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Estimation of Entrance Surface Dose of Adult Patients undergoing Computed Radiography Examinations in Two Hospitals

Daniel Ackom[1,2], Edem Sosu[1,2,3], Stephen Inkoom[2,4], Cyril Schandorf[2]
*[1]Department of Physics, University of Cape Coast, Cape Coast, Ghana
[2]Department of Medical Physics, School of Nuclear and Allied Sciences, University of Ghana, Atomic Campus, Accra, Ghana
[3]Medical Radiation Physics Centre, Radiological and Medical Sciences Research Institute, Ghana Atomic Energy Commission, Accra. Ghana
[4]Radiation Protection Institute, Ghana Atomic Energy Commission, Accra. Ghana

ABSTRACT

This study seeks to investigate the distribution of doses to adult patients undergoing computed radiography using the free-in air method and the factors that affect the doses received by the patients, and hence develop the methodology for optimization of protection of the patient. The entrance surface dose (ESD) was estimated for a total of 619 patients with 243 males (39.3%) and 376 females (60.7%) for two hospitals A and B. The minimum and maximum age of the patients that formed part of this study were 18 and 82 years. The mean ESDs calculated were in the range of 0.29±0.0041 mGy to 6.08±0.55 mGy for chest PA, lumbar spine AP and LAT, cervical spine AP and LAT, skull AP and LAT and abdomen AP examinations. All the results for the various anatomical parts were lower compared with published results and diagnostic reference levels except chest PA examination which the value estimated at hospital B was by a factor of 2.56, 2.20 and 1.65 higher than the mean ESDs values by Inkoom et al, the IAEA and Public Health of UK respectively. An increment by factor of 3.07, 2.87 and 2.15 were found in the estimated mean ESDs for chest PA examination at hospital A compared with the published results respectively. The study therefore has shown that the estimated mean ESD of the hospitals were within the recommended references values except chest PA.

Keywords: Entrance Surface Dose (ESD), Computed Radiography (CR), Quality control (QC), Diagnostic Reference Level (DRL).

I. INTRODUCTION

Since the discovery of X-rays in 1895 by a German experimental physicist, Wilhelm Roentgen, diagnostic imaging has evolved and advanced to an extent that it has become an indispensable component of patient diagnosis, management and in certain cases, treatment [1]. The type of X-ray systems used in medicine are conventional (computed or direct digital radiography), dental, fluoroscopy, orthovoltage, megavoltage, c-arms mammography, and computed tomography. In all these imaging equipment, optimization, the balance between radiation dose and image quality, of X-ray imaging parameters remains a continuous challenge in radiology since digital imaging provides new possibilities because of the wide dynamic range of digital detectors and the digital image processing possibilities. The use of X-ray facilities and equipment has increased rapidly in medical practices. Diagnostic radiology has an enormous share of public dose from man-made sources. With the advent of new digital imaging systems in radiography departments, it is therefore important to focus on keeping the dose as low as reasonably practicable whilst producing an image of diagnostic quality for digital radiography. The lack of consistent feedback to technologists concerning the use of optimal acquisition techniques is also a major problem with the use of computed and direct digital radiography. This problem, along with the much larger dynamic range of digital systems, has led to a gradual increase in patient radiation dose [2]. Computed and direct digital radiography as at 2011, formed only 4% of the conventional X-ray machines in Ghana to help improve the delivery of quality healthcare system [3] and this has increased significantly due to the introduction of CR systems to all the regional hospitals in Ghana by the government. They have the advantage of being low cost, non-invasive, familiarity with medical professionals, relative harmlessness and fast imaging times. However, there are reports showing that low doses of ionizing radiation exposure encountered in diagnostic examinations may induce malicious conditions [4]. Since the introduction of CR in Ghana in the year 2011, no attempt has been made to conduct the assessment of entrance surface dose (ESD) to patient quality to trigger the need for optimization of protection of patients. To address this problem, this study seeks to accurately estimate the ESD of the patients (adults) undergoing selected CR examinations, compare the estimated ESDs to the diagnostic reference levels established by international organizations, determine the potential for optimization of protection of patients for the selected examinations under the study and make appropriate recommendations from the findings for the management of patient dose in CR and DR in Ghana. To fulfil the Medical Exposure Directive (MED, 97/43, Euratom) requirement of a good image quality at a radiation dose that is as low as reasonably achievable, optimization of medical imaging systems is therefore deemed necessary [5].

