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Entrance Surface Air Kerma for Chest X-ray Examination in some Diagnostic Radiologic Facilities in Akwa Ibom State, Nigeria

Samuel O. Inyang[1], Imeh E. Essien[2] and Akaninyene D. Antia*[2]
[1]Department of Physics, University of Calabar, Calabar, Nigeria.
[2]Department of Physics, University of Uyo, Uyo, Nigeria.

Abstract
This study evaluated patient doses in diagnostic radiology facilities in Akwa Ibom State. Patient doses were evaluated using equations and software. One thousand five hundred and forty one (1541) patients took part in the study. Eight hundred and six (52.3 %) were female while six hundred and thirty five were male patients. Sixty percent (60 %) patients were of mean age group below 50 years, and 40 % of the patients were of mean aged above 50 years, their mean body thickness t_p range between 6.5-8.0 Kg/m, their height range between 1.5-1.7 cm and mean body mass range between 43.2-82.0 Kg. The ESAK value obtained from the software ranged between (0.38-1.69) mGy for male and female ESAK ranged (0.37-1.69) mGy while 0.015 – 0.091mGy for male nd 0.015- 0.095 mGy for female were obtained from equation. This study shows that, 6 facilities representing 66.6 % of the facilities recorded mean ESAK values that are within the UK range while only 3 facilities representing 33.3 % recorded ESAK higher than the UK range but within the Montenegro and Serbian range. Mean ED (mSv) values obtained for the examinations in the different facilities show ED ranges of (0.03-0.12) mSv. The differences in mass and height of patients affect the ESAK value from equation because body thickness of the patient depends on body mass and height. Other reasons for this dose variation are chiefly human factor.

1.0 Introduction

The use of X-ray in medical examination is of great concern since it could cause harmful effect to the body, the benefits of diagnosis and therapy notwithstanding. Extensive use of X-ray radiation have been reported to result in a large radiation burden on the patients and medical personnel (Vano, 2003, Padovani and Rodella, 2001) and radiation injuries to eye lens also reported in literature (Vano *et al.,* 1998). As a result, the use of ionizing radiation in medicine as well as in other human endeavour is under regulatory control in Nigeria (NNRA 1995) to ensure that all applications of ionising radiation are conducted under stipulated regulations enacted to assure the practitioners and the public of safety against harmful effects of these radiations. These controls are; the setting up of regulatory bodies, references dose, dose limits, facility shielding, quality assurance and quality control, personnel and patients dosimetry (ICRP 1996, NNRA 2006).

The need for radiation protection and safety is paramount in radiology practice. In radiology as is the case in other medical practices utilizing ionizing radiation, radiation safety and protection procedures are based on the basic principles of justification of the practice and optimization of procedure to maintain the dose of exposure as low as reasonably achievable (ALARA) taking into account the economic, environmental, social factors and dose limitations. To achieve optimization of procedure in x-ray examinations in diagnostic radiologic facilities, it is required that each diagnostic radiology facility in Nigeria should set up quality control (QC) program, conduct routine QC tests on the equipment emitting ionising radiation, staff training and patient dose measurements etc (NNRA 2003, IAEA 2007) .

1.1 Aim of study

This study is set up to evaluate patient doses for male and female patients during chest examination in diagnostic radiologic facilities in Akwa Ibom State using analytical method and software.

2.0 Materials and Method

A total of fourteen (14) functional diagnostic radiologic facilities in the state were considered for this study but only nine (9) with robout data enough for analysis were further investigated. These facilities which are in hospitals that are referal centers for other hospitals in the state included facilities in a teaching hospital, three government owned general hospitals and five private hospitals. The distribution of the hospitals is 1-3 are general hospitals, 4-8 are private hospitals and number 9 is a University teaching hospital.

Equipment and personnel data in the facilities were obtained from the most senior radiographer in the facility using a predesigned equipment form A, while information on number of professionals and thier area of experience in the facility were obtained from the head of the facility using a personnel form B. Patient atributes required for this study were age, sex, weight and height. The consent of each patient who was presented for x-ray examination in the facilities selected was sought after which the research was duly explained to them. However, they were not made to sign consent form in view of the fact that the patient data were extracted from the x-ray examination records and presented in form C. Exposure factors used in this study include tube potential (kVp), tube loading (mAs) and focus to film distance (FFD). The exposure factors were selected on the machine panel by the radiographer who recorded same in form D.

