Research Paper

Estimation of Entrance Surface Dose and Sex Specific Effective Doses during Chest X-Ray Examinations in Diagnostic Radiology Facilities

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Abstract

The use of ionizing radiation in medical diagnosis has been in practice in Nigeria for sometimes now. The Nigerian Nuclear Regulatory Authority (NNRA) recommends regular assessment of radiation doses from radiation emitting devices in our hospitals to ensure radiological safety of the patients, staff and public. The aim of this study is to estimate the entrance surface doses during routine chest x-ray examinations in diagnostic radiology facilities. These facilities included tertiary (1), secondary (2) and private (1). Three hundred and fifty (350) adult patients took part in the study comprising of 188 male patients (53.7%) and 162 female patients (46.3%). The information required for estimating the entrance surface dose (ESD) included the peak tube potential (kVp), tube loading (mAs), focus to skin distance (FSD), x-ray machine output factor Y(d) and the back scattered factor (BSF) that were substituted into a semi empirical formula. The results show variation in the estimated ESD from facility to facility and between genders. The ESD for male and female patients in the tertiary facility ranged from 0.25 - 0.58 mGy with a mean value of 0.43±0.04 mGy and 0.26 - 0.56 mGy and with a mean value of 0.41± 0.05 mGy respectively. Mean ESDs of 0.29±0.01 mGy and 0.24 ±0.02 mGy were obtained for male and female patients respectively in one secondary facility while the mean ESDs of 0.22 ±0.02 mGy and 0.19±0.02 mGy were obtained for the other secondary facility. The mean ESD values obtained from the private facility were 0.17 ±0.01 mGy for male and female patients respectively. The sex estimated effective dose using the recommended tissue weighting factors by the Kramer *et al* and Xu and Recee shows that the radiation effective dose for female patients could be underestimated when gender of the patients has been not considered.

Key words: Diagnostic Radiologic Facilities, Chest, Entrance Surface Dose and Effective Dose

Introduction

The use of ionizing radiation, especially x-radiation in diagnostic radiology, is on the increase in Nigeria. Application and use of radiation, if not regulated properly, could be injurious to health. The Nigerian Nuclear Regulatory Authority (NNRA) which was established by law to regulate the use and application of nuclear sources and radiation emitting devices recommends regular assessment of radiation doses from radiation emitting devices in our hospitals in order to ensure safety of the patients and health workers within the facility. It is also necessary to assess the doses delivered by the x-ray machines in our hospital as some of them are aged and are without any history of quality control (QC) measurements [1]. Challenges such as dearth of medical physicists, lack of QC equipment and low level of radiation safety awareness are some of the impediments against the proper implementation of QC programs in most of the diagnostic radiology facilities in the Country [2].

The formation and functions of the tissues during normal human development is guided by different

hormonal backdrops which are dependent on gender. In essence, the formation of the female and male tissues is different and could be differently sensitive to radiation. [3]

The aim of this study is to estimate the entrance surface doses and sex specific effective dose during routine chest x-ray examination in some diagnostic radiology facilities in Akwa Ibom State, Nigeria and compare the results obtained with those of a previous study by Inyang *et al*. [4].

Materials and Methods

Criteria for Selection of Facility

The criteria for the selection of the facilities considered for this study included; the high number of patients that visit the facility for x- ray examination, the number of highly trained personnel in the facility. The studied facilities were considered as tertiary facility, secondary facility and privately-owned facility. The tertiary facility considered was a facility at the University of Uyo Teaching Hospital (UUTH) and identified as facility 1. The radiology facility in University of Uyo teaching Hospital has about 30 professionals at the time of this study and is used for diagnosis, training of personnel and as a referral center for many hospitals within the State. The secondary facilities selected were the University of Uyo medical centre (UMC) with over 7 professionals and saint Luke's hospital, Uyo (SLH). UMC identified as facility 2 has about 7 professional to manage the large number of students and staff of the University while SLH identified as facility 3 with 5 professional, Jim Van medical centre (JVM) identified as facility 4 with 5 professionals is located in Ikot Ekpene and is the only privately-owned facility considered in this study.

