5.22	15	0	19
		109	3.86	5.09	15	0	19
		117	3.31	4.89	15	0	19
		121	3.07	4.8	15	0	19
		125	2.84	4.7	15	0	19

🟦 Technical parameters selected for the lowest radiation dose with acceptable image quality FFD: film-focus distance

Table 6. Technical parameters used for AP Abdomen together with the DAP values and image quality obtained from the experimental study

Technical parameter				Dose	Image Quality		
FILTER	FFD (cm)	kVp	mAs	DAP	High Contrast	Low Contrast	Resolution
0.2mm Cu	100cm	70	43	63.84	10	8	12
		75	31.8	57.52	9	6	12
		81	23.3	51.82	9	6	13
		85	19.4	48.87	9	6	13
		90	15.9	45.96	9	7	13
	110cm	70	48.47	60.79	10	6	13
		75	36.2	54.95	10	5	13
		81	26.5	49.61	10	5	13
		85	22.1	48.86	10	6	13
		90	18.1	44.06	10	7	13
	120cm	70	57.5	58.44	10	6	13
		75	42.7	52.91	10	5	14
		81	31.3	47.79	10	5	14
		85	26.1	45.17	10	6	14
		90	21.4	42.55	10	7	14

▭ Technical parameters selected for lowest radiation dose with acceptable image quality

Table 7. Technical parameters used for anteroposterior lumbar sacral spine, together with the DAP value and image quality obtained from the experimental study

Technical parameter				Dose	Image quality		
Filter	FFD (cm)	kVp	mAs	DAP	High contrast	Low contrast	Resolution
0.2mm Cu	100 cm	70	52.6	68.14	11	7	13
		75	45.2	59.96	11	6	13
		81	32.2	52.61	11	6	13
		85	26.4	48.74	11	7	13
		90	21.2	45.11	11	7	13
	110 cm	70	76.2	68.5	11	7	13
		75	55.2	60.44	10	6	13
		81	39.3	52.97	10	6	13
		85	32.3	49.28	10	7	13
		90	25.9	45.3	11	7	14
	120 cm	70	90.1	68.29	11	7	14
		75	65.2	60.21	10	6	14
		81	46.5	52.91	10	6	14
		85	38.2	49.2	11	7	14
		90	20.7	45.42	11	7	14

▭ Technical parameters selected for lowest radiation dose with acceptable image quality
FFD: film-focus distance

Table 8. Technical parameters used for lateral lumbar sacral spine, together with the DAP values and image quality obtained from the experimental study.

Technical parameter				Dose	Image quality		
Filter	FFD (cm)	kVp	mAs	DAP	High contrast	Low contrast	Resolution
0.2 mm Copper	100 cm	81	115	191.1	11	7	14
		85	93.9	175.44	11	7	14
		90	74.3	159.81	11	7	14
		96	57.8	144.66	11	7	14
		102	46.5	133.01	11	7	14
	110 cm	81	140	189.87	11	7	14
		85	113	173.7	10	8	14
		90	89.6	158.32	10	8	14
		96	69.6	143.2	11	8	14
		102	55.9	131.77	12	8	14
	120 cm	81	161	183.52	10	8	14
		85	131	168.76	10	8	13
		90	103	153.68	10	8	13
		96	81.2	140.02	11	8	13
		102	65.2	128.75	11	9	13

🟦 Technical parameters selected for lowest radiation dose with acceptable image quality
FFD: film-focus distance

Table 9. Summary of the technical parameters selected from the experimental study to be used in the optimization study

Variables	PA chest		AP abdomen		AP lumbar sacral		Lateral lumbar sacral	
	Phantom	Patient	Phantom	Patient	Phantom	Patient	Phantom	Patient
kVp	125	125	81	81	81	81	85	85
Thickness (cm)	27	27	26	26	26	26	32	32
Gender**	Male	Male	Male	Male/Female	Male	Male/Female	Male	Male/Female
Filter (Cu in mm)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
FFD	180	180	115	115	115	115	115	115
AEC (Chamber)	2 Sides	2 Sides	2 Sides	2 Sides	Centre	Centre	Centre	Centre

** Female 27 cm AP thickness – 113 kVp (PA chest only)
FFD: film-focus distance, PA: posteroanterior, AP: anteroposterior

