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Entrance skin dose assessment of selected computed radiography facilities in Ghana

E. Gyan[1*], S. Inkoom[2], G. Amoako[1]

[1]Department of Physics, School of Physical Sciences, University of Cape Coast- Ghana, Ghana
[2]Radiation protection institute, Ghana Atomic Energy Commission Department of Physics, School of Physical Sciences, University of Cape Coast- Ghana, Ghana

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Corresponding authors:
Emmanuel Gyan, Ph.D.,
E-mail:
gyanyaw48@yahoo.com

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ABSTRACT

Background: The basic challenge with computed radiography (CR) systems is the large dynamic range which provides an opportunity for radiographers to gradually increase exposure factors and still produce good image quality, a practice that can lead to dose creep. ***Materials and Methods:*** The aim of this study was to establish the entrance skin dose (ESD) values for nine selected examinations in three CR facilities in Ghana (chest PA, abdomen AP, lumbar Pelvis AP, lumbar spine LAT, cervical spine AP, cervical spine LAT, skull PA and skull LAT). ESD was estimated by the indirect method involving the use of a standard equation. The study involved 150 females and 120 males with the average age of 50 ± 14 years. The average weight of the study population was 69 ± 8 kg, and the average height of 162 ± 9 cm. The CR systems used at all the hospitals were manufactured by Shimadzu medical systems (Kyoto, Japan) and the model number was UD150L-40E. ***Results:*** The average ESDs (mGy) for each examination were; 0.93 ± 0.7, 3.04 ± 0.4 , 4.95 ± 0.9, 0.59 ± 0.3, 0.63 ± 0.4, 1.77 ± 0.3, 1.64 ± 0.3, 2.31 ± 0.4 and 3.15 ± 0.6 for chest PA, lumbar spine AP, lumber spine LAT, cervical spine AP, cervical spine LAT, skull PA, skull LAT, pelvis AP, and abdomen AP respectively. The single factor ANOVA t-test that was performed indicated a significant difference (p-value = 5.73×10^{-15}) among the ESDs for chest PA examination. ***Conclusion:*** Over exposure of patients is very possible with CR systems, it is therefore important for patient dose to be audited periodically in order to achieve the principles of As Low As Reasonably Achievable (ALARA).

Keywords: *Optimisation, radiation, variations, protection, dose.*

INTRODUCTION

Computed radiography (CR) technology is rapidly replacing screen film systems in diagnostic medical imaging in Ghana. All teaching, regional, some district and private hospitals in Ghana are using CR technology. The advantages of CR technology over the screen film system are; wider dynamic range, post processing capabilities, possibility of electronic transfer, low repeat rate, non-chemical processing and electronic storage [1-3]. However, there is no consistent feedback to radiographers and technologists regarding the use of optimal acquisition technical factors as in the case of screen film [4, 5]. Image contrast and brightness no longer relate directly to the exposure techniques due to post-processing algorithms and the larger dynamic range [1]. For these reasons, CR technology has the potential to increase patient radiation dose significantly [6]. Over exposure of 5 – 10 times the normal exposure can occur and the image will still appear as properly exposed because of the compensation of the digital detector [7].

Regularly optimising protocols and procedures of CR systems are necessary to reduce the overexposure to patients and reduce

risk of exposure to ionising radiation. Entrance skin dose (ESD) and dose-area product (DAP) are useful dosimetry quantities for dose auditing, monitoring and comparing radiation doses from different radiological examinations [8]. Entrance skin dose (ESD) is the most reliable dosimetric quantity for patient radiation dose in simple radiographic examinations [9].

ESD can be estimated by direct or indirect methods using human patients or phantoms [10]. In the direct measurement method, a thermoluminescent dosimeter (TLD) is placed on the skin of the patient. The main challenge with TLDs is that there is a minimum absorbed dose of 0.1 mGy to produce reasonable accurate results [11].

Patient radiation dose for chest (PA) was estimated using TLD in Ethiopia [13]. ESD estimation for seven radiographic examinations (chest PA, abdomen AP, pelvis AP, lumbar AP, skull AP, knee AP, and hand AP) were performed using TLD in Nigeria [14]. The indirect method of measurement uses computational approach either by formulas or patient dosimetry software such as Monte Carlo Simulations and CALDOSE_X5. In Ghana, patient doses were estimated for thorax/chest (PA/RLAT), pelvis (AP), cervical spine (AP/LAT), thoracic spine (AP/LAT) and lumbar spine (AP) using CALDOSE_X5 programme [15].

