A Comparison of Two Indirect Methods for Skin Dose In Chest Radiography

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ABSTRACT: This study aims to determine the Entrance Surface Dose (ESD) in chest radiography using two different indirect methods, in comparison to the Standard Diagnostic Reference Level (DRL) introduced by The European Union Council Directive 97/43/EURATOM and the adoption of detector Correction Factor (CF) during ESD measurement. This Entrance Surface Dose (ESD) in chest radiography was calculated using two different indirect methods, using DAP method with correction factor ($ESD_{DAP\ with\ CF}$) and manual calculation method (ESD_c). Both methods of ESD calculation were obtained with x-ray energy ranging between 70kVp to 125kVp, and compared to the standard. The $ESD_{DAP\ with\ CF}$ was adopted from the Standard with consideration for correction factors during measurement whereas ESD_c was the indirect method used without using the DAP meter. The $ESD_{DAP\ with\ CF}$ was found to be slightly different compared to the Standard but not to a significant. The ESD_c however showed a significant difference compared to the Standard with 23% to 33% difference in all energy ranges. The obtained results indicate that CF should be considered during ESD measurement for better and more accurate dosimetry measurement.

Keywords: Chest radiography, Correction factor (CF), Entrance surface dose (ESD), Diagnostic reverence level (DRL)

Introduction

Radiographic imaging becomes the most frequent and essential source of radiation for the world population among medical exposures. Ionizing radiation gives a significant radiation dose to a patient during radiographic examination. Ionizing radiation in term of biological effect may damage Deoxyribonucleic acid (DNA) and is hazardous to the cell tissue (Akhdar *et al*., 2007).

All exposures to diagnostic x-rays must be justified and optimized, taking into consideration the benefits and risks to the patients (Freitas *et al.*, 2003). The number and types of x-ray examination, the physical parameters and radiation dosage delivered to a patient must be justified as a requirement of radiation protection.

Chest radiography has become one of the most common examinations performed at the radiological department in Malaysia. Chest x-ray is the most necessary in all kinds of sub speciality examinations such as pre-assessment examination, patient condition examination and post surgical interventions. The number of imaging done in 2003 alone was 63% out of the radiographic procedures in Malaysia (Ramli *et al*., 2003). This was due to the capability of the resulting images to diagnose a wide range of clinical problems. The frequent use and diagnostic importance of chest x-rays make the optimization of image quality and patient radiation dosage important areas of research.

The Entrance Surface Dose (ESD) is defined as the absorbed dosage to air where the x-ray beam intersects the skin surface of a patient (Sharifat *et al*., 2009). ESD can be calculated from Dose Area Product (DAP) measurement (ESD_{DAP} and $ESD_{DAP\ with\ CF}$). The mathematical model calculation of ESD is based on x-ray tube output (ESD_C). Comparatively, the mathematical model calculation of ESD based on output is easier to use compared to the ESD determined from the DAP. ESD depends on the x-ray penetrating power and parameters used during the x-ray examination. The other reason for evaluating surface dosage is because the dose is greater at the surface compared to the internal organ, indicating that radiation effect on the skin is more significant. An example is burnt skin (also known as skin erythema) (Ibid). Skin erythema dose was defined as the dose of x-rays necessary to cause a certain degree of erythema within a specified time. The reaction of skin to ionizing radiation and the degree of damage has been found to depend on the radiation quantity, quality, dose rate and location of exposure (Bushberg *et al*., 2002).

DAP meter is used to measure the dose per area and is converted manually to the ESD value with an appropriate backscatter factor. The European Guideline (1996) recommended the backscatter factor for chest x-ray at 1.35 (Sharifat *et al*., 2009). The Commission of European Communities

(CEC) recommended an applied voltage for the chest x-ray posterior-anterior (PA) in the range of 100 kVp-150 kVp with an Automatic Exposure Control (AEC) chamber.