3.0 Evaluation of Entrance Surface Air Kerma

The International Atomic Energy Agency (IAEA) recommends the use of equation 1.0 in patient dose assessment because incident air kerma is easier to measure accurately and could ease the practical problem associated with achieving electronic equilibrium in the field (Olivera, 2003). The entrance surface air kerma is the air kerma on the central x-ray beam axis at the point where the x-ray beam enters the patient or phantom with contribution of backscattered radiation is included (ICRU 2005).

Indirect method of measuring patient dose is through the evaluation of entrance surface air kerma (ESAK) from measured x-ray exposure technique factors (kVp, mAs, FFD) using the semi empirical formula as recommended in International Atomic Energy Agency protocol and code of practice (IAEA 2007). The ESAK value is obtained using the empirical formular

$$ESAK = Y(d) \times mAs \times \left(\frac{d}{FFD - t_p} \right)^2 \times BSF \qquad 1$$

where Y(d) is the x-ray tube output at distance 100cm normalized by 10 mAs, FFD is the focus-film- distance, where t_p is the patient thickness and BSF is the backscatter factor which depends on tube potential, device filtration and the size of radiation field (ICRU 2005, IAEA 2007).

Patient thickness could be deduced from patient weight (W) and height (h) as given by equation 2.0 below (Nyathi, et al 2009)

$$t_p = 2\sqrt{\frac{W}{\pi \times h}} \qquad 2$$

X–ray tube output Y(d) in equation 1.0 is defined according to IAEA, (2007) as the quotient of the air kerma (K) at a specified distance, d, from the x-ray tube focus to the point of measurement and mAs is the product of the tube current mA and the exposure time in seconds (s), mA is the tube current passing through x- ray filament in the cathode. The radiation output Y (d) for different phases of x-ray machine at a sourceto target distance of 100 cm could be obtained analytically using equation 3.0 (Kothan and Tungjai, 2011).

Single phase (SP)

$$Y(d) = 0.5 \times 6.53 \times 10^{-4} mR \qquad 3a$$

Three phase (TP)

$$Y(d) = 0.8 \times 6.53 \times 10^{-4} mR \qquad 3b$$

For high frequency generator (HFG)

$$Y(d) = 1.0 \times 6.53 \times 10^{-4} mR \qquad 3c$$

The output value in equation (3a-c) is converted to $\frac{mGy}{mAs}$ by multiplying it by a factor $0.00877 / mAs$ (Oluwasifoye, et al 2010).

3.1 Evaluation of ESAK Using Computer Software

The entrance surface air kerma (ESAK) was also calculated using computer software, the Caldose- X.5.0 version. Caldose is a software tool for calculation of ESAK, body organ absorbed doses (BOD) and effective dose (ED) in diagnostic radiology using exposures conditions defined by the users (Kramer, *et al.,* 2007). The exposure parameters used in the estimation of patient doses are kVp, mAs and FFD. These exposure parameters are obtained from the exposure parameters form D. The software contains conversion coefficients (CCs) calculated previously by Hart *et al.*, (1994) to convert ESAK to BOD and effective dose for sex specific phantoms MAX06 and FAX06 according to ICRP (2007).

3.2 Radiation Output Used by the Software

The output K(d) is calculated using curve fitting formula given below (Kramer, *et al.,* 2007).

$$K(d) = 0.0419 \times V^{1.774} \quad (4)$$

V is the tube potential in kV_p and $K(d)$ is the tube output measured at d = 100 cm away from the foc us of the x-ray tube.

The patient doses to be evaluated are, entrance surface air kerma (ESAK), body organ doses (BOD) and effective dose (ED).

