การตั้งค่าปริมาณรังสีที่เหมาะสมในการถ่ายภาพรังสีช่องท้องด้วยเครื่องเอกซเรย์เคลื่อนที่ระบบดิจิทัล
Optimization of radiation dose and image quality in abdominal radiography using digital mobile x-ray system

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บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์เพื่อหาค่าพารามิเตอร์ที่เหมาะสมสำหรับการถ่ายภาพเอกซเรย์ช่องท้องด้วยเครื่องเอกซเรย์เคลื่อนที่ระบบดิจิทัลที่โรงพยาบาลจุฬาลงกรณ์ สภากาชาดไทย โดยทดสอบในหุ่นจำลองที่มีขนาดความหนาของช่องท้อง 21 เซนติเมตร ตั้งค่าพารามิเตอร์โดยใช้ค่าเควีพีระหว่าง 70 ถึง 90 และค่าเอ็มเอเอสตั้งแต่ 3.2, 6.3, 12.5, 25.0 และ 32.0 จัดระยะห่างจากหลอดเอกซเรย์ถึงตัวรับภาพ 100 เซนติเมตร วัดค่าปริมาณรังสีผ่านที่ผิวของหุ่นจำลองที่ได้รับโดยใช้หัววัดยี่ห้อ Radcal รุ่น ACCU-Gold และประเมินคุณภาพของภาพเอกซเรย์ในเชิงคุณภาพจากองค์ประกอบของภาพรังสีช่องท้องตามมาตรฐานของทบวงการพลังงานปรมาณูระหว่างประเทศ และระดับของสัญญาณรบกวนโดยผู้ประเมินผล 3 ท่าน ประเมินคุณภาพของภาพถ่ายรังสีช่องท้องในเชิงปริมาณของภาพในรูปแบบของอัตราส่วนสัญญาณต่อสัญญาณรบกวน (เอสเอ็นอาร์) 3 ตำแหน่ง ได้แก่ ตับ, กระดูกสันหลังส่วนบั้นเอวระดับที่ 4 บริเวณทรานซ์เวอร์สโปรเซส, และกระดูกสะโพก และประเมินอัตราส่วนความคมชัดบนภาพต่อสัญญาณรบกวน (ซีเอ็นอาร์) ใน 3 บริเวณ ได้แก่ บริเวณตับ, บริเวณไตข้างซ้ายกับกระดูกสันหลังส่วนบั้นเอวระดับที่ 4 บริเวณ บริเวณทรานซ์เวอร์สโปรเซส, และบริเวณไตข้างขวากับกระดูกสะโพก ผลการศึกษาพบว่าค่าพารามิเตอร์ที่เหมาะสมสำหรับการถ่ายภาพรังสีช่องท้องโดยเครื่องเอกซเรย์เคลื่อนที่ระบบดิจิทัลในหุ่นจำลองที่มีขนาดความหนาของช่องท้องไม่เกิน 21 เซนติเมตร คือ 80 เควีพี และ 6.3 เอ็มเอเอส โดยให้ค่าดัชนีชี้วัดปริมาณรังสีเท่ากับ 381 ในส่วนของคะแนนเฉลี่ยจากการประเมินคุณภาพของภาพและระดับของสัญญาณรบกวนจากผู้ประเมิน 3 ท่านมีค่าเท่ากับ 5.67 และ 1 คะแนนตามลำดับ จากการเปรียบเทียบปริมาณรังสีดูดกลืนที่ผิวของหุ่นจำลองของค่าพารามิเตอร์ที่เหมาะสมกับค่าพารามิเตอร์ที่ใช้ในทางคลินิกพบว่าการใช้ค่าพารามิเตอร์ที่เหมาะสมสำหรับการถ่ายภาพรังสีช่องท้องที่ความหนา 21 เซนติเมตร ปริมาณรังสีที่ผิวของหุ่นจำลองลดลงร้อยละ 77 โดยยังคงสามารถรักษาคุณภาพของภาพเพื่อการวินิจฉัยไว้ได้

คำสำคัญ: ปริมาณรังสีที่เหมาะสม, เอกซเรย์เคลื่อนที่ระบบดิจิทัล, ภาพถ่ายทางรังสีช่องท้อง, ค่าปริมาณรังสีผ่านเข้าผิว