The European Union Council Directive 97/43/EURATOM introduced the concept of Diagnostic Reference Levels (DRL) as an efficient standard for radiation indicators. DRL is defined as the dosage levels in medical radio diagnostic practice to patients based on the standard phantom, for typical examinations and broadly defined types of equipment. These levels should not exceed standard procedures and normal practice is applied for diagnostic and technical performance (Osibote *et al*., 2008). ESD is commonly used as the recommended parameter for monitoring DRL in conventional radiography. An example of the ESD for the chest x-ray posterior-anterior (PA) projection uses a DRL between 0.25 mGy to 0.4 mGy of ESD for adult patients. Note that in the "*National protocol for patient dose measurements in diagnostic radiology*", the measurement of the ESD was proposed for individual radiograph.

Methodology

Irradiating Apparatus

A Phillips Optimus 80 with a 3-phase x-ray generator was used. The measured Half Value Layer (HVL) for this machine is 3.0 mm Aluminium (Al) at 81 kVp. It has a total filtration of 2.5 mm Aluminium (Al). The tube outputs are between 40kVp and 250kVp with a mAs range between 0.5 mAs and 850 mAs.

Dosimetry Apparatus

DRL has recommended the use of DAP meter as the most practicable to derive the ESD. The advantages of DAP compared to the TLD are the DAP measurement takes into account the whole area of examination, the position of the patient in the beam is less important, and the measurement does not interfere with the examination of the patient.

The Victoreen Rad-Check Plus X-ray Exposure (Model 06-526-2200) dosimetry apparatus has a reproducibility within 2% short term over 100 mR to 2 R range and energy response to photons from 30 kVp to 150 kVp within ±7%. This dosimetry apparatus was connected to the Rad-Check Plus to measure the radiation output in mGy. The dimension of Ionization Chamber was 10.2 cm x 10.2 cm x 1.4 cm with 113 gram weights.

DAP meter GAMMEX RMI model 841-RD (Model 08-0176-5-19-99) was used to measure the absorbed dose in air. The ionization chamber of the DAP was connected to DAP meter during the measurement. The maximum current detection is 100 mA and with the energy range of detection from 50 kVp to 150 kVp. The ionization chamber is transparent and encased in a slim rigid frame with 140 mm x 140 mm active area that allows the frame to be slided into rails on the collimator. The ionization chamber is positioned across the primary beam near the output port of the x-ray tube beyond the collimator.

RMI 240A Multi-function meter (serial no. 240A-2562) with a size 15 cm x 15 cm was used to measure effective and peak energy of the x-ray machine. This Multi-function meter has both the fluoroscopic and radiographic modes.

Simulation of Patient

The Anthropomorphic phantom (Alderson Rando) used in this study was based on the standard male defined by ICRP (1975) with the phantom's weight of 73.5 kg and 173 cm in height. The phantom contained bone equivalents in the form of human skeleton surrounded by soft tissues. The phantom composed of 35 transverse slices with 2.5 cm thickness each.

DAP Meter Calibration

Calibration factor for the DAP meter was determine. This was done to identify the uncertainty between DAP displayed by the meter with actual DAP radiation. IC connected to DAP was placed at the tube collimator and IC connected with Rad-Check Plus was placed on the table.

Field size 10 cm x 10 cm was used with 100 cm FFD and exposed three times with 81 kVp and 10 mAs. Correction factor (CF) was measured using the formula as follow:

$$CF_{DAP} = \frac{\text{Dose reference} \times CF_{RCP} \times \text{Area}}{\text{DAP measured}}$$

Note: Dose reference is the value of dose from Rad-Check Plus.
DAP measured is the value from the DAP meter.
All the DAP readings needed to multiplied with this correction factor to obtain true readings.