II. METHODS AND MATERIAL

Specifications of the CR systems used for the study has been given in Table 1.

Table 1: Details of computed radiography systems used

Manufacturer	Year	Tube model number	Tube filtration	Max. kVp	Max. mAs
Philips Medical Systems	2002	989000085271	2.5 mmAl at 75 kVp	150	300
Schimadzu Corp.	2012	53224558	1.5 mmAl at 70 kVp	150	300

A calibrated solid state ionization chamber Piranha RTI (Piranha 657) with serial number CB2-11020219 was employed in this study. It has a dose range of 4 µGy/h - 273Gy/h or 0.4 mR/h - 31 kR/h, active detector area of 10×10 mm. The study also employed beam alignment and collimator tools for the quality control process and a pair of callipers to measure patient anatomical thickness.

Quality Control (QC) of the CR systems

Performance of each CR system was assessed through QC to detect any change in the performance of X-ray system, which may lead to an unacceptable image quality and/or high dose to patient and staff. These include tube voltage accuracy, timer accuracy, voltage reproducibility, exposure reproducibility, half value layer, current-time linearity and collimation. The summary of QC results is presented in Table 1.

Patient Data Collection

Patient data including area of examination (e.g. chest), patient age, sex, patient thickness, applied tube voltage (kVp), current-time product (mAs) and focus-to-film distance (FFD) for each type of examination were recorded using a specially designed datasheet. Exposure parameters and patient data were collected for a total of 619 patients with 243 males representing 39.3% and 376 females representing 60.7% for the two hospitals (A and B). The minimum and maximum age of the patients that formed part of this study were 18 and 82 years. This age group is considered adult due to the fact that it is within the adult age category by the International Commission on Radiological Protection [6].

ESD Estimation

The ESD received by each patient undergoing each type of examination considered in this study was calculated by using the following equation [7]:

$$ESD = ESAK \times BSF \quad (1)$$

where ESAK is the entrance surface air kerma given by

$$ESAK = Output\left(mGym^{-1}A^{-1}s^{-1}\right) \times mAs \times \left[\frac{100}{FSD}\right]^2 \quad (2)$$

FSD is the focus-to-skin distance which is obtained by subtracting the patient anatomical thickness from the focus-to-film distance. That is

$$FSD = FFD - t_p \quad (3)$$

where t_p is the patient anatomical thickness. A backscatter factor of 1.35 was used. This is because according to the European commission, [8], backscatter factors vary between 1.3 and 1.4 for the X-ray qualities used for various projections included in the quality criteria except for mammography. Therefore, a single average value of 1.35 can be used in most cases without appreciable error.

III. RESULTS AND DISCUSSION

Quality Control

Results obtained from assessing the CR systems performance are presented in Table 1 for hospitals A and B. Table 2 shows that the performance of CR systems were consistent with the standards set by the Institute of Physics and Engineers in Medicine (IPEM) [9]. Comparing half value layers of the CR systems to the acceptable limit of ≥ 2.10 mmAl show that the X-ray beams were of good quality. Hence, much of the X-rays with lower energies which do not form part of image but contributes to patient dose were eliminated.