4.0 Results and Discussion

The results of investigation on the doses of x-ray delivered to patients who presented themselves for chest x-ray examination in 9 diagnostic radiology facilities in Akwa Ibom State, Nigeria, are presented. The calculated entrance surface air kerma (ESAK) was converted into body organ doses (BOD) and effective doses for radiation safety analysed. In Table 1, RT - radiologist, RR - radiographer, MP - medical physicist, XT- X-ray technician and DA- darkroom assistant. UMC- University of Uyo, Medical Centre , GHK – General Hospital, Ikot Ekpene , SLHA –Saint Lukes Hospital, Anua, Uyo, ADCK – Angel's Diagnostic Centre, Ikot Ekpene, RDC– Rocksure Diagnostic Centre, Uyo , ULM –Ultimate Medicals, Uyo, MED3– Medi-3 Global Ltd, and UUTH – University of Uyo Teaching Hospital, Uyo.

Table 1: Equipment and Personnel Data

FACILITY NO	Hospital	Type	Year of manufacture	Year of installation	Personnel	No
1	UMC	TP	1997	2010	RR XRT DA	1 3 1
2	GHK	SP	1990	1999	RR	1
3	SLHA	SP	1980	2003	RT XRT	1 2
4	EHE	HFG	1985	2009	RR XRT	1 2
5	ADCK	TP	2004	2008	XRT	1
6	RDC	SP	No record	2009	RT XRT	1 3
7	ULM	TP	2000	2007	RR XRT	1 3
8	MEDI-3	TP	2006	2011	RR RT XRT	1 1 2
9	UUTH	TP	2005	2009	RT MP RR XRT	4 1 14 4

The gender distribution in terms of age group and mean (range) attributes of the patients in all the facilities studied are reported in Table 2.

Information from the table shows that 1541 patients took part in the study. Eight hundred and six (52.3 %) were female while six hundred and thirty five were male patients. Sixty percent (60 %) of the patients were of mean age group below 50 years, and 40 % of the patients were of mean aged above 50 years, their mean body thickness t_p range between 6.5-8.0 Kg/m, their height range between 1.5-1.7 cm and mean body mass range between 43.2-82.0 Kg. The exposure factors used in the investigation were extracted from form D and their mean calculated and recorded in Table 3.

Table 2: Sex Distribution and Mean (range) Values of Patient Parameters

Facility no	Mean (range) Patient Parameters					
	SEX	No	Age (yrs)	Mass (Kg)	Height (cm)	t_p (Kg/m)
1	M	100	31(20-46)	64(45-85)	1.6(1.5-1.8)	7.1 (6.4-7.8)
	F	120	31(20-46)	64(45-85)	1.6(1.5-1.8)	7.1 (6.4-7.8)
2	M	50	37(18-70)	55(32-83)	1.5(1.4-1.8)	6.8 (5.4-7.7)
	F	30	33(17-62)	43.2(32-52)	1.5(1.4-1.7)	6.1(5.4-6.0)
3	M	80	47(30-70)	73(62-90)	1.7(1.5-1.9)	7.5 (7.4-7.6)
	F	85	39(23-46)	60(59-65)	1.6(1.6-1.6)	6.8(6.8-6.8)
4	M	80	35(23-45)	64(55-75)	1.6(1.5-1.7)	7.1 (7.0-7.2)
	F	78	36 (23-45)	53(50-75)	1.6(1.5-1.7)	6.5 (6.5-7.5)
5	M	75	61(50-72)	71(45-80)	1.5(1.4-1.8)	7.7 (6.6-7.7)
	F	81	52(30-72)	82(55-120)	1.5(1.4-1.6)	8.3 (7.1-9.8)
6	M	80	37(31-73)	69(62-90)	1.6(1.5-1.7)	7.4 (7.3-7.5)
	F	70	33(30-60)	71(62-90)	1.6(1.5-1.7)	7.4 (7.3-7.5)
7	M	70	33(30-44)	65(60-72)	1.6(1.4-1.8)	7.7 (7.6-7.8)
	F	75	32(30-38)	66(49-81)	1.6(1.5-1.7)	6.2 (2.3-7.7)
8	M	90	55(35-46)	79(72-83)	1.6(1.5-1.6)	8.0 (8.0-8.1)
	F	87	55(35-46)	79(72-83)	1.6(1.5-1.6)	8.0 (8.0-8.1)
9	M	110	54(35-75)	63(52-73)	1.5(1.4-1.8)	7.2 (7.0-7.3)
	F	180	54(35-75)	63(52-73)	1.5(1.4-1.8)	7.2 (7.0-7.3)