Abstract

The purpose of this study was to optimize the radiation dose and image quality for abdominal radiography using digital mobile x-ray system in anthropomorphic phantom at King Chulalongkorn Memorial Hospital (KCMH). Digital mobile x-ray system model OptimaXR220amx, and the Kyoto Kagaku phantom model PBU-60 with 21 cm of abdominal thickness were used. The exposure parameters were set between 70-90 kVp, and 3.2, 6.3, 12.5, 25, and 32 mAs. Source to image receptor distance (SID) was set at 100 cm. The entrance surface air kerma (ESAK) in experimental and routine parameters were measured using ionization chamber (IC) dosimeter manufactured Radcal model ACCU-Gold. The qualitative image quality criteria based on IAEA protocol and qualitative were scored by three observers. The signal-to-noise ratio (SNR) was measured by placing three regions of interest at liver, transvers process at 4^{th} lumbar spine, and pelvis respectively. The contrast-to-noise ratio (CNR) was evaluated on three areas at liver, left kidney and transverse process at 4^{th} lumbar spine, right kidney and pelvis. We found that the optimal parameter for 21 cm thickness of abdomen at 100 cm SID was 80 kVp, 6.3 mAs with the exposure index of 381. The average image quality and qualitative noise scoring from three observers were 5.67 and 1, respectively. The average SNR in 1^{st}, 2^{nd}, and 3^{rd} ROIs were 39.56, 61.55, and 18.24, respectively, and the average of CNR at 1^{st}, 2^{nd}, and 3^{rd} areas were 5.97, 7.27, and 1.50, respectively. The ESAK obtained from optimal parameter was lower than 77% compared to the routine clinical parameter. The optimal exposure parameters in this study, however, can maintain the image quality with acceptable diagnosis for portable abdominal radiography.

Keywords: optimization, digital mobile x-ray system, abdominal radiography, entrance surface air kerma (ESAK)

Introduction

Digital radiography (DR) is an x-ray imaging system in which digital image receptor is used instead of screen-film. DR technology provides user with a good image quality as its wide dynamic range and digital image processing compensates for inappropriate techniques[1-3]. With higher dose efficiency, radiological technologist can use less radiation dose to produce an image of similar contrast to screen-film system. The technology of digital radiography has also been extended to mobile x- ray system for portable examination such as chest x-ray, and other organs with high exposure (abdomen, hip, pelvis, spine, and skull). The advantages are expressed in many aspects for immobilized patients especially intensive care unit (ICU) or emergency room (ER) without moving patient to the x-ray room. However, most patient wards are not well designed for radiation protection, and the patient might receive the exposure several times for clinical follow-up investigation[4]. Therefore, the selection of the exposure parameter is based on the knowledge and experience of the operator justification. The appropriate parameter could reduce the radiation dose to patient, and secondary radiation to staff and public. Currently, there is no standardized technique for abdominal radiography using mobile x-ray system at King Chulalongkorn Memorial Hospital (KCMH). The objective of this study was to optimize the radiation dose and image quality for abdominal radiography in phantom using digital mobile x-ray system.

Materials and Methods

Digital mobile x-ray system

This study was conducted at Department of Radiology, King Chulalongkorn Memorial Hospital (KCMH), Thai Red Cross Society, Bangkok. The digital mobile x-ray system manufactured by GE model OptimaXR 200amx, and digital flat panel detector model Platpad with anti-scatter grid ratio of 6:1 were used as shown in Figure 1(A). The image area of detector is 40.4 x 40.4 cm^2.

Figure 1. (A) Digital flat panel detector with grid manufactured by GE. (B) The whole-body phantom KYOTO KAGAKU model-60.

The quality control of digital mobile x-ray system was performed to verify the system performance and to measure the x-ray tube output. For digital image receptor, the detector dose indicator consistency was examined to verify the exposure index (EI) consistency and the variation of EI including the radiation dose reach to image receptor. The quality control of display monitor was also performed to ensure that the performance of the monitor was within the good condition for image quality interpretation.

Anthropomorphic phantom

The whole-body phantom manufactured by Kyoto Kagaku model PBU-60 as in Figure 1(B) was used. Such anthropomorphic phantom is a life-size human phantom with a syntactic skeleton embedded in a radiological soft-tissue substitute. The abdominal part of the phantom, 21 cm thickness, is inserted with simulated organs for liver, kidneys, spleen, pancreas, stomach (with air), sigmoid colon and rectum.