Table 2: Summary of QC results on CR at the two hospitals

Parameter	Deviation of CR system		Acceptable Deviation by (IPEM) [9]	Remarks
	Hospital A	Hospital B		
Tube Voltage Accuracy	-1.90%	-1.15%	≤ ± 6.000 %	Pass
Timer Accuracy	4.49%	-5.25%	≤ ±10.000%	Pass
Tube Voltage Reproducibility at 80 kVp (Coefficient of Variation)	0.001	0.01%	≤ 0.050	Pass
Timer Reproducibility at 80 kVp (Coefficient of Variation)	0.011	0.014	≤ 0.050	Pass
Exposure Reproducibility at 80 kVp (Coefficient of Variation)	0.002	0.032	≤ 0.050	Pass

Output Measurement

Figures 1 and 2 show the relationship between the X-ray output (mGy/mAs) and the applied tube voltages (kVp) at a constant tube current-time product (mAs) of the CR systems used in this study. R^2 values of 0.9856 and 0.9971 observed from the output curves of Figures 1 and 2 show that there exist a strong correlation between the parameters measured and thus show a good fit. The nature of the graph is also in good agreement with the graph obtained from output versus kVp obtained from the work of Tamboul et al, [10].

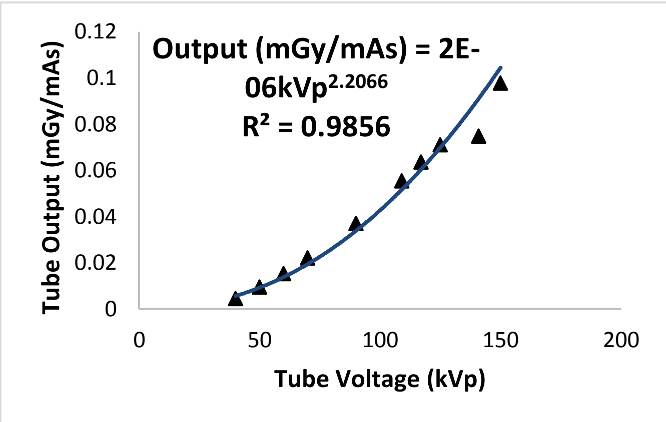

Figure 1: Output curve of CR system at hospital A.

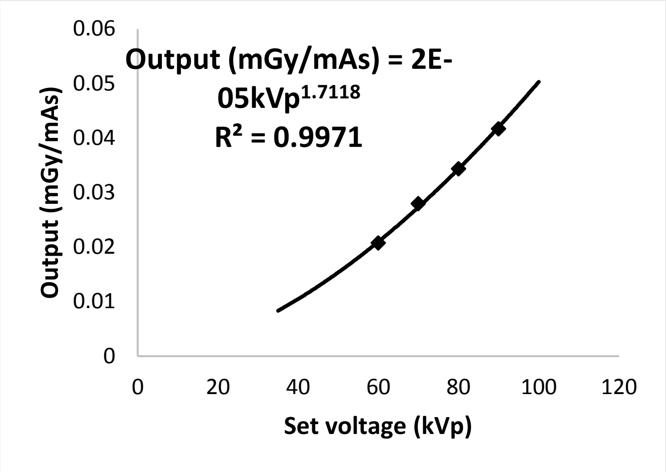

Figure 2: Output curve of CR system at hospital B.

ESD Estimation

Figure 3 compares the distribution of the mean ESDs obtained from the hospitals. This is supported by Tables 3 and 4. In addition to mean ESD, maximum and minimum ESD for each anatomical projection considered with their standard deviations are presented in Tables 3 and 4. The highest mean ESD of 3.01 mGy and 6.08 mGy were estimated for lateral projection of lumbar spine for hospital A and hospital B respectively. There was a difference of 3.07 mGy for lumbar LAT projection between the two hospitals which shows that the mean ESD recorded at hospital B was higher than that of hospital A by a factor of 2.02. However, the mean ESDs recorded for skull AP projection for both hospitals were almost the same with a difference of 0.04 mGy.

