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Dose Evaluation for Common Digital Radiographic Examinations in Selected Hospitals in Pahang Malaysia

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ABSTRACT

Introduction: In digital radiography, radiographers tend to increase exposure factors to acquire an acceptable image quality thereby increasing radiation dose to patients. Regarding this, the present study aimed to re-evaluate the exposure parameters and to ascertain the entrance surface dose (ESD) and effective dose (ED) of posterior-anterior (PA) chest, abdomen, and anterior-posterior (AP) lumbosacral spine radiography.

Materials and Methods: This study was conducted on 180 physically able patients with age of 20-60 years and weight of 60-80 kg referred to Hospital Sultan Haji Ahmad Shah (HOSHAS) and Hospital Tengku Ampuan Afzan (HTAA).Image acquisition was performed using digital radiography. The ESD and ED were determined using CALDose_X 5.0 software.

Results: The ESD and ED for PA chest were 0.098 mGy and 0.012 mSv in HOSHAS, while in HTAA were 0.161 mGy and 0.021 mSv respectively. Regarding the abdomen, the ESD and ED were 2.57 mGy and 0.311 mSv in HOSHAS and 2.16 mGy and 0.262 mSv in HTAA respectively. For AP lumbosacral spine, the ESD and ED for HOSHAS were 2.65 mGy and 0.222 mSv, while in HTAA were 2.357 mGy and 0.201 mSv respectively.

Conclusion: The findings revealed the use of high kVp, automatic exposure control, correct focus image receptor distance, tight collimation and additional filter resulted in a lower ESD. The ESD and ED obtained in this study were comparable with those reported by other studies and lower than the values recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation in 2008.

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Introduction

Radiographic procedures play a significant role in assisting the radiologist to detect abnormalities, monitor the progression of diseases and evaluate the treatment response. Millions of radiographic procedures are performed every year and the requests for radiological procedures are annually increasing due to the advent of digital radiography [1]. The enhancement of radiographic examinations could be partly due to the aging population, new technological inventions in digital radiography (which are useful in radiological diagnosis) and increase of doctors in the medical field [2].

Although digital radiography can bring about a lower radiation dose; however, there is a tendency to significantly increase the dose since the radiographer unknowingly elevate the exposure factors to acquire an acceptable image quality for diagnosis [3]. Regarding the significant increase of exposure settings amongst the radiographers [1], it is important to assess and re-evaluate this parameter and measure the dose received during the imaging process.

Given that all radiographic procedures use radiation source, the patient would have a risk of developing cancer and exposing to adverse health effects [4]. This issue created the interest to measure the dose received by the patients while considering the risk associated with radiological examination [3]. The entrance surface dose (ESD) denotes the amount of dose received by the patient as the X-ray beam enters the targeted region while taking into account the scattered radiation. Meanwhile, the effective dose (ED) is used to express the relative health risk the patient is exposed to, which is obtained by the estimation of the whole body absorbed dose from non-uniform irradiated organs during the radiographic procedure.

With this background in mind, the present study was conducted to estimate the ESD and ED of adults aged within 20-60 years for the posterior-anterior (PA) chest, anterior posterior (AP) abdomen and AP lumbosacral spine radiography using CALDose_X 5.0 (i.e., a computer based software using Monte Carlo method)

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Materials and Methods

This study was conducted on 180 physically able patients with the age of 20-60 years and weight of 60-80 kg, referred to two public hospitals in Pahang, Malaysia. The study was carried out at Hospital Sultan Haji Ahmad Shah (HOSHAS) and Hospital Tengku Ampuan Afzan (HTAA) during March-May 2016 and June-July 2016, respectively. Ethical approval was obtained from the Research Ethics Committee of the International Islamic University, Malaysia (approval number: IIUM/305/14/11/2 /IREC581).