Ethical Consent and Inclusion Criteria of Patients

The researchers visited the selected facilities and held discussions with the most senior radiographer at the facilities. The patients involved in the study were also interacted with and their consent to take part in the study obtained. Permissions for the use of the facilities were also obtained from the management of the facilities. The adult male and female patients aged between 25 and 70 years and weight between 57 kg and 83 kg [5] were included in the study.

Personnel and Equipment Data

The information on the type, model, and year of

manufacture of the machine were obtained from the most senior radiographer in the facility using a predesigned equipment data form. Personnel information such as: the number of professionals in the facility, their qualifications and years of experience were also obtained from the head of the radiography unit using a predesigned form.

Patient Demographic Information

Demographic information such as sex, age, weight and height of the patients were obtained from the patient after due consent from each patient who presented themselves for chest X-ray examination within the period of this study. A predesigned form was used to obtain these data from the patient. The weights of the patients were taken using a weighing balance and recorded on a form. Both male and female patients were considered in the study.

Machine Technical Parameters

The exposure factors used in the study were obtained using a predesigned data form and these included; tube potential (kVp), tube loading (mAs) and Focus to Skin distance (FSD). These factors were selected by the radiographer from the machine panel and recorded by the researchers. It should be noted that there was no history of any recent QC measurements undertaken by the facilities owners on the machine and the researchers did not undertake it due to lack of the QC kits. Therefore, the study was conducted based on the insitu nature of the machine.

Evaluation of Entrance Surface Dose

The International Atomic Energy Agency (IAEA) recommends the use of analytical methods in patient dose assessment to ease the problems associated with direct dose measurements on patients [5]. The entrance surface dose was obtained from the air kerma on the central x-ray beam axis at the point where the x-ray beam enters the patient or phantom with contributions of backscattered radiation included [6]. Indirect method of measuring patient dose is through the evaluation of entrance surface dose (ESD) from measured x-ray exposure technique factors (kVp, mAs, FSD) using the semi empirical formula as recommended in International Atomic Energy Agency protocol and code of practice [5].

The Entrance Surface Dose (ESD) was calculated using the formula according to [8]

$$ESD = Y(d) \times \left(\frac{kV}{80}\right)^2 \times \left(\frac{100}{FSD}\right)^2 \times mAs \times BSF \quad (1)$$

The radiation output Y (d) for different types of X-ray machines at a source to target distance of 100 cm could be obtained using Equations 2-4 [9], [10]. The radiation output Y(d) for single phase (Equation 3), three phase (Equation 4) and high frequency (Equation 5) generators X – ray machines are given as

$$3.27 \times 10^{-4} \, mR \quad (2)$$

$$5.22 \times 10^{-4} \, mR \quad (3)$$

$$6.53 \times 10^{-4} \, mR \quad (4)$$

These values were multiplied by 0.00877/mAs to convert from milliroentgen to air kerma in mGy/mAs [11]. The backscattered factors (BSF) were obtained as published [5] for different geometric factors.

The patients' body thickness could be obtained analytically from equation 5:

$$t_P = 2\sqrt{\frac{W}{\pi dh}} \quad (5)$$

Evaluation of Effective Dose

Effective dose is defined as the sum of the product of the equivalent dose to the organs or tissues of the body and the weighted factor of the tissue of organ and expressed as [12], [13]

$$E = \sum W_T \sum W_R D_{T,R} \quad (6)$$

where the product of the radiation weighting factor and the radiation dose is defined as the equivalent dose. However, the effective dose as defined in equation above has been considered not quite suitable in evaluation of individual risk because effect of age and sex in the evaluation of radiation risk are not considered in the equation. In view of this reason Kramer [14] estimated effective dose as an arithmetic mean (E) of two sex specific effective doses as given in Equation 8 [10]. The female patient effective dose is E_f while the male patient effective dose is E_m

$$E = \frac{1}{2}\left(E_f + E_m\right) \quad (7)$$

Again, the method of estimation of E by Kramer by using the mean effective dose for both female and male patients respectively has been reported not most appropriate for assessing individual risk since the sex specific effect is not distinctly appreciated in the E. Therefore, it is wise to calculate effective dose using sex specific tissue weighted factors as given in Equations 8 and 10[15].

$$E_f = \sum W_T{}^f H_T{}^f \quad (8)$$

$$E_m = \sum W_T{}^m H_T{}^m \quad (9)$$

where E_f and E_m are the female and male specific effective doses, and   are sex specific tissue weighting factors for the female and males patients while   and   are the equivalent doses for the female and male patients respectively. The sex specific tissue weighting factors for the different tissues in the female and male bodies are listed in [15] and as shown in Table 1.