Table 3: Mean (range) of exposure factors

Facility No	Sex	Mean (range) Exposure factors		
		KV_p	mAs	FFD (cm)
1	M	74.0 (73.0-77.0)	4.8 (4.5-5.5)	150.0 (150.0-150.0)
	F	75.0 (70.0-77.0)	5.0 (4.5-5.5)	150.0 (150.0-150.0)
2	M	72.0 (60.0-75.0)	17.8 (15.0 -19.0)	174.9 (169.0- 180.0)
	F	61.2 (52.0-65.0)	17.6 (15.0-19.0)	173.6 (169.0-180.0)
3	M	47.3 (45.0-48.0)	8.8 (8.0-10.0)	152.4 (152.4-152.4)
	F	46.8 (45.0-48.0)	9.2 (8.0-10.0)	152.4 (152.4-152.4)
4	M	62.2 (50.0-71.0)	37.3 (13.0-69.0)	180.0 (175.0-180.0)
	F	63.9 (60.0-71.0)	32.0 (13.0-54.0)	175.7 (165.0-180.0)
5	M	60.0 (55.0-65.0)	23.3 (15.0-45.0)	180.0 (180.0-180.0)
	F	65.0 (55.0-70.0)	43.0 (25.0-60.0)	180.0 (180.0-180.0)
6	M	72.2 (70.0-80.0)	25.0 (25.0-25.0)	160.0 (160.0-160.0)
	F	70.1 (58.0-80.0)	25.0 (25.0-25.0)	160.0 (160.0-160.0)
7	M	64.0 (60.0-90.0)	41.0 (24.0-50.0)	176.0 (120.0-193.0)
	F	64.0 (50.0-70.0)	34.0 (21.0-47.0)	158.0 (126.0-190.0)
8	M	75.0 (75.0-75.0)	18.0 (18.0-18.0)	150.0 (150.0-150.0)
	F	70.0 (70.0-70.0)	20.0 (20.0-20.0)	150.0 (150.0-150.0)
9	M	75.0 (70.0-80.0)	15.0 (15.0-15.0)	150.0 (150.0-150.0)
	F	75.0 (70.0-80.0)	13.0 (10.0-18.0)	145.0 (130.0-150.0)

The mean (range) of exposure parameters selected for the chest x-ray examinations are presented in Table 3. The mean tube potential range between 46.8-75.0 KVp and the mean produt of tube current and exposure time mAs ranged 4.8 -43.0 mAs. It is observed that there is a wide variation in the selection of the technique factors for the same examination in different facilities. Table 3 shows that the highest mean tube potential of 75 kV_p was employed by facilities 1, 8 and 9, again a mean tube loading factors, mAs of 4.8, 8.8 and 13 .0 were employed by facilities 1, 3 and 9 respectively. These variations in the selected exposure factors could affect the dose of x-ray delivered by the machine (IAEA 2004).

For the optimisation of protection of the patient without compromising the diagnostic information required, it is recommended that high kVp and low mAs be selected (IAEA 2004) as observed in facilities 1, 8 and 9. This observation could be because these facilities are training facilities for radiation workers in the state with more experienced hands. The observed variations in the choice of the exposure factors in these facilities and the possible causes were previously reported by the authors (Essien and Inyang, 2015).

5.0 Analytical Patient Doses

The mean ESAK values evaluated analytically from a semi empirical formula given in equation 1.0. The x-ray tube output in mGy/mAs at any particular exposure setting (kV_p, mAs) was calculated using the curve fitting of equation 3.0 and the value of the patient thickness t_p obtained from equation 2.0 and the backscatter factors (BSF) were obtained from BSF published by IAEA (2007). The results of the analytically estimated ESAK are reported in Table 4.