The entrance surface air kerma was obtained using the dose area product (DAP) meter (Kerma X_plus) that was placed under the collimator to intercept the entire area of radiation field when the radiographic examination was performed. In this study, the ED was estimated using CALDose_X 5.0 (Department of Nuclear Energy, University of Pernambuco, Brazil) which is a computer-based software using Monte Carlo method. This software predicts the incident air kerma (INAK) value by referring to the output curve of an X-ray tube.

Accordingly, the ESD was obtained by multiplying the INAK value with the backscatter factor. The conversion coefficient of this software was calculated for male adult phantom (MASH) and female adult phantom (FASH) as well. The conversion coefficient facilitates the calculation of the absorbed dose and ED (for gender-specific organs and patient positioning) as well as the patient's cancer risk for radiographic examinations. The FASH and MASH phantoms have tissue masses and organs that follow the anatomical reference data from the International Commission on Radiological Protection (ICRP), 2002 [5].

They were modelled on standing, supine, lateral, and oblique positioning, which covered 22 examinations with 2.5 mm aluminium filter integrated with the X-ray tube. This software also requires the user to manually input the patients' characteristics and technical factors, such as age, gender, position, type of examination, tube potential (kVp), tube current-time product (mAs), body thickness, DAP reading, collimation size, and focus-film distance (FFD). The ESD can be calculated using the recorded outputs (i.e., kV, mAs, and FFD) through the following equation [6]:

$$ESD = O \text{ x} \left(\frac{v}{80}\right)^2 \text{x} \left(\frac{100}{d}\right)^2 \; CTf \qquad (1)$$

Where v is tube voltage in kV, d is focus-skin distance in cm, C is current in mA, T is the exposure time in s, f is the scatter factor, and O is the tube output in mGy/mAs. Once the ESD is estimated, the ED can be calculated and the relationship can be expressed by the following equation:

$$E = \sum \frac{W_T[H_T(female) + H_T(male)]}{2} = \frac{1}{2}\left[\sum W_T H_T(female) + \sum W_T H_T(male)\right] = \frac{1}{2}[F + M] \qquad (2)$$

Referring to the above equation, the elicited ED is the average of both gender-specific weighted doses as determined in the ICRP (2007) [7]. To ensure if all the equipment was in satisfactory condition, they were tested and calibrated according to the preventive maintenance schedule provided by the manufacturer companies. Therefore, we tested the X-ray field alignment, generator and automatic exposure control (AEC) performance of the X-ray unit.

Statistical Analysis

Given the non-normality of the data, the Spearman's rank order correlation was used to evaluate the correlation of ESD with mAs and that of tube voltage with weight. In addition, the linear regression was utilized to assess the contribution of variance of mAs to ESD. The data analysis was performed using the SPSS version 18.

Results

The summary of the patients' demographics and types of examinations for the two centers is shown in Table 1. Additionally, Table 2 presents the technical factors used in this study. The comparison of the exposure factors used in this study with those reported in the literature is demonstrated in Table 3. Further, the ESD and ED for the chest, abdomen and AP lumbosacral obtained in this study were compared with other published data (Tables 4 and 5).

Table 1. Summary of patients' characteristics for the various examinations for the two centers

		Mean Age Mean (S.D)		Weight Mean (S.D)		No. of Patients		AP thickness Mean (S.D)		BMI Mean (S.D)	
Examination	Projection	HOSHAS	HTAA	HOSHAS	HTAA	HOSHAS	HTAA	HOSHAS	HTAA	HOSHAS	HTAA
CXR	PA	46.3 ± 11.03	48 ± 13.0	65.6 ± 7.69	68.3 ± 7.9	30	30	25.5 ± 3.97	28 ± 3.2	24.5 ± 2.7	26 ± 2.03
AXR	AP	41.63 ± 13.7	47.2 ±13.0	66.31 ± 7.22	67.95 ± 10.0	30	30	23.4 ± 4.01	23.02 ± 3.06	25.6 ± 3.04	25.2 ± 4.17
Lumbar	AP	41.83 ± 12.43	49.3 ± 12.5	67.35 ± 8.4	67.3 ± 7.11	30	30	25.1 ± 3.79	26.2 ± 4.62	24.8 ± 3.01	26.7 ± 4.35