Radiation Output Measurement

Output (O/P) is the measurement of the dose per product of the tube current and the exposure time (mGy/mAs). Based on the ESD formula (Osibote, *et al*, 2008), output measurement is standardized at 81 kVp and 10 mAs and normalized at 100 cm. Using Rad-Check Plus, at least three readings were taken and the Radiation Output (O/P) calculation was carried out using the following formula:

$$\mathbf{O/P = \frac{Dose(mGy) \times CF_{RCP}}{mAs}}$$

With $\mathbf{CF_{RCP}}$ is the correction factor obtained from the Rad-Check Plus electrometer reading and **mAs** is the selected tube current from the control panel.

ESD Calculation

The measurement of ESD calculation using DAP was conducted on the Anthropomorphic phantom with the experimental set up as illustrated in **Figure 1**. The focus to film distance (FFD) is 180 cm. The field size (36 cm x 37 cm) and FSD (168 cm) used in this study were measured during the experiment setup including the chest region of the phantom.

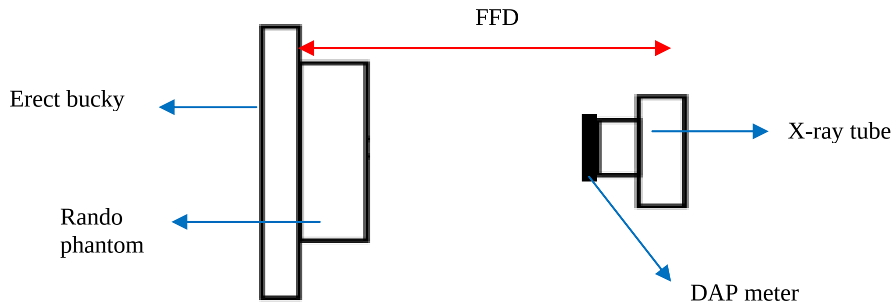

Figure 1: Other materials used for the purpose of this experiment

A flat ionization chamber connected to the DAP meter was placed on the x-ray tube and perpendicular to the beam output. The setup parameter settings were determined by increasing kVp and fixed mAs on the control panel and exposure to the IC_{DAP} and the phantom. The exposure was repeated three times to obtain an average value for every different kVp used.

DAP data collection was converted to the ESD (mGy) based on the equitions suggested by Meade, *et al*. (2003), and Livingstone, et al. (2006), Formula of ESD using DAP is shown below:

$$\mathbf{ESD_{DAP\ with\ CF} = \frac{DAP}{Area\ (FSD)} \times BSF \times CF_{DAP}}$$ (Meade *et al*. 2003)

$$\mathbf{ESD_{DAP} = \frac{DAP}{Area\ (FSD)} \times BSF}$$ (Livingstone *et al*. 2006)

$$\mathbf{Area\ (FSD) = Area\ (FFD) \times (FSD/FFD)^2}$$ (Meade *et al*. 2003)

BSF for chest x-ray was 1.35 taken from the European guideline 1996 (Sharifat *et al.*, 2009). The correction of DAP was measured using IC Rad-Check Plus. Area is the area at FSD. DAP was measured in mGy/cm^2. ESD was calculated using the formula given below based on the parameter setup on the control panel.

$$\mathbf{ESDc = Output,\ O/P \times (kvp/80)^2 \times mAs \times BSF}$$ (Osibote *et al*.)

The output of the x-ray tube in mGy/mAs was measured at 81 kVp at a distance of 100 cm normalized to 10 mAs. Note that kVp is the tube potential and mAs is the product of the tube current and the exposure time. The range of kVp used in this procedure was between 70 kVp and 125 kVp with fixed mAs (4 mAs).

Results

The ESD (mGy) and DAP ($mGycm^2$) estimation for the chest PA radiography with increasing kVp and the comparison between ESD_{DAP}, $ESD_{DAP\ with\ CF}$ and ESD_C is shown in **Table 1** below. DAP was converted into ESD, using the formula provided by Meade *et al*. (2003) and Livingstone *et al*. The ESD_C was calculated using a mathematical model and has showed pronounced differences compared to the ESD_{DAP} and the $ESD_{DAP\ with\ CF}$. The percentage difference between ESD_C with ESD_{DAP} was between 23 % and 33 % and ESD_C with $ESD_{DAP\ with\ CF}$ was between 17% and 29% with the increasing of kVp.