Discussion

Tube Potential

The optimum tube potential depends on the body part being imaged, patient size, image receptor response and required information. The tube potential used for radiological examinations are normally established based on experience. Typical values for the radiography of the abdomen and AP lumbosacral spine for the adults of average size range within 80-85 kVp. However, for the lateral lumbosacral spine, higher tube potential values of 85-90 kVp are employed due to the body part being thicker [8]. Generally, radiographic examinations are carried out using the highest optimum tube potential and the lowest tube-current product so as to produce an image of maximum acceptable noise with minimum acceptable contrast, yielding the required diagnostic information [9]. In line with the recommendation of the fore-mentioned studies, the tube potentials for AP abdomen/lumbosacral spine and the lateral lumbosacral spine were set at 81 and 85 kVp respectively for the present study.

Patient radiation dose would significantly increase provided that higher tube potentials are employed. If tube potential remains within the range of 80-100 kVp, ESD will be doubled for each additional 50 mm of tissue. Furthermore, in case the tube potential is reduced to 60 kVp, the ESD will be increased 2.5-3 times [8]. This implies the importance of selecting the optimum kVp for the body organ being imaged and the information required for diagnosis.

Even though the sensitivity of barium fluorohalide decreases with the photon energy of 60-150 kVp, high kVp technique is generally the preferred choice for chest radiography. This is due to the higher contrast noise ratio (CNR) obtained when using this technique in high-density structures, such as the heart. In this regard, greater X-ray beam penetrability results in the transmission of a small range of beam intensities through the organ being imaged. This then enables all parts of the anatomy to be portrayed within a narrow exposure range [10].

For an average-size patient, 125 kVp is the tube potential recommended for high kVp technique [9], which is consistent with the findings of the present experimental study. However, the use of high tube potential results in the production of more scatter. When 100 kVp or more are used for chest radiography, high scatter is produced, which necessitates the use of a high grid ratio, such as 12:1 or 18:1 [8].

Filtration

As required by national guidelines, thin sheets of aluminum or copper are recommended to be incorporated into medical X-ray tubes to absorb the low-energy photons that do not contribute to the image formation. 2.5 mm aluminum equivalent filter is incorporated as a standard in diagnostic X-ray tubes [11, 12]. In the current study, the lowest radiation dose with an adequate image quality was attained using 0.2 mm copper for all the four examination (i.e., PA chest, AP abdomen and AP and lateral lumbosacral spine).

This is in accordance with the findings obtained by Martin [8] who reported the significant attenuation of low-energy photons when using 0.2 mm copper or less, compared to that when using aluminum. The tube potentials of 70-80kVp facilitate the reduction of ESD as much as 50% despite the need to increase tube output in providing the required air kerma. The reduction of low-energy photons will affect the CNR [10]; however, as indicated in the current study, the effect is not large.

Focus to grid distance

As indicated by the experimental study, dose variations due to grid cut-off, otherwise called focus grid decentering due to the absorption of some of the primary x-ray beam by the grid slats was found to be a major contribution of dose variation [13]. Regarding the Siemen unit employed for this study, the focus to grid distance was 110 cm. Therefore, the use of a focus to film distance shorter or higher than the focus grid distance or decentering distance will result in the occurrence of grid cut-off (tables 6, 7, and 8). The amount of grid cut-off is directly proportional to the decentering distance and the grid ratio [14]. Due to the grid cut-off, the automatic exposure control activation will be prolonged resulting in the utilization of higher exposure (mAs) for the radiographic procedure, and therefore a higher DAP reading.

Conclusion

In conclusion, patient radiation dose is dependent on tube potential, filtration, and exposure parameters. Generally, studies involving X-rays should utilize the highest tube potential (kV) appropriate for X-ray examination and the lowest tube current product to produce an image of acceptable image quality with the minimum acceptable contrast and highest acceptable noise. The increased tube potential and filtration result in the achievement of increased beam penetrability reducing the patient radiation dose. The grid can be utilized in compensating for the increased scatter, which causes concomitant radiographic contrast loss. Phantom study, such as the current research can be utilized for the optimization purposes by selecting the imaging parameters with the lowest ESD and acceptable image quality whilst adjusting for patient size.

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