Table 2. Technical parameters used at the two centers

Examination	kVp		mAs		Coll Size (m^2)		FFD		AEC Chamber/ filter	
	HOSHAS Mean (S.D)	HTAA Mean (S.D)	HOSHAS Mean (S.D)	HTAA Mean (S.D)	HOSHAS Mean (S.D)	HTAA Mean (S.D)	HOSHAS Mean (S.D)	HTAA Mean (S.D)	HOSHAS	HTAA
CXR [PA]	121.5 ± 1.74	124.57 ± 1.70	1.57 ± 0.56	2.4 ± 0.19	0.11 ± 0.014	0.12 ± 0.04	180	180	2 Sides/ No	No/ 0.1Cu
AXR [AP]	74.9 ± 2.75	80.13 ± 4.69	40.38 ± 27.36	33.09 ± 7.11	0.18 ± 0.03	0.162 ± 0.02	105.1 ± 18.23	115.1 ± 3.9	2 Sides/ No	No/ 0.1Cu
Lumbar Sacral Spine [AP]	77.16 ± 4.02	80.06 ± 4.29	51.2 ± 32.67	36.7 ± 6.16	0.13 ± 0.034	0.11 ± 0.09	114.9 ± 0.365	108.6 ± 6.1	Centre/ No	No/ 0.1Cu

Table 3. Comparison of exposure factors used in this study and other published data

Examination	This Study				Abdullah et al. 2010 [8]		Aliasgharzadeh et al., 2015 [4]		EC (1996) [9]	
	KVp		mAs							
	HOSHAS Mean (Range)	HTAA Mean (Range)	HOSHAS Mean (Range)	HTAA Mean (Range)	kVp Mean	mAs Mean	kVp Mean (Range)	mAs Mean (Range)	kVp Mean	mAs Mean
Chest (PA)	121.5 (121-129)	124.57 (120-125)	1.57 (0.97-2.59)	2.4 (1.9-2.5)	65	5	70 (63-76)	19 (16-22)	125	-
Abdomen (AP)	74.9 (70-81)	80.13 (78-85)	40.38 (3.72-98)	33.09 (28.8-35.2)	72	35	75 (70-83)	24 (13-36)	75-90	-
Lumbar sacral spine (AP)	77.1 (70-87.5)	80.0 (77-92)	51.2 (22-105)	36.7 (28-50)	73	35	75 (68-79)	24 (13-36)	75-90	-

Table 4. Comparison of entrance surface dose (mGy) derived from the routine radiographic examinations for the two centers with other published data

Examination	This Study		Aliasgharzadeh et al., 2015[4]	Abdullah et al., 2010[8]	Osei & Darko, 2012[1]	Hart et al., 2010[10]	UNSCEAR 2008[11]
	HOSHAS Mean (S.D)	HTAA Mean (S.D)					
Chest (PA)	0.098 (± 0.06)	0.161 (± 0.025)	0.37	0.18	0.14	0.15	0.33
Abdomen (AP)	2.57 (± 1.64)	2.16 (± 0.74)	2.01	4.89	1.82	4	3.64
Lumbar sacral spine (AP)	2.65 (± 1.42)	2.357 (± 0.72)	2.18	5.74	3.72	5.7	4.07

Table 5. Comparison of effective dose (mSv) derived from the common radiographic examinations from the two centers with other published data