Table 1 shows the relationship between ESD_{DAP} with increasing kVp. ESD_{DAP} increased almost linearly with R^2=0.999 when the kVp was increased. Linear regression analysis showed that the p-value for ESD_{DAP} chest PA radiography was lower than 0.05. A linear relationship between kVp and ESD_{DAP} was demonstrated. At low kVp (70 kVp), the ESD_{DAP} was 0.083 mGy and at high kVp (125 kVp) ESD_{DAP} was 0.237 mGy with the same mAs for each kVp.

Table 1: Comparison of ESD_{DAP}, ESD_{DAP} with correction factor and ESD calculation using tube output

kVp	DAP ($mGycm^2$)	ESD_{DAP} (mGy)	$ESD_{DAP\ with\ CF}$ (mGy)	ESD_C (mGy)
70	68.0	0.083	0.087	0.105
81	91.0	0.111	0.117	0.140
90	111.0	0.136	0.142	0.173
102	139.0	0.170	0.178	0.222
109	155.2	0.189	0.199	0.253
117	174.5	0.213	0.224	0.292
125	194.0	0.237	0.249	0.333

Comparison of ESD from DAP with and without CF.

Table 2 and **3** show the relationship between $ESD_{DAP\ with\ CF}$ and ESD_{DAP} versus kVp using Paired Sample T-Test, which was conducted to compare $ESD_{DAP\ with\ CF}$ and ESD_{DAP}. The significant value was greater than 0.05. This result shows that there is no significant difference between $ESD_{DAP\ with\ CF}$ (Mean=0.188, SD= 0.144) and ESD_{DAP} (Mean=0.179, SD=0.137).

Table 2: Paired Samples T-Test Statistics

Paired Samples Statistics					
		Mean	N	SD	SEM
Pair	ESD_{DAP}	.17899	1	.136919	.128293
1	$ESD_{DAP\ with\ CF}$	.18799	1	.144237	.135150

Table 3: Paired Samples T-Test

Paired Samples Test								
	Paired Differences					t	Df	Sig. (2-tailed)
	Mean	SD	SEM	95% CI				
				Lower	Upper			
Pair 1 $SD_{DAP} – ESD_{DAP\ CF}$	-.009000	.007415	.006948	-912.278224	912.260224	-1.295	0	.767

Figure 2 below shows the comparison of ESD_{DAP}, $ESD_{DAP\ with\ CF}$ and ESD_{C} with DAP measurements. The DAP is a measurement of dose without BSF in the area of examination. ESD_{C} showed higher measurement in comparison with the ESD_{DAP} and $ESD_{DAP\ with\ CF}$. All the ESD measurement increased consistently with the increase of DAP. However, The ESD increased at higher rate compared to DAP reading after 139mGy/cm^2.