Table 4: Estimated ESAK values from mean exposure parameters and patients' parameters using equation 1.0

Facility	SEX	mAs	$FFD - t_p$ (cm)	$Y(d)*10^{-3}$ mGy/mAs	BSF (IAEA, 2007)	ESAK (mGy)
1	M	4.8	142.9	0.00458	1.36	0.015
	F	5.0	142.9	0.00458	1.36	0.015
2	M	17.8	168.1	0.00286	1.36	0.025
	F	17.6	166.8	0.00286	1.32	0.024
3	M	8.8	144.9	0.00286	1.37	0.016
	F	9.2	144.9	0.00286	1.37	0.017
4	M	37.3	172.8	0.00573	1.33	0.095
	F	62.1	168.7	0.00573	1.33	0.083
5	M	23.3	172.3	0.00458	1.31	0.051
	F	43.0	172.3	0.00458	1.33	0.089
6	M	25.0	152.6	0.00286	1.36	0.042
	F	25.0	152.6	0.00286	1.35	0.041
7	M	41.0	168.3	0.00458	1.33	0.088
	F	34.0	150.5	0.00458	1.33	0.091
8	M	18.0	142.0	0.00458	1.37	0.056
	F	20.0	142.0	0.00458	1.35	0.061
9	M	15.0	142.8	0.00458	1.37	0.046
	F	13.0	137.8	0.00458	1.35	0.041

The ESAK value ranging between 0.015 -0.095 mGy was obtained for male patient while female patients recorded ESAK value ranging from 0.015 -0.089mGy.

5.1 Software Calculated Patient Doses

The ESAK values for the examinations considered in this study were also calculated from Caldose software. The ESAK values were calculated automatically by the software when the exposure factors were inputed, the tube potential inputed is corrected by the software according to equation 4.0 and the software estimated ESAK value obtained recorded in table 5.0. The mean body organ doses (BOD) and the consequent effective dose (ED) were estimated from the software and reported in Table 6.

Table 5: Software estimated ESAK

Facility No	Sex	Mean exposure factors			ESAK (mGy)
		KV_p	mAs	FFD (cm)	
1	M	74.0	4.8	150.0	0.38
	F	75.0	5.0	150.0	0.37
2	M	62.0	17.8	174.9	0.92
	F	61.2	17.6	173.6	0.65
3	M	47.3	8.8	152.4	0.74
	F	46.8	9.2	152.4	0.69
4	M	62.2	37.3	180.0	1.39
	F	63.9	32.0	175.7	1.38
5	M	60.0	23.3	180.0	0.80
	F	65.0	43.0	180.0	1.63
6	M	72.2	25.0	160.0	1.63
	F	70.1	25.0	160.0	1.63
7	M	64.0	41.0	176.0	1.69
	F	64.0	34.0	158.0	1.69
8	M	75.0	18.0	150.0	1.48
	F	70.0	20.0	150.0	1.31
9	M	75.0	15.0	150.0	1.23
	F	75.0	13.0	145.0	0.85

Table 6: Mean Body Organs Doses (mGy) in all the Facilities

Facility	1	2	3	4	5	6	7	8	9
BOD									
Liver	0.30	0.05	0.06	0.14	0.10	0.11	0.11	0.10	0.07
Lungs	0.08	0.15	0.16	0.38	0.25	0.32	0.32	0.30	0.21
Oesophagus	0.05	0.08	0.09	0.18	0.01	0.19	0.16	0.16	0.16
Spleen	0.05	0.09	0.11	0.25	0.17	0.20	0.20	0.19	0.13
Stomach	0.02	0.09	0.05	0.10	0.07	0.08	0.08	0.08	0.06
ED	0.03	0.05	0.05	0.12	0.08	0.10	0.10	0.09	0.07

The mean age of a greater percentage of the patients for this study was below 50 years. This age bracket is younger than age used in similar studies in other States in Nigeria (Ogundare *et al* 2004) but within (18-90) years used in the study conducted on some radiological facilities in South Western Nigeria (Akinlade, *et al* 2012). The patients in this study are of reproductive ages which are vulnerable to the risk of radiation induced heritable effects; therefore adequate radiation protection procedures are required when undergoing x-ray examination.