Examination	This Study		Osei & Darko, 2012 [1]	Compagnone et al., 2008[12]	Aliasgharzadeh et al., 2015[4]	Hart et al., 2010[10]	UNSCEAR 2008[11]
	HOSHAS Mean	HTAA Mean					
Chest (PA)	0.012	0.021	0.14	0.11	0.04	0.014	0.05
Abdomen (AP)	0.311	0.262	1.82	2.47	0.28	0.43	0.8
Lumbar sacral spine(AP)	0.222	0.201	3.72	2.57	0.23	0.39	1.2

According to the results, there was a statistically significant correlation between mAs and ESD for HOSHAS (r=0.75, P<0.05) but insignificant correlation for HTAA (r=0.47, P<0.01), for PA chest radiography. Based on the linear regression model, for PA chest radiography it reflected that the contributions of mAs towards the variance of ESD were 22.3% and 56% for HTAA and HOSHAS, respectively (Figure 1). These results were indicative of a significant value for HOSHAS and an insignificant value for HTAA.

In the AP abdomen radiography, a significant correlation was observed between the mAs and ESD for HTAA (r=0.86, P<0.01); moreover, these two variables had a lower correlation in HOSHAS (r=0.75, P<0.01). However, the contributions of variance of mAs towards ESD as explained by the linear model were 73.4% and 56.6% for HTAA and HOSHAS, respectively (Figure 2). Regarding the AP lumbosacral spine radiography, there were was only a low correlation between mAs and ESD (r=0.39, P<0.01) in HOSHAS. The contributions of mAs towards the variance of ESD in this region were 14.9% and 3.6% for HOSHAS and HTAA, respectively (Figure 3).

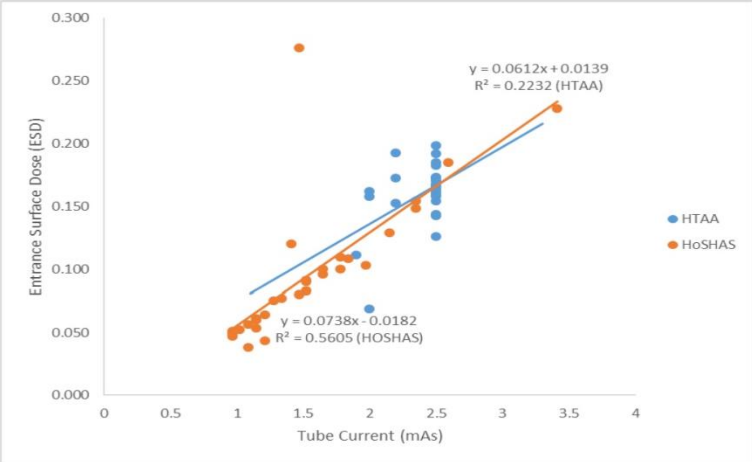

Figure 1. Relationship of ESD and mAs for PA chest radiography at the two centers

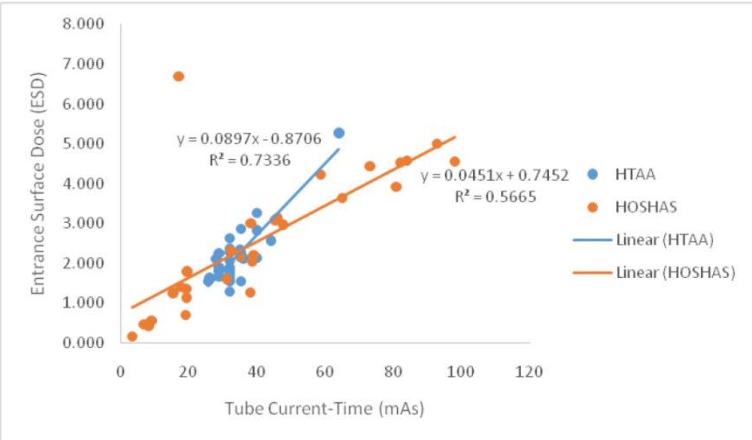

Figure 2. Relationship of ESD and mAs for AP abdomen radiography at the two centers