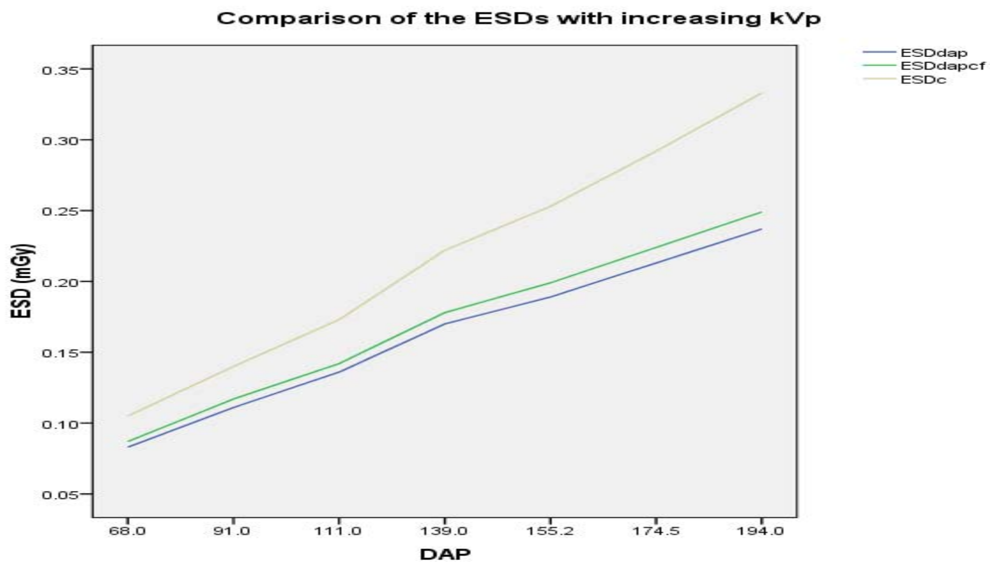

Figure 2: Graph of the ESD determination versus DAP measurement.

Discussion

Our experiment showed that the percentage of difference between ESD_C with ESD_{DAP} was 23% to 33% while ESD_C and $ESD_{DAP\ with\ CF}$ was 17% to 29%. The higher value of ESD_C may be due to the external detector calibration (IC_{RCP} calibration) procedure of Rad-Check Plus. The internal Rad-Check Plus produced almost twice the measurement compared with the IC_{RCP}. The DAP meter calibration can improve less than 10% accuracy in the measurement (Järvinen, 2006).

The ESD measurement did not show any significant difference using AEC and manual mode. Increasing the kVp resulted in greater transmission and less absorption of x-ray through the phantom. For AEC and manual mode, high kVp with low mAs was used. The reduction of mAs decreased the radiation exposure to the phantom and prevented involuntary (heart beat) and voluntary (breathing) movements. The high kVp and low mAs gave the lowest radiation dosage to the phantom and at the same time optimized the quality of the radiography image (Egbe *et al.*, 2009). Therefore, the European Guideline recommended using AEC mode with 125 kVp for good radiographic images of chest PA examination.

DRL based on the IAEA, NRPB, AAPM and European Commission (EC) recommended that the X-ray system and the image processing software must be optimised. In clinical practice, AEC is used to justify the level of image quality for clinical usage and to optimize the quality of radiographic images. It also helps to avoid theIf not, there is a danger of increasing the patient dosage without clinical justification with no improve outcome. AEC is very easy to be used and practitioners should be aware of the patient dose per image and limit the number of images to what is strictly necessary for the diagnosis of a particular patient.

A study by Egbe, *et al.*, (2009) concluded that ESD for both patients and phantom were similar. The phantoms offered the opportunity for regular, easy and daily QA studies for dose as it satisfies the requirement for ease of use, simplicity and portability. Our the result showed that the ESD measured on the phantom was comparable to the standard recommendation of DRL. The minimum and the maximum percentage difference of ESD_{DAP}, $ESD_{DAP\ with\ CF}$ and ESD_{C} compared to the standard from DRL recommendation were 23% and 51% (ESD_{DAP}), 19% and 47% ($ESD_{DAP\ with\ CF}$), and 47% and 16.5% (ESD_{C}). The different values may be due to the different exposure parameters used in the DRL. It is worth nothing that the equipment performance may cause uncertainties in the ESD measurement and calculation. Older x-ray equipment may also cause differences in ESD values.

Conclusion

The results of this experiment indicated that increasing kVp will lead to higher ESD_{DAP}, $ESD_{DAP\ with\ CF}$ and ESD_{C} measurements. This experiment demonstrated that the method used here for estimating ESD_{C} could be a reliable and serve as cheaper alternative for patient dosage monitoring in in daily routine of a diagnostic radiology department, provided that the x-ray system works within international DRLs. In addition, ESD_{C} based on a mathematical model can be adopted for purposes of patient dosimetry in place where the essential facilities for patient radiation dosage monitoring is unavailable.