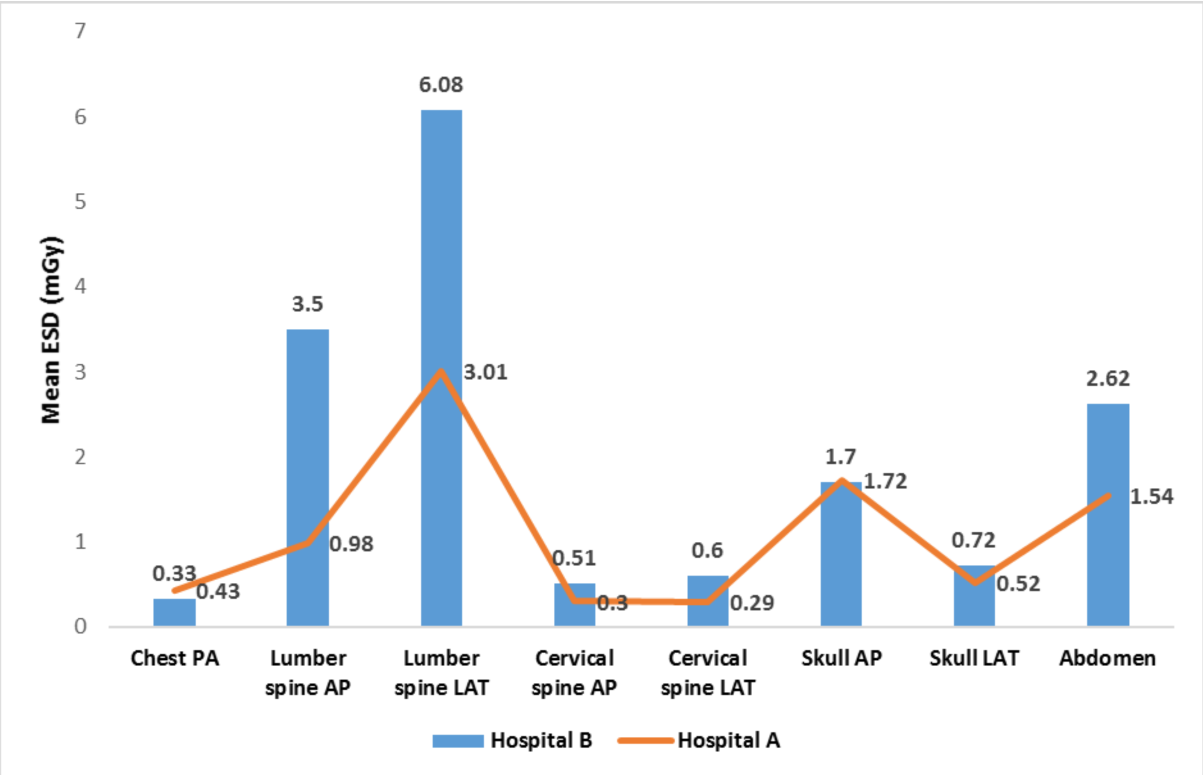

Figure 3 : Chart comparing the mean ESDs from the two hospitals

A lower mean ESD of 0.29 mGy was recorded for cervical spine AP and LAT projections at hospital A. It is also evident from Tables 2 and 3 that a patient received a maximum dose as 0.71 mGy during chest examination at hospital A as compared to 0.36 mGy of hospital B for the same type of examination. In general, all the mean ESDs recorded at hospital B were higher than their corresponding mean ESDs recorded at hospital A except for chest PA and skull AP projections. The differences in the doses may be attributed to the different exposure factors (kVp, mAs, field sizes, etc.) and techniques being employed by the radiographers at the hospitals. The difference in the doses may also be due to variations in the number of examinations per day and the thickness of the patients being examined.