ESAK determination in phantom

Backscatter factor (BSF) measurement

In order to evaluate the BSF based on 21 cm abdomen thickness of phantom, the ionization chamber (IC) dosimeter with sensitive volume of 38 mm^3 manufactured Radcal Corporation model Accu-Gold with ion chamber dose sensors model 10X6-6 was used. The x-ray tube of digital mobile x-ray unit and IC dosimeter were set up in air by positioning 100 cm of source to detector distance (SD), 79 cm of source to chamber distance (SCD) which is closed to the surface of the phantom, and 41x41 cm^2 of field size. The chamber was exposed with the experimental and routine clinical parameters of 70, 75, 80, 85, 90 kVp, and tube-current time of 3.2, 6.4, 12.5, 25, 32 mAs in order to determine the incident air kerma (K_i) without matter. The phantom was then placed under the dosimeter and exposed accordingly with the same parameters in order to measure the entrance surface air kerma (ESAK). The setting of BSF measurement is illustrated as in Figure 2. The BSF was calculated using the formula as followings:

$$BSF = \frac{ESAK}{K_i} \quad (1)$$

The ESAK in whole-body phantom was calculated for various exposed experimental parameters of 70-90 kVp and 3.2-32.0 mAs using the Ki and BSF as mentioned previously. These also included the routine clinical parameters of 75 kVp and 32 mAs for portable abdominal radiography at 100 cm SID. The ESAK (mGy) can be calculated using equation (2) and (3) as followings[5]:

$$K_i = Y(d) \times P_{it} \times \left(\frac{d}{d_{FTD} - t_p} \right)^2 \quad (2)$$

$$ESAK = K_i \times BSF \quad (3)$$

where K_i represents the incident air kerma (mGy), Y(d) is the x-ray tube output (mGy/mAs) which was measured during the x-ray machine performance was performed, P_{it} is a tube loading (mAs), d is focus to chamber distance (cm), d_{FTD} is focus to table top distance (cm), t_p is the phantom thickness (cm), and BSF is the backscatter factor.

Figure 2. (A) Incident air kerma, Ki, measurement and (B) ESAK measurement for 21 cm thickness of abdomen in phantom.

Qualitative image quality

For qualitative analysis, the image quality of the abdominal radiography in each parameter was evaluated by randomized blinded method by at least two years' experience of three observers. The image quality score was analyzed based on the International Atomic Energy Agency (IAEA) criteria[6] as shown in Table 1, where the acceptable of image quality score must equal or more than five from seven points. For qualitative noise, the criteria score was evaluated based on the whole visualized image noise (rate of qualitative noise score: 0 = free of noise, 1 = scarce noise, 2 = significant noise, 3 = obvious noise), where the acceptable score was between 1 and 2 points.

Quantitative image quality

For quantitative image analysis, the abdominal radiographic image was evaluated in terms of signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR). The SNR was evaluated by placing 3 regions of interests (ROIs) on the image and measuring the pixel value three times for each location (middle of the liver, left side of transverse process in 4th lumbar spine, and right side of flat bone in pelvis) as shown in Figure 3 (A). The SNR was calculated using the equation as followings:

$$SNR = \left(\frac{mean\ pixel\ value\ in\ ROI}{SD\ in\ ROI}\right) \quad (4)$$

In order to determine CNR for evaluating the contrast between two adjacent areas, three ROIs were added on the image to measure mean pixel value and SD in the background region as illustrated in Figure 3(B); where 4th ROI represents lower lobe of liver, 5th ROI represents left kidney, and 6th ROI represent right kidney. The CNR was determined using equation as followings:

$$CNR = \frac{(\bar{x}_s - \bar{x}_{bg})}{\sigma_{bg}} \quad (5)$$

where $\bar{x}_s$ is mean pixel value of ROI in the interested region, $\bar{x}_{bg}$ is mean pixel value of ROI in the adjacent background, and σ_{bg} is the standard deviation of ROI in the background.

Table 1. Image criteria score[6].

Item	Image criteria
1	Sharp visualization of ribs.
2	Visualization of lower margin of liver, spleen and kidneys.
3	Visualization of spleen.
4	Visualization of kidneys.
5	Sharp visualization of stomach and bowel loop.
6	Visualization of ribs and transverse processes of lumbar vertebrae.
7	Markers indicating either upright or supine position.