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References

Akhdar, H.F. *et al.* (2007). Assessment of Entrance Skin Dose and Effective Dose of Some Routine X-ray Examinations Using Calculation Technique. Department of Physics and Astronomy.

Bahreyni, M.T. *et al*. (2006). Application Of Dose-Area Product Compared With Three Other Dosimetric Quantities Used To Estimate Patient Effective Dose In Diagnostic Radiology. *Iran. J. Radiat*. *Res*, 21-27.

Bond, N. (1999). Optimization of Image Quality and Patient Exposure in Chest Radiography. *The College of Radiographers*, 29-31.

Egbe, N.O. et al. (2009). Doses and Image Quality for Chest Radiographs in Three Nigerian Hospitals. *European Journal of Radiography*, 30-36.

E. Yakoumakis, et al. (2001). Differences in Effective Dose Estimation from Dose–Area Product and Entrance Surface Dose Measurements in Intravenous Urography. *The British Journal of Radiology*, 74: 727–734.

Faulkner, K. et al. (1999). Patient Dosimetry Measurement Methods. *Applied Radiation and Isotopes*, 50: 113-123.

Johnston D.A. et al. (2000). Reference Dose Levels for Patients undergoing Common Diagnostic X-ray Examinations in Irish Hospitals. *The British Journal of Radiology*, 73: 396-402.

Kisielewicz K. et al. (2010). Evaluation of Dose Area Product vs. Patient Dose in Diagnostic X-Ray Units. *Physica Medica*, 1-4.

Meade, A.D. et al. (2003). Draft Proposal for Three International Standards for Dose Area Product (DAP) Measurement, Patient Dose Records and Connectivity between Equipment.

Mohamadain, K.E.M. et al. (2003). Dose Measurements Using Thermoluminescent Dosimeters and Dose Cal Software at Two Paediatric Hospitals in Rio de Janeiro. *Applied Radiation and Isotopes*, 59: 53–57.

Ng, K.H. et al. (1998). Doses to Patients in Routine X-ray Examinations in Malaysia. *The British Journal of Radiology*, 71: 654-660.

Osibote, O.A. et al. (2008). Estimation of Adult Patient Doses for Common Diagnostic X-Ray Examinations in Rio De Janeiro, Brazil. *Physica Medica,* 24: 21-28.

Ramli, K. et al. (2003). Computed and Conventional Chest Radiography: A Comparison of Image Quality and Radiation Dose, Australas. *Radiology*, 49(6):460-466.

Roshan S. Livingstone, et al. (2006). Fine Tuning of Work Practices of Common Radiological Investigations Performed Using Computed Radiography System. *Radiography, 13: 126-132.*

Shahbazi-Gahrouei, D. (2006). Entrance Surface Dose Measurements for Routine X-Ray Examinations in Chaharmahal and Bakhtiari Hospitals. *Iran. J. Radiat. Res.,* 29-33.

Sharifat, I, (2009). Patient Entrance Skin Doses at Minna and Ibadan for Common Diagnostic Radiological Examinations. *Bayero Journal of Pure and Applied Sciences*, 2(1): 1-5.

Suliman, I.I. (2007). Entrance Surface Doses To Patients Undergoing Selected Diagnostic X-Ray Examinations In Sudan. *Radiation Protection Dosimetry*, 123(2):209–214.

Toivonen, M. (2001). Patient Dosimetry Protocols in Digital and Interventional Radiology. *Radiation Protection Dosimetry,* 94(1–2):105–108.

V. Tsapaki, et al. (2007). Radiation doses to patients undergoing standard radiographic examinations: a comparison between two methods.