Table 3: Estimated mean ESD at hospital A

	ESD (mGy)			
Area of Examination	**Mean**	**Max**	**Min**	**StdDev**
Chest PA	0.43	0.71	0.12	0.1022
Lumbar spine AP	0.98	1.57	0.63	0.2594
Lumbar spine LAT	3.01	4.19	2.46	0.2447
Cervical spine AP	0.29	0.30	0.29	0.0042
Cervical spine LAT	0.29	0.30	0.29	0.0041
Skull AP	1.74	1.87	1.19	0.1945
Skull LAT	0.53	0.54	0.52	0.0090
Abdomen AP	1.54	3.49	1.27	0.6107

Table 4: Estimated mean ESD at hospital B

	ESD (mGy)			
Area of Examination	**Mean**	**Max**	**Min**	**StdDev**
Chest PA	0.33	0.36	0.30	0.01
Lumbar spine AP	3.50	3.99	3.03	0.23
Lumbar spine LAT	6.08	7.12	4.50	0.55
Cervical spine AP	0.51	0.59	0.44	0.03
Cervical spine LAT	0.60	0.71	0.51	0.05
Skull AP	1.70	1.79	1.65	0.04
Skull LAT	0.72	0.74	0.71	0.01
Abdomen AP	2.62	2.96	2.45	0.15

Comparison of ESD with other Published Results

From Figure 4, the highest mean ESD was recorded for the lateral projection of lumbar spine examination for both hospitals but they were however lower than their corresponding mean ESDs from literature. At hospital B, the mean ESD was lower than that of Inkoom et al., [3] by a factor of 1.61, 1.64 and 2.47 for UK [11] and IAEA [12] respectively. For the same lumbar LAT projection, hospital A recorded a lower value by a factor of 3.24, 3.32 and 4.98 for Inkoom et al., [3] UK [11] and IAEA [12] respectively. Figure 3 further shows that all the mean ESDs for the various examinations were lower than their corresponding published data and DRLs except for chest examinations in which the ESDs (0.43 mGy for hospital A and 0.33 mGy for hospital B) obtained from this study for both hospitals were higher than their corresponding published data and reference levels by UK and IAEA. There was a difference of 0.19 mGy, 0.18 mGy and 0.13 mGy between the estimated mean ESD for chest examination at hospital B and Inkoom et al., [3] and the DRLs set by UK [11] and IAEA [12] respectively.