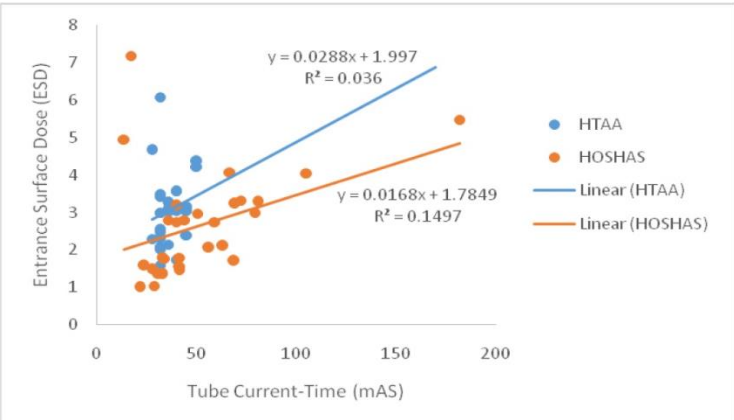

Figure 3. Relationship of ESD and mAs for AP lumber sacral spine radiography at the two centers

Discussion

Both hospitals used a high kilovoltage technique for the PA chest radiography as recommended by the European Commission [9]. The mean tube potential employed by HOSHAS and HTAA were 121.5 and 124.6 kVp respectively, which resulted in the use of a lower mAs (Table 3). It was found that most of the radiographers did not manually calculate the AP thickness of the imaged region prior to the X-ray examination.

According to the findings, regarding the significant moderate correlation of the patient weight and kVp observed in HOSHAS, kVp selection for the PA chest radiography was established based on the patients' weight in this hospital. Furthermore, kVp showed no statistically significant correlation with the AP thickness of the chest and weight of the patients in the HTAA (Figure 4). Regarding this, it seemed that the selection of kVp for the chest radiography in HTAA was not based on the patient weight or AP thickness. However, the utilization of the AEC in HOSHAS with the correct chamber selection facilitated the reduction of the radiographer's misjudgement in setting suboptimal exposures.

Despite the increase in photon fluence per unit of energy and exposure (mm^2keV) and mean energy of the photons (keV) when using 125 kVp in HTAA with additional 0.1 mm copper filtration as opposed to that of 121 kVp without additional filtration in HOSHAS, the ESD for the PA chest radiography in HOSHAS was lower than that of HTAA. The higher ESD attained in HTAA could be attributed to the maladjustment of exposure factors in relation to the patient's AP thickness (Table 2). Although higher kVp were used in HTAA, this hospital also applied a higher mAs, compared to those used in HOSHAS.

Furthermore, the higher ESD in HTAA could be due to the lower detective quantum efficiency (DQE) of the computed radiography (CR) system (single read out) used in this hospital as compared to the active-matrix flat panel imagers technology employed in the DR system in HOSHAS. A lower DQE would result in a higher exposure factor when using the CR system and therefore a higher radiation dose to achieve a given signal noise ratio [13].table

As indicated in tables 4 and 5, the comparison of ESD and ED obtained in this study with other published data revealed that these values were much lower for the PA chest radiography in HOSHAS than those reported by the literature. In HTAA, the ESD and ED were higher than those obtained by Osei and Darko [1] as well as Hart et al. [10].

In terms of the AP abdomen radiography, the ESD and ED were lower in HTAA than those in HOSHAS. However, the ESD and ED of the two hospitals were found to be higher than those reported by three other studies [1, 4, 12]. Furthermore, in this study, the ED for lumbosacral radiography was lower than all published data in the literature. In this regard, this value was at the least 70% lower than those reported by three studies [8, 10, 11]. Nevertheless, the ESD obtained for the two centers in this study was found to be higher than that indicated by Aliasgharzadeh et al. [4].