* Rate image score: 0, 0.5, and 1, where 0 = not fulfilled, 0.5 = partly fulfilled, 1 = fulfilled

Optimal parameter consideration

The optimal exposure parameters were justified using the value of ESAK which is not exceeded 1.86 mGy according to the study of Aldrich JE et al[7], the EI closed to the target EI at 336 (the value recommended by the vendor)[8], Image criteria score from three observers, and qualitative and quantitative image analysis. Ideally, the lowest radiation dose while obtaining acceptable images quality would be selected.

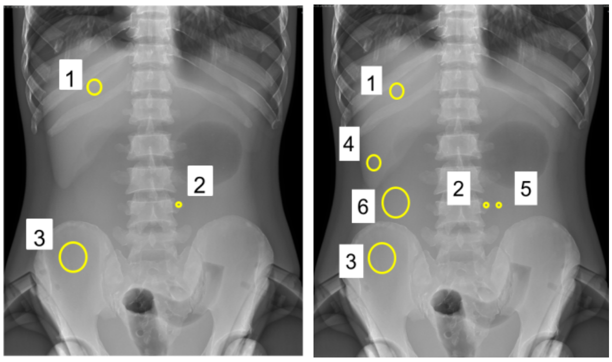


Figure 3. (A) ROIs for measuring SNR on the abdominal radiographic image. (B) Six ROIs for CNR evaluation.

Results

Table 2 shows the results of ESAK and average image quality evaluated by three observers in each parameter. The ESAK in both experimental and clinical were between 0.234 and 3.218 mGy. Table 3 shows the average SNR. The 1st ROI represents liver with the range of 26.52-47.71, the 2nd ROI represents left transverse process at 4th lumbar spine, the range was 37.00-98.98, and the 3rd ROI represents right side of flat bone in pelvis, the range was 15.43-21.20. Table 4 shows average CNR. The 1st area range was 5.46-7.02, the 2nd area range was 4.94-9.32, and the 3rd area range was 0.74-2.16.

It was found that there were 12 parameters in which the image quality score met the image criteria (≥ 5) and the ESAK was lower than 1.86 mGy[7] as illustrated in Figure 4. Although the parameters of 80 kVp, 3.2 mAs, 70 kVp, 6.3 mAs and 75 kVp, 6.3 mAs obtained the lowest ESAK at 0.318, 0.461, and 0.541 mGy, those image quality score had range between 4.5 to 5.5, 4.5 to 6, and 4.5 to 5.5. The results showed that probably one of three observers gave image score lower than the image criteria and the EI were not closed to the target EI. Finally, the range of optimal parameter selected for the whole-body phantom in 21 cm thickness of abdomen of 80-85 kVp and 6.3 mAs with the EI 381 approximately is recommended. This optimal parameter can provide the ESAK of 0.626 mGy while giving the qualitative image quality range between 5.5 and 6. The summary of routine protocol and optimal protocol were compared as in Table 5 and the abdominal radiographic images were illustrated in Figure 5.

Using the optimal parameter, the reduction of ESAK was decreased by 77% from the routine clinical parameter. For qualitative analysis, the image quality score was 15% lower than the routine parameter while the quantitative image analysis score was slightly different. For the quantitative analysis, the average SNR of 1st and 2nd ROIs were decreased by 13% and 17% and 3rd ROI was increased 2% from the routine parameter. The average CNR of 1st, 2nd, and 3rd areas were decreased by 3%, 23%, and 18%, respectively.

Table 2. Results of ESAK and qualitative image quality evaluation.

Parameters		Exposure index	ESAK	Scoring	
kVp	mAs		(mGy)	Image quality	Qualitative noise
70	3.2	91	0.234	4.67	2
	6.3	185	0.461	5.00	1
	12.5	363	0.915	6.33	1
	25.0	706	1.830	6.00	1
75	3.2	133	0.275	4.67	2
	6.3	272	0.541	5.00	1
	12.5	520	1.074	5.67	1
	25.0	1009	2.147	6.50	1
	32.0*	1262	2.748	6.67	1
80	3.2	188	0.318	5.17	2
	6.3**	381	0.626	5.67	1
	12.5	717	1.242	6.00	1
	25.0	1370	2.443	6.17	1
85	3.2	252	0.364	4.67	1
	6.3	509	0.716	5.67	1
	12.5	949	1.420	6.00	1
	25.0	1788	2.841	5.50	1
90	3.2	329	0.412	4.83	1
	6.3	650	0.811	5.50	1
	12.5	1206	1.609	6.50	1
	25.0	2252	3.218	5.33	1