The mean weight recorded for all the patients was (70±13kg) as recommended in the IAEA (2007). It could be extracted from the semi empirical formula that patient of higher t_p requires higher radiation dose while patients with lower t_p requires lower radiation dose. The trend shows that high kVp were selected for patient with high t_p which is expected as kVp control the penetrative power of radiation. This trend could have influenced both the analytical and software evaluated entrance surface doses.

The choice of exposure (technique) factors done manually by the radiographers could lead to a non correlation between patient dose and technique factors, hence variation in patient dose. This challenge could be corrected through the use of automatic exposure control (AEC) in medical imaging (Olowookere, *et al.,* 2011). Body mass also could be the cause of the variations in the patient dose obtained in his study. The a evaluated dose results (tables 2-5) show that, body weight of the patients as identified with the patient's body thickness had an effect on the patient dose. The effect of patient age on the dose was not observed for the age group considered in this study which was mostly adults.

6.0 Comparison Between Analytical and Software Evaluated ESAK
It could be observed in tables 4.0 and 5.0 that the deviation between the ESAK values obtained from software and equation varied from facility to facility. It was also observed that the ESAK value from equation is lower than the ESAK obtained from software. This difference could be due to the parameters of the mathematical phantoms of adult patient used in developing the software which was different from that of human patients used in this study. Software uses weight of 70 kg and height of 176.0 cm for reference male (MAX 06) and height of 174.0 cm for reference female phantom (FAX 06) whereas in this study the equation evaluated dose takes into account the real physical attributes of the patients.

The differences in mass and height of patients affect the ESAK value from equation because body thickness of the patient depends on body mass and height. Other reasons for this dose variation include, choice of exposure parameters, radiographic technique, focus to film distance (FFD), equipment type and processing performance (Mohamadain *et al.,* 2004). In table 5.0 the ESAK (software) value obtained ranged between (0.38-1.69) mGy for male and 0.37 mGy - 1.69 mGy for female with the minimum and highest ESAK value obtained from facility 1 and 7 respectively with variation in ESAK (Equation) value ranged between 0.015 mGy – 0.088mGy for male and 0.015-0.091mGy for female.

Comparison of the ESAK values from this study with other studies in UK, Montenegro and Serbia (Milatovic, 2011), IAEA and South Africa (Nyathi, *et al.,* 2009) and South Western Nigeria (SWN) (Olowookere *et al.,* 2011), show variations in the ESAK value obtained from this study in some facilities with those obtained in thier studies. In this study, mean ESAK value in 66.7% of the facilities fall within the UK range of 0- 1.5 mGy while 33.3% of the facilities have ESAK value higher than the UK value while the minimum value of ESAK obtained from software in this work is lower than the IAEA recommended value of 0.4 mGy. It is observed that the ESAK value evaluated from equation is quite lower.

However, variations in dose levels in diagnostic radiology facilities is a common feature as seen in the ESAK values from other studies (Milatovic, *et al.,* 2011, Nyathi, *et al.,* 2009). These variations in radiation doses within the same facility can be minimize by adopting a functional QC in the facility so that the inconsistencies and error in the selection of radiographic techniques and equipment can be discovered early and corrected.

Comparison of the ED obtained in this study with result obtained in other studies shows that the EDs obtained for this study are less than those obtained in South Western Nigeria, SWN (Olowookere, *et al.,* 2011). In this study the mean ED obtained is ranged between 0.03-0.12mSv lower than 0.1-0.2 in SWN but higher than that obtained by Mettler, et al (2008) and Ciraj, et al (2003).

It is worthy of note that this differences in EDs in same examination by different facilities indicate the difference in radiographic procedures used by the different facilities and reflected the non-application of optimal procedures to enhance dose reduction. This human factor in the dose variation for the same examination in different facilities can be minimized through personnel training and retraining, and the standardization of the radiographic procedures. However, the success of standardization of procedures can be hampered by equipment failure due to old age and long period of operation.

7.0 Conclusion
Routine measurement of patient doses in diagnostic radiology facilities is recommended by both the national and international regulatory bodies. Patient dose evaluation is an important requirement and tool in quality control, dose reduction and radiation protection in diagnostic radiology.

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