The ESD acquired from the AP abdomen radiography for HOSHAS was almost 19% higher than that of HTAA. The lower ESD received by the patients in HTAA could be due to the use of lower mAs, "tighter collimation", correct FFD and additional 0.1 mm copper filter (Table 2). The utilization of a higher kVp for radiography would result in a lower mAs. Therefore, this indirectly would reduce the ESD received by the patient as mAs is proportional to ESD.

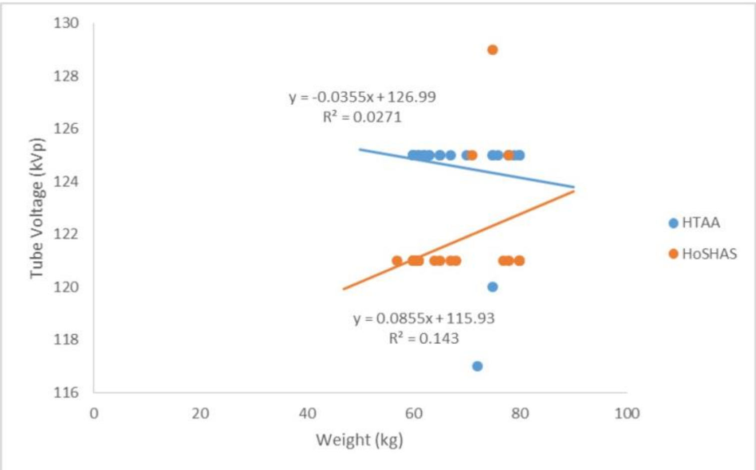

Figure 4. Relationship of kVp and patient's weight for PA chest radiography for the two centres

In addition, the application of "tighter" collimation in HTAA (0.162 m^2) as opposed to that of HOSHAS (0.18 m^2) for the AP abdomen radiography could be attributed to the lower ESD received by the patient since collimation would reduce the scattered radiation from being reflected back to the patient and consequently reduce the radiation dose [14]. The use of correct FFD as recommended by Siemens in HTAA could also be the factor that contributed in lowering the ESD.

The focus-grid distance of the Siemens unit was 115 cm for both hospitals. Therefore, if the utilized FFD is lower than the focus-grid distance, it will result in grid cut-off [14]. The combination of correct FFD, AEC and correct chamber selection can optimize the applied mAs [15]. Another factor that contributed to the lower dose received by the patient in HTAA may be the effect of using 0.1 mm additional copper filter while performing the AP abdomen radiography. In this regard, the added filtrations significantly absorb the lower energy photons imparted to the patient, which in turn reduced the ESD in HTAA.

The evaluation of the ESD for AP lumbosacral spine radiography (Table 4) indicated a higher ESD in HOSHAS (2.65 mGy), compared to that in HTAA (2.36 mGy). The higher ESD in HOSHAS could be due to the use of lower kVp (Table 2), which resulted in the application of higher mAs. This was indicated by the attainment of a moderate but significant correlation between mAs and ESD in HOSHAS. Moreover, the employment of a larger collimation (0.13 m^2) in HOSHAS as compared to that in HTAA (0.11 m^2) could be another attributed factor in this regard.

Additional filtration of 0.1 mm copper further improved the photon fluence and photon energy, which could be the factors that resulted in the lower ESD in HTAA for the AP lumbosacral spine radiography.

Conclusion

As the findings revealed, the use of high kVp, AEC, correct focus-image receptor distance when using focused grid, "tight" collimation and additional filter resulted in a lower ESD in HTAA compared to that in HOSHAS for the abdomen and lumbosacral spine examinations. The lower ESD received by the patients for the chest radiography in HOSHAS was mainly due to the technology employed in the digital radiography system resulting in a higher DQE when compared to the single read out CR system used in HTAA.

The ESD and ED obtained from this study for the PA chest radiography, abdomen, and lumbosacral radiography examinations were comparable with those reported by other studies and lower than those recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation in 2008. It also indicated that further effort should be made to lower the radiation dose particularly for the abdomen radiography.

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