*the routine clinical parameter, **optimal parameter

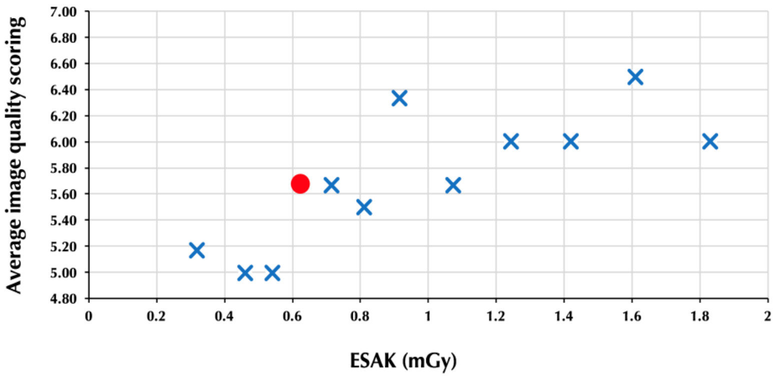


Figure 4. Scatter plots between the ESAK and the average image quality scoring after image analysis in 21 cm thickness of abdomen. The blue cross color represents the parameter that image scoring meets the criteria for optimal parameter selection. The red dot represents the optimal parameter selected for 21 cm thickness of abdomen.

Table 3. Results of SNR in each parameter.

Parameters		Average SNR		
kVp	mAs	1st ROI	2nd ROI	3rd ROI
70	3.2	26.52	37.00	15.43
	6.3	36.56	49.62	15.86
	12.5	40.02	54.76	16.20
	25.0	41.41	60.81	16.58
75	3.2	29.75	47.33	16.82
	6.3	38.51	55.30	17.11
	12.5	42.48	59.42	17.66
	25.0	43.07	66.52	17.76
	32.0*	45.66	74.59	17.85
80	3.2	36.89	50.53	18.05
	6.3**	39.56	61.55	18.24
	12.5	43.87	62.34	18.35
	25.0	45.09	72.36	18.69
85	3.2	37.61	62.29	19.35
	6.3	45.06	72.77	19.73
	12.5	45.36	75.56	19.93
	25.0	46.68	78.36	20.19
90	3.2	43.59	69.30	20.66
	6.3	46.32	73.22	20.86
	12.5	47.31	83.86	20.99
	25.0	47.71	98.98	21.20

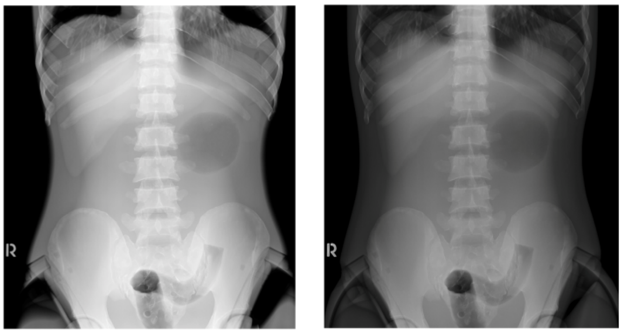
Table 4. Results of CNR in each parameter.

Parameters		Average CNR		
kVp	mAs	1st area	2nd area	3rd area
70	3.2	5.46	4.94	0.74
	6.3	5.62	6.59	1.09
	12.5	5.67	7.66	1.40
	25.0	6.00	8.61	1.46
75	3.2	5.51	4.99	0.77
	6.3	5.64	7.01	1.18
	12.5	6.00	8.32	1.65
	25.0	6.04	8.78	1.72
	32.0*	6.16	9.44	1.83
80	3.2	5.92	5.32	0.96
	6.3**	5.97	7.27	1.50
	12.5	6.18	8.66	1.75
	25.0	6.28	9.06	1.86
85	3.2	6.17	5.46	0.99
	6.3	6.44	7.44	1.63
	12.5	6.59	8.75	1.80
	25.0	6.74	9.28	1.93
90	3.2	6.35	5.51	1.26
	6.3	6.48	7.50	1.81
	12.5	6.82	8.88	2.03
	25.0	7.02	9.32	2.16