Table 1. Tissue weighting factors [15]

Tissue	W_T^m	W_T^f	W_R
Breast	0.00	0.30	1
Lungs	0.12	0.12	1
Red Bone Marrow	0.12	0.12	1
Thyroid	0.02	0.04	1
Bone Surface	0.03	0.03	1
Liver	0.05	0.05	1
Skin	0.01	0.01	1
Esophagus	0.05	0.05	1

Result and Discussion

The patients' mean (range) demographic data, which included the age, sex, weight, height and calculated body thickness are presented in Table 3 subject to the equipment data in Table 2.

Comparison of the demographic data in this study with those in a previous study conducted by the author [4] shows variation that could be due to differences in the body thickness of patients that visited these facilities as at the time of the two studies. This is the likely cause of the differences in the ESDs obtained in this study and the entrance surface air kerma (ESAK) in the previous study. The ESAK and ESD are dose estimators in diagnostic radiology because they are considered numerically equal at diagnostic energy range but vary if the medium differs [16]

The chest examination was carried out in a post anterior (PA) position. The technical parameters of the x-ray machines used in the investigation in the three facilities studied are presented in Table 4.

Table 2. Equipment data.

| Name	UUTH	UMC	SLH	JVM
Model of Machine	Toshiba	Siemens Mobillete	Mediroll- mobile	Philip Practix 21
Year of purchase	2013	2010	2003	2014
Year of manufacturing	2012	1997	1980	1998
Year of installation	2013	2010	2003	2014
Phase	High frequency	Three phase	Single phase	Single phase

Table 3. Mean (range) patient's demographic factors.

| Facility	Age	Sex	No. of Patient	Mass (kg)	Height (m)	Body Thickness (kg/m)
UUTH	34.5 (30-38)	M	59	73.4 (58.0 – 79.0)	1.57 (1.43 – 1.63)	7.68 (6.79 – 8.18)
		F	41	65.6 (58.0 – 77.0)	1.56 (1.40 – 1.62)	7.44 (6.86 – 7.92)
UMC	23.0 (19 – 30)	M	56	71.5 (65.0 – 79.0)	1.62 (1.53 – 1.72)	7.44 (6.59 – 8.00)
		F	44	70.5 (68.5 – 76.5)	1.58 (1.48 – 1.67)	7.53 (7.12 – 7.85)
SLH	34.5 (30 – 39)	M	52	73.0 (70.0 – 76.0)	1.76 (1.6 – 1.81)	7.27 (6.99 – 7.92)
		F	48	70.0 (67.0 – 75.0)	1.63 (1.58 – 1.72)	7.15 (6.85 – 7.76)
JVM	36.0 (30 – 39)	M	21	70.2 (67.0 – 77.0)	1.57 (1.42 – 1.66)	7.53 (6.97 – 8.06)
		F	29	71.3 (64.0 – 78.0)	1.55 (1.41 – 1.68)	7.65 (7.18 – 7.92)

Table 4. Mean (range) of technical parameters.

Facility	Sex	kVp (v)	mAs	FSD (cm)
UUTH	Male	76.9 (70.0 – 79.0)	17.6 (12.5 – 22.5)	172.30 (171.81 – 173.20)
	Female	73.7 (69.0 – 78.0)	18.6 (12.5 – 22.5)	172.56 (171.56 – 173.11)
UMC	Male	72.3 (69.0 – 76.0)	16.9 (16.0 – 18.0)	172.56 (172.00 – 172.98)
	Female	70.8 (65.0 – 75.0)	14.8 (14.0 – 16.0)	172.47 (172.16 – 172.91)
SLH	Male	71.5 (68.0 – 75.0)	21.1 (14.0 – 25.0)	175.73 (175.08 – 176.01)
	Female	71.3 (68.0 – 75.0)	19.4 (14.0 – 25.0)	177.85 (177.24 – 178.15)
JVM	Male	70.9 (65.0 – 75.0)	16.6 (16.0 – 18.0)	172.37 (171.94 – 173.01)
	Female	71.2 (65.0 – 75.0)	16.3 (16.0 – 18.0)	172.48 (171.88 – 172.80)

Table 5. Calculated Sex specific effective dose.