Some investigators have used mathematical method for estimating patient radiation dose [16-18]. The computational method for estimating ESD permits dose survey to be carried out on larger number of examinations with less cost than the use of TLDs. Again, assessments of low dose examinations which may deliver doses below the sensitivity level of TLDs and some DAP meters are also possible [16]. This may explain why most investigators and national surveys are carried out using indirect methods; few studies have however used a combination of both the direct and indirect methods [8].

In this work, we used indirect method on human patients to estimate entrance skin dose of nine radiographic examinations using CR. The aim of this study was to establish the entrance skin dose (ESD) values for nine selected examinations in three CR facilities in Ghana (chest PA, abdomen AP, lumbar spine AP, lumbar spine LAT, cervical spine AP, cervical spine LAT, skull PA and skull LAT).

MATERIALS AND METHODS

Study participants

The study was involved 270 participants; 150 females and 120 males. The average age, weight and height of the participants and their standard deviations were; 50 ± 14 years, 69 ± 8 kg, 162 ± 9 cm respectively. The data obtained from this study was kept under lock file which was only accessible to the researchers. Presentation of the data did not disclose the identity of individual participants in any form. Informed consent was obtained from every participant who took part in this study. Ethical approval was obtained from Institutional Review Board of University of Cape Coast-Ghana. The ethical approval number was UCCIRB/CANS/2017/06.

CR systems

The CR systems used at the three hospitals were manufactured by Shimadzu Medical systems (Kyoto, Japan). The brand was RADSPEED System MF with model number UD150L-40E. The equipment were all purchased by Ghana Government under health sector infrastructure improvement project. These were high-frequency inverter equipment with tube voltage ranging from 40 kVp to 150 kVp.

Dose assessment measurements

To estimate the ESD for these projections, patient habitus (age, weight, height and sex) were recorded. The weight was obtained using weighing scale while the height was measured using a five-meter tape measure. Exposure parameters (kVp, mAs), focus to detector distance (FDD), focus to skin distance (FSD) and the thickness of body part to be examined were also measured and recorded during the examination. The ESD was estimated using equation 1.

$$\text{ESD} = \textit{Tube output}\left(\frac{mGy}{mAS}\right) \times mAs \times \left(\frac{FDD}{FSD}\right)^2 \times BSF^{(19,20)} \quad (1)$$

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Where BSF is the backscatter radiation, FDD is the focus to detector distance, FSD is the focus skin distance and mAs is the product of current and time. Backscatter factor of 1.37 recommended by International Atomic Energy Agency [21] and had been used by some researchers [20] was used to calculate all the ESDs.

The first component of the equation (1), $Tube\ output\left(\frac{mGy}{mAS}\right)$ differs from one X-ray equipment to another. Therefore, the radiation $Tube\ output\left(\frac{mGy}{mAS}\right)$ for each X-ray equipment involved in this study was calculated and substituted into equation 1 as shown in equations 2, 3 and 4.

$$ESD = 0.007kVp^2 - 4.5522\left[\frac{\mu Gy}{mAs}\right] \times mAs \times \left(\frac{FFD}{FSD}\right)^2 \times BSF \quad (2)$$

$$ESD = 0.0084kVp^2 - 0.7464\left[\frac{\mu Gy}{mAs}\right] \times mAs \times \left(\frac{FFD}{FSD}\right)^2 \times BSF \quad (3)$$

$$ESD = 0.0087kVp^2 - 4.4438\left[\frac{\mu Gy}{mAs}\right] \times mAs \times \left(\frac{FDD}{FSD}\right)^2 \times BSF \quad (4)$$

RaySafe X2 (3.10R01f) radiation dosimeter manufactured and calibrated by Unfors RaySafe AB in Sweden was used to measure air kerma free in air (µGy) at 100 cm focus-to-detector distance (FDD). Different kVp setting from 50 to 110 kVp at step increment of 10 (50, 60, 70, 80, 90, 100, and 110) and fixed mAs of 4 were used. Three exposures were made for each set of technical factors and average doses (µGy) were recorded. The X-ray tube output was determined as the ratio of average dosimeter reading (in air kerma) to the tube current-time-product (mAs) used for the voltages (50 – 110 kVp). A plot of tube output (µGy/mAs) against kVp^2 was developed for all the three equipment. The tube output (µGy/mAs) values for each equipment were derived from the relationship between tube output (µGy/mAs) and kVp^2. ESDs for HP1, HP2 and HP3 were then calculated using equations 2, 3, and 4 respectively.