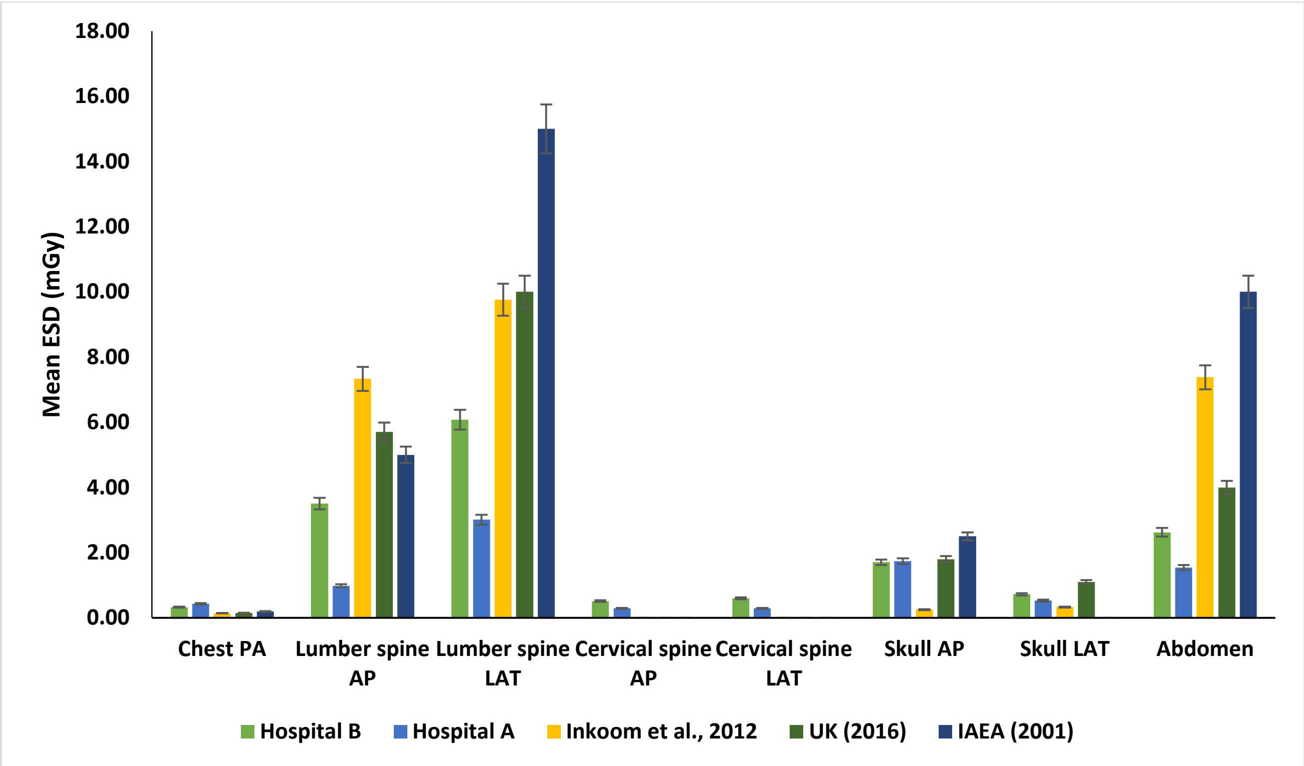

Figure 4: Comparison of ESDs with published results and DRLs from international organizations

The difference shows that the mean ESD recorded at hospital B was 135.71%, 117.86 % and 63.40 % higher than the ESDs obtained by Inkoom et al., and the DRLs set by the Public health of UK [11] and the IAEA [12] respectively. A percentage increment of 207.14%, 188.92 % and 116.68 % were found in the estimated mean ESD for chest examination at hospital A for Inkoom et al., [3] UK [11] and IAEA [12] respectively. This differences was due to the selection of exposure parameters and technique factors including the coning of the X-ray beam. This is due to the fact that the field size of the beam entering a patient produces a larger field size on the film due to beam divergence (fans out). When considering the size of beam restriction (coning) to minimize dose, it is preferable to select size of required collimation before positioning a patient but this sometimes rather leads to increase in patient dose because the cones sometimes become bent when dropped or bumped and cause irregular and insufficient coning leading to exposure of other parts of the body which is not included in the examination.

Other reason for the large variation in the mean ESD for chest may be due to patient size, suboptimal usage of the equipment or equipment malfunctioning generally because of the absence of regular quality control and radiation protection programme. These differences suggest that much can be done to reduce the ESDs by adequate changes of physical parameters (kVp, mAs, etc) without loss of image quality. Therefore, the radiology departments of the hospitals should undertake a review of their radiographic practice which should involve reviewing whether the benefits outweigh the risk or detriment associated with a requested examination by a patient in order to bring their doses to optimum levels.

IV. CONCLUSION

The mean ESD estimated for all the examinations considered under this study was in the range of 0.290 ± 0.004 mGy to 6.08 ± 0.55 mGy which was due to the different exposure parameters and technique factors used for various examinations in the two hospitals considered. The exposure parameters used for the examinations considered were generally higher at hospital B as compared to the exposure parameters used at hospital A.

The results show that all the mean ESDs obtained for the various anatomical parts were lower compared to other published results and DRL set by international organization except the mean ESD for chest examination which was higher than the other published results. The results also showed that the CR systems produce images that contain useful clinical information. Since the two hospitals considered did not have a quality assurance (QA) and QC programmes in place the results shows that with proper QA/QC programmes in place, there is the potential to reduce doses to patients while keeping images of diagnostic quality.

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