Facility	Sex	ESD (mGy)	Effective Dose (mSv) Ref.[15]	Effective Dose (mSv) Ref.[4]
UUTH	M	0.42	0.164	0.230
	F	0.41	0.295	
UMC	M	0.29	0.118	0.146
	F	0.24	0.173	
SLH	M	0.21	0.190	0.165
	F	0.19	0.139	
JMV	M	0.17	0.068	0.096
	F	0.17	0.123	
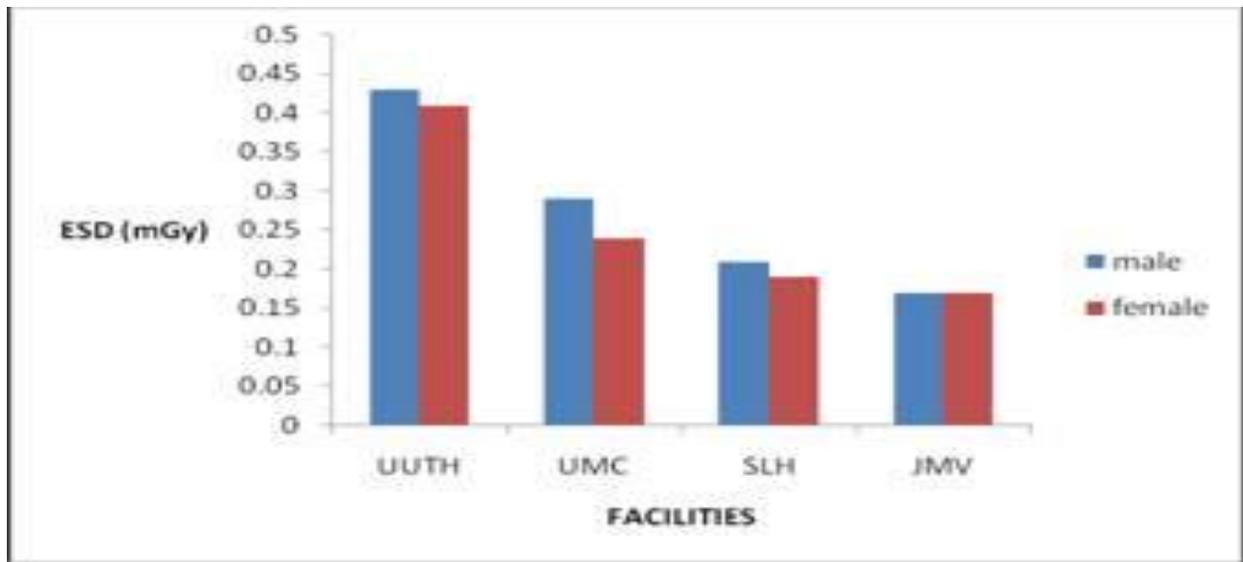
Figure 1. Mean estimated ESD for male and female patients for the four facilities
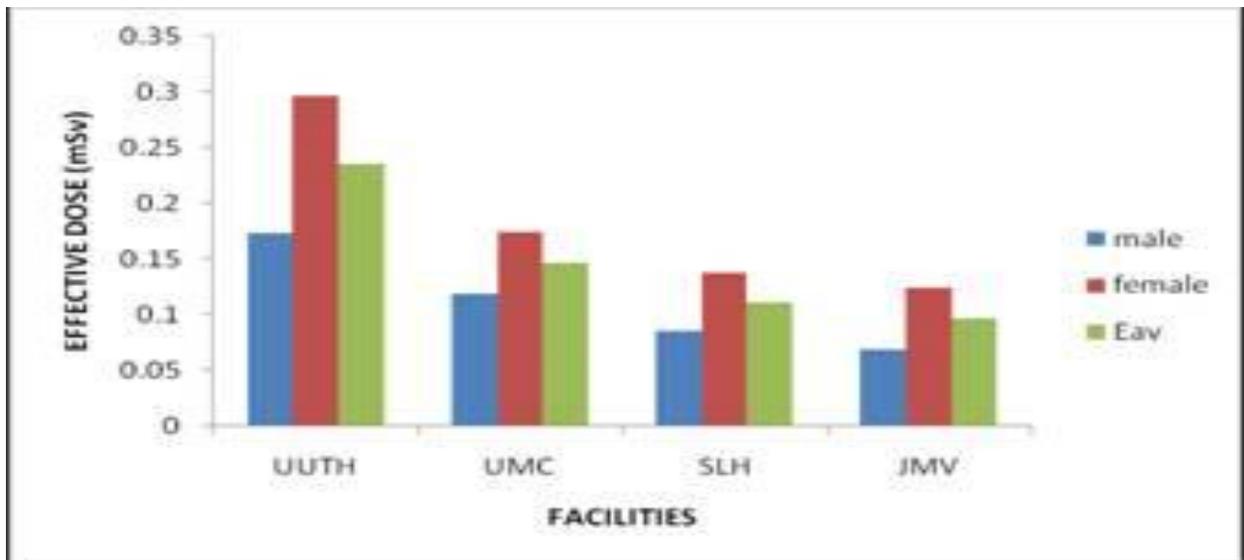
Figure 2. Sex specific effective doses for all the facilities