Data analysis

Data analysis was carried out using Excel (2013). ESDs and technical factors were presented in mean and standard deviations. Analysis of variance (ANOVA) was carried out using single factor t-test to determine the significant difference in ESDs among the hospitals.

RESULTS

Technical factors used for the estimation of ESD (mGy) are presented in table 1. There were significant differences (p-values < 0.05 for all the examinations) in technical factors (kVp and mAs) for same examination among the hospitals. For chest PA examinations, HP3 used lower kVp than HP1 and HP2. However, HP3 used higher mAs for chest PA examination as compared to HP1 and HP2.

Table 1. Technical factors used for ESD estimation at hospitals HP1, HP2 and HP3.

	HP1				HP2				HP3			
Examination	kVp	mAs	FDD (cm)	FSD (cm)	kVp	mAs	FDD (cm)	FSD (cm)	kVp	mAs	FDD (cm)	FSD (cm)
Chest PA	101.6±1.2	2.8±0.9	150	126.5±2.6	86.5±2.1	7.8±3.3	200	176.4±3.0	73.4±2.2	23.5±2.5	180	156.6±2.3
Lumbar spine AP	96.0±8.9	25.8±3.5	100	76.7±1.5	74.4±2.4	25.5±4.4	100	76.5±4.3	74.3±1.1	27.8±4.7	100	76.9±2.7
Lumbar spine LAT	96.2±8.9	30.3±5.5	100	74.8±1.5	79.3±1.6	32.6±4.6	100	74.2±4.2	74.2±0.8	56.9±4.7	100	74.1±2.6
Cervical spine AP	71.3±2.3	6.5±0.3	100	88.5±1.1	58.5±0.9	8.2±1.9	100	87.5±1.2	71.4±1.2	14.6±2.2	100	87.8±1.3
Cervical spine LAT	72.5±2.7	6.5±0.4	100	85.5±1.2	58.5±0.9	8.2±1.9	100	85.5±0.8	71.0±1.1	14.6±1.6	100	86.0±1.3
Skull PA	78.6±4.5	12.5±4.5	100	81.4±1.9	70.0±0	16.8±3.4	100	81.0±1.7	71.7±0.9	20.4±0.9	100	80.2±2.3
Skull LAT	78.4±0.9	20.7±4.4	100	78.2±3.3	69.3±1.0	16.8±3.4	100	83.0±1.7	71.7±0.7	19.4±0.9	100	80.0±2.0
Pelvis AP	85.0±4.7	21.4±4.5	100	78.0±1.4	73.9±3.5	24.5±3.7	100	74.4±3.1	72.2±2.1	21.7±2.6	100	79.3±1.6
Abdomen AP	90.0±10.2	25.6±6.7	100	78.6±1.9	74.3±2.3	22.0±1.9	100	74.5±1.9	73.4±1.4	25.5±3.8	100	76.9±1.8

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The estimated ESD (mGy) for HP1, HP2, and HP3 in mean and standard deviations are shown in table 2. The results demonstrated differences in ESD for all considered examinations. For chest PA, HP3 recorded the highest ESD with an average of 1.76 mGy while HP1 recorded the lowest ESD with an average of 0.37 mGy. Lumbar spine LAT recorded the highest ESD among all the examinations with an average of 4.95 mGy while cervical spine LAT recorded the lowest ESD of 0.63 mGy.

Table 2. Calculated ESD (mGy) for three hospitals HP1, HP2 and HP3.

Examinations /projections	HP1 ESD (mGy) Average (SD)	HP2 ESD (mGy) Average (SD)	HP3 ESD (mGy) Average (SD)	Mean ESD (mGy) (SD)
Chest PA	0.37±0.2	0.67±0.2	1.76±0.3	0.93±0.7
Lumbar spine AP	3.56±0.7	2.80±0.8	2.77±0.6	3.04±0.4
Lumbar spine LAT	4.44±0.9	4.33±1.0	6.08±0.5	4.95±0.9
Cervical spine AP	0.35±0.1	0.42±0.1	1.02±0.2	0.59±0.3
Cervical spine LAT	0.40±0.1	0.43±0.1	1.07±0.2	0.63±0.4
Skull PA	2.15±0.2	1.43±0.4	1.72±0.2	1.77±0.3
Skull LAT	1.96±0.1	1.33±0.3	1.64±0.1	1.64±0.3
Pelvis AP	2.16±0.5	2.74±0.4	2.05±0.4	2.31±0.4
Abdomen AP	3.79±1.5	2.34±0.2	2.46±0.5	3.15±0.6

HP1 recorded the lowest ESD in chest PA (0.37 mGy), cervical spine AP (0.35 mGy) and cervical spine LAT (0.40 mGy) but recorded the highest ESD in lumbar spine AP (3.56 mGy), skull PA (2.15 mGy), skull LAT (1.96 mGy) and abdomen AP (3.79 mGy). HP2 had the highest ESD in pelvis AP (2.74 mGy) with the lowest ESD in skull AP (1.43 mGy) and skull LAT (1.33 mGy). HP3 recorded the highest ESD in chest PA (1.76 mGy), lumbar spine LAT (6.08 mGy), cervical spine AP (1.02 mGy) and cervical spine LAT (1.07 mGy). However, HP3 recorded the lowest ESD in lumbar spine AP (2.77 mGy) and abdomen AP (2.46 mGy). There were significant differences in ESDs variations of all the examinations among the hospitals. The p-values were; 5.73×10^{-15}, 0.034565, 1.0×10^{-13}, 0.000635, 3.08×10^{-13}, 4.5×10^{-09}, 3.8×10^{-06}, 6.75×10^{-05}, 0.000498 for chest PA, lumbar spine AP, lumbar spine LAT, cervical spine AP, cervical spine LAT, skull AP, skull LAT, pelvis AP and abdomen AP respectively. Figure 1 illustrates a comparison of the ESD of individual examinations among the participating hospitals.

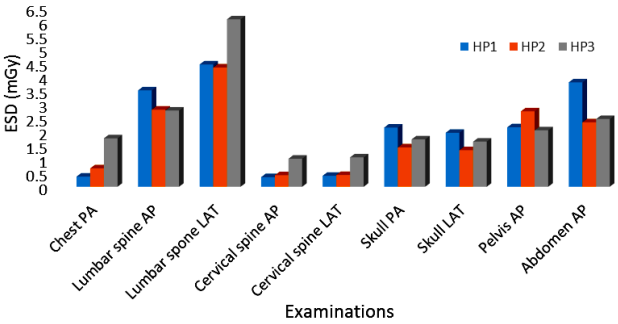

Figure 1. Variation of ESD (mGy) among the hospitals surveyed.

The result of this study was compared with other results published in literature as shown in table 3. The result of this comparison indicated differences between the current study and the previous studies [2, 8 22]. ESD of 10.32 mGy in lumber spine examination was recorded by one study [22] compared to 4.95 mGy in this current work and 4.01 mGy was recorded by Alameen *et al.* 2016 [2].

Table 3. Comparison of ESD (mGy) with other published literature.

Examinations /Projections	Current study ESD (mGy)	[2] ESD (mGy)	[22] ESD (mGy)	[8] ESD (mGy)
Chest PA	0.93 ± 0.7	0.29	0.24	0.2
Lumbar spine AP	3.04 ± 0.4	2.72	3.95	6.7
Lumbar spine LAT	4.95 ± 0.9	4.01	10.32	20
Cervical spine AP	0.59 ± 0.3	-	-	1.3
Cervical spine LAT	0.63 ± 0.4	-	-	0.8
Skull PA	1.77 ± 0.3	2.11	-	-
Skull LAT	1.64 ± 0.3	1.29	-	1.8
Pelvis AP	2.31 ± 0.4	1.53	2.06	4.3
Abdomen AP	3.15	-	2.44	5.3

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DISCUSSION

This current study estimated ESD for nine radiographic examinations using CR systems (chest PA, lumbar spine AP, lumbar spine LAT, cervical spine AP, cervical spine LAT, skull PA, skull LAT, abdomen AP, and pelvis AP). Three regional hospitals in Ghana were involved and the total population participated in this study were 270 adults. Manufacturer or departmental developed exposure charts were not found in any of the study centres during the period of this study. Exposure factors were manually selected by radiographers since none of the X-ray equipment has automatic exposure control (AEC) system. These exposure factors were selected depending on the radiographers' experience and knowledge while considering the patient habitus. This observation could contribute to overexposure of patient radiation dose since there is no protocols to ensure standardize practice. Five quality control tests (QC); kVp accuracy, kVp reproducibility, exposure linearity, exposure reproducibility, and timer accuracy were performed. The variations in the results of these QC were within the recommended range of ± 5% or ± 10%, [23] and so all the X-ray equipment passed the QC tests. In Ghana, QC tests are periodically conducted by Nuclear Regulatory Authority (NRA) for renewal of license and authorization of new facility. However, other professionals like servicing engineers and radiographers also perform some QC tests. This study reviewed that QC tests on X-ray equipment are conducted once within three years by NRA. Khoshnazar, et al., (2013) recommends that there is the need to perform QC test more regularly and suggested six to twelve months interval especially as X-ray equipment are aging [24]. Regular QC tests would ensure high image quality, reduce patient radiation dose and reduce repeat examinations.

There were variations in the tube output values among the X-ray equipment measured during the QC examinations. Reasons for the variations in tube output could be difference in the values of total filtration, kVp output differences and time of exposure. Tube filtration removes lower energy X-rays from the X-ray spectrum which otherwise would have caused unnecessary radiation dose to patients and degrade image quality. This observation was consistent with similar observation by Sezdi (2011) who reported that tube filtration could also affect tube output of X-ray equipment [25]. It was observed that kVp has quadratic effect on the tube output therefore, difference in measured kVp from different equipment would result in variations in the tube output. In this study, it was also found out that voltage fluctuations on the power supply lines to radiographic facilities could cause variations in tube output. Therefore, it is important that constant and reliable power supply be provided to radiographic facilities. These variations in the X-ray tube output values may have contributed to the variations in the estimated ESDs. The average ESDs (mGy) for the participating hospitals in table 2 indicates differences among ESDs of same examinations. The causes of these variations could be as a result of difference in X-ray tube output, technical exposure parameters (kVp, and mAs), patient thickness, focus detector distance and lack of proper quality control. In a study conducted by Yacoob and Hariwan [26] similar observations were made in the causes of variations in ESD. The high ESD obtained at HP3 for chest PA examination could be as a result of higher tube output and the selection of exposure factors. Low kVp (70 – 77kVp) with high mAs (18 – 25 mAs) technique was used in the case of HP3 while HP1 used high kVp (102 – 104 kVp) with low mAs (1.80 – 5 mAs) technique as shown in table 1. The use of low kVp with high mAs has been associated with increasing patient radiation dose as compared to the use of higher kVp with low mAs [27]. Comparison between the current study and other published studies shows variations in ESD as shown in table 3. For chest PA, the current study recorded highest average ESD of 0.93 mGy higher than the other studies [2, 22, 8]. The high ESD of chest PA of this study was due to higher ESD of HP3 (1.76 mGy).

Variations in ESD between radiographic centres are common in the practice of diagnostic radiography, which have been reported by many investigators [28 – 30]. However, there should be

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concerns when significant variations are recorded especially as shown in the chest PA examination of HP1 and HP2 of this study. One of the basic means to deal with patient dose variations in diagnostic radiography is through regular audit of patient radiation dose with purposes of optimising the radiation dose. The practice of periodically auditing patient radiation dose is not formalised in Ghana which might contribute to these variations in patient radiation doses. Optimisation of patient radiation dose in diagnostic radiography is very necessary due to the potential radiogenic risks associated with medical exposure to ionising radiation.

CONCLUSION

This study has shown that variations in patient radiation dose exist in the radiographic facilities surveyed in this work. The variations occurred mainly due to the differences in selection of exposure parameters (kVp and mAs), tube output values, patient thickness and FDD. In CR systems over exposure of patients is very possible and therefore to ensure the ALARA principles it is important patient doses are audited periodically. Regular training in the physics of CR detector for radiographers and technicians will help to minimise these variations and hence reduce patient radiation dose in diagnostic radiography.

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