*the routine clinical parameter, **optimal parameter

Discussion

Currently, the technology of DR could decrease the radiation dose as well as maintain the image quality for diagnosis in medical imaging field. The radiation dose to the patient, therefore, could be significantly reduced as well. The present study is revealed the investigation of the optimal exposure parameters in abdominal radiography using digital mobile x-ray system in phantom at King Chulalongkorn Memorial Hospital. From the DRL recommended by IAEA, the ESAK in abdomen AP radiography based on screen-film system was 10 mGy. According to Muhogora WE et al(9), the average ESAK to adult patients (70±10 kg) of abdominal radiography in Thailand was 3.9 mGy using film-screen system. The data were collected from 4 local hospitals. The incident air kerma for each adult patient was investigated by the product of the x-ray tube output value that derived from the output per mAs–kVp curve corrected for the inverse distance effects between the patient's distance from the x-ray focus and the distance at output measurements, and the actual tube loading (mAs). Unfortunately, there were no reports of DRL based on digital radiography from other publications.



A. Routine clinical parameter
75 kVp 32 mAs
ESAK = 2.748 mGy

B. Optimal parameter
80 kVp 6.3 mAs
ESAK = 0.626 mGy

Figure 5. Abdominal radiography using routine clinical and optimal parameter in 21 cm thickness in abdomen.

The exposure index (EI) is the indicator of the amount of radiation dose at the image receptor(10). For GE digital radiography system, the EI is directly related to radiation dose that reach to image receptor. The higher of radiation dose to image receptor, the greater of the EI. The target EI for abdominal radiography of 336 is recommended by the vendor(8). The comparison between EI and the image quality score in each parameter needs to be considered as the EI in some parameters were lower than the target EI. The obtained image quality score, however, was still within the acceptable limit.

Table 5. Comparison between the routine clinical and optimal parameter.

	Clinical parameter	Optimal parameter
ESAK (mGy)	2.748	0.626
Exposure index (EI)	1262	381
Qualitative image quality score	6.67	5.67
Qualitative noise score	1	1
Quantitative noise score		
Average SNR		
- 1st ROI	45.66	39.56
- 2nd ROI	74.59	61.55
- 3rd ROI	17.59	18.24
Average CNR		
- 1st Area	6.16	5.97
- 2nd Area	9.44	7.27
- 3rd Area	1.83	1.50

For quantitative image analysis in both of SNR and CNR, the pixel value was directly measured from the raw data radiographic images on the display monitor of the digital mobile x-ray system instead of measuring on PACS monitor. The main reason was the pixel value of the radiographic image after transferring to PACS system was fluctuated due to the image processing algorithm of manufacturer. Using the optimal parameter, the average SNR of the 1st and 2nd ROIs were decreased by 13% and 17%, and 3rd ROI was slightly increased by 2% compared to the routine parameter. Likewise, the average CNR of the 1st, 2nd, and 3rd areas were decreased by 3%, 23%, and 18% from the routine clinical parameter, respectively. As the SNR and CNR values were relatively increased with increasing the doses, the moderated SNR, CNR as well as qualitative noise scoring obtained from optimal protocol were selected instead. However, lower doses in the rest of parameters will provide lower SNR, CNR and blurring image accordingly.

The average ESAK of the abdomen AP using digital radiography of 1.86 mGy was studied by Aldrich JE et al(7) and 2.24 mGy by Asada Y et al(11) (assuming that the ESAK is approximately equal to ESD). In this study, the ESAK of the optimal parameter in 21 cm thickness of abdomen was

0.626 mGy. Therefore, optimal exposure parameters in this study were comparable to the previous studies[7,11-12] and can reduce the radiation dose substantially.

Conclusions

The appropriated parameter for the abdominal radiography using digital mobile x-ray system at King Chulalongkorn Memorial Hospital in anthropomorphic phantom was investigated. The optimal exposure parameters can reduce the radiation dose based on phantom study substantially by 77% for the thickness of abdomen equal or less than 21 cm compared to the routine clinical parameter. This protocol could be used as the recommended parameters for radiological technologists in abdominal radiography using digital mobile x-ray system for clinical study in the future work.

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การตั้งค่าปริมาณรังสีที่เหมาะสมในการถ่ายภาพรังสีช่องท้องด้วยเครื่องเอกซเรย์เคลื่อนที่ระบบดิจิทัล

Optimization of radiation dose and image quality in abdominal radiography using digital mobile x-ray system

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