The mean (range) of technical parameters presented in Table 4 were used in the empirical formula to obtain the mean entrance surface dose (ESD) and presented in Fig 1. The choice of these parameters in this study also varied differently from those in the previous study [4]. This could be due to the difference in masses and height of the patients as observed by the personnel on duty and perception of the personnel that handled the procedure. This also affected the estimated ESD, which depends on the geometric factors. In addition, the use of empirical method is better than the direct method because the real attributes of the patients are taken into consideration and the inconvenience of direct dose measurements on patients is minimized [5].

The mean estimated ESD presented in fig.1 shows variation for male patients and female patients. These variations in dose could be due to patient size, equipment factors or equipment problems generally because of lack of regular quality control and radiation protection programs.   [17]. This could be because some tissues in the female body are highly sensitive to radiation than in their male counterparts.

 The estimated ESD was used in the calculation of effective doses on the female and male patients using the two different recommendations and the results presented in Table 5 and Fig.2 shows that male patients have higher ESDs than female patients in some of the facilities whereas the female patients show higher effective doses than the male patients. It is observed that at equal ESDs, effective dose to female patients is different from that of their male counterparts. This is because the weighting factors used in the estimation of the effective doses are sex specific. In the published weighting factors [14], different weighting factors are assigned to female and male tissues (Table 1). These weightings account for the sensitivity of these tissues to the x-radiation interacting with them.

The sex specific effective doses as presented in Fig.2 shows that the average effective dose (E_{av}) does not truly represent the effective doses for both sexes. Rather, they show the underestimation of the effective dose of female (E^f) and overestimation of the male effective dose (E^m) while the use of Xu and Reece recommendations give a good representation of the estimated sex specific effective dose for the different sexes. Therefore, the use of average effective dose as a risk indicator is not safe and does not truly reflect an individual risk to the radiation.

Conclusion

The entrance surface dose has been estimated and the sex specific effective dose for all the facilities also estimated. It found out that there are bound to have variations in the present and previous study from the same facilities. However, though variations are observed, some of the facilities employed safe and optimal procedures of using high kVp and low mAs as a means of dose reduction. In addition, the use of average effective dose as an individual risk indicator is not safe rather sex specific effective dose is recommended.

Abbreviations

ESD: Entrance surface dose; ESAK: entrance surface air kerma; BSF: Backscattered factors.

Acknowledgments

Author Contributions

IE, IE, SOI and UU contributed equally to this study. All authors gave their final approval.

Competing Interests

The authors have declared that no competing